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International Handbooks on Information Systems

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Variations

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# Handbook on Decision Support Systems 2

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*Dedicated to*
*Andy Whinston*
*and*
*the memory of Oleg Larichev*
*as prime movers who sparked our interests, imaginations, and insights*
*along the decision support frontier*

&

*Dedicated to*
*Our Families*
*in deep appreciation for their patience and support*
*which have made possible this and other contributions to the field*

# Preface

Decision support systems comprise a core subject area of the information systems (IS) discipline, being one of several major expansions that have occurred in the IS field. The decision support system (DSS) area, as a subject of research and practice, continues to grow along ever-widening horizons – often blending with other major IS expansions such as organizational computing, electronic commerce/business, and pervasive computing. Diverse exemplars of DSS advances are found in this ***Handbook on Decision Support Systems***. They range from basic advances that have shaped the DSS realm over the years to emergent advances that are shaping tomorrow's DSS conceptions and impacts.

The two-volume ***Handbook on Decision Support Systems*** serves as an extensive and fundamental reference for anyone interested in the IS field in general, or its DSS arena in particular. Its peer-reviewed chapters are written by an international array of over 130 DSS researchers and practitioners spanning six continents. They share their thoughts and experiences about the historical milestones, current developments, and future trends of technologies and techniques for helping people faced with the often difficult task of making decisions. The seventy-one chapters address an array of issues and approach decision support from a wide variety of perspectives. These range from classic foundations to cutting-edge thought. They approach DSS topics from both informative and provocative standpoints. They cover theoretical and practical angles, human and technological dimensions, operational and strategic viewpoints. The chapters include first-hand experiences, best practices, thoughtful recommendations, stimulating insights, conceptual tools, and philosophical discussion.

The ***Handbook on Decision Support Systems*** serves as a "must-read/first-read" reference point for any theoretical or practical project related to DSS investigation or study. It contains essential material of long-term benefit for the library of every DSS practitioner, researcher, and educator. The content is designed to be of interest to, and at a level appropriate for, those not yet exposed to the DSS realm of IS – while at the same time containing novel, insightful perspectives for DSS experts. The authors have taken special care to make sure readers are supplied with pointers to relevant reference materials in case they want to pursue their exploration of selected DSS topics of interest in more depth.

# Impetus and Roots

The ***Handbook on Decision Support Systems*** has grown out of a long-time interest in the concept of decision support systems, in the creation of such systems, in the interplay between DSSs and their users, and in the ability of a DSS to add value to processes and outcomes of decisional episodes that occur in varying situations. Recognizing that decision support systems, at a fundamental level, are concerned with representing and processing knowledge for the purpose of improving decision making, this book is a companion to the two-volume ***Handbook on Knowledge Management*** (Holsapple 2003a, 2003b) recently published by Springer. The ***Handbook on Decision Support Systems*** has risen out of decades of efforts by a multitude of researchers and practitioners who have made the DSS realm what it is today – having created a substantial cumulative tradition (Eom 2007). We are deeply indebted to them for furnishing the strong roots that have brought this new ***Handbook*** to fruition.

It is worthwhile to pause to briefly ponder the place that DSSs occupies in the information systems field. We contend that *decision support systems stand in an essential, integral position within the IS discipline*. Decision support systems do not occupy some narrow niche or specialty fringe of the IS field, but rather contribute mightily to its very substance. Documenting this rich and ongoing contribution is a major impetus for assembling the ***Handbook on Decision Support Systems***.

A recent study involving interviews of forty-five business school deans probed their thoughts about the role of IS (if any) within the core content for MBA programs (Dhar and Sundararajan 2006). Deans overseeing the ninety-four highest ranked US MBA programs were invited to participate. The study finds that a preponderance of participating deans (forty-three) agree that IS does deserve a place in the MBA. Each dean explained why he/she takes this stance. In analyzing their rationales, Dhar and Sundararajan discover three main reasons that IS is deemed to be significant in the training of managers. One of these three reasons is especially salient to our contention that the DSS realm is a central facet of the IS field: "Success as a business executive depends critically on *innovation and creativity in the use and application of data for decision making*" (Dhar and Sundararajan 2006). This critical IS theme is, of course, what decision support systems are all about. This theme and its variations define the substance of these two volumes.

## Expansions in the Information Systems Field

Over the past fifty-plus years, the field of information systems has undergone a progression of expansions that have come to define its subject matter. Each expansion has built on its predecessors and enriched them in the process. Each expansion has involved ongoing advances in IS ideas, research, and practice. From its initial emphasis on transaction processing and record keeping (i. e., data processing systems), what we now call the IS discipline expanded to encompass management information systems (MIS) – which emphasize the retrieval of records to produce various kinds of pre-specified reports containing information believed to be useful for managers. In a major expansion beyond MIS, the information systems field embraced systems designed to support the needs of decision makers. These decision support systems are distinguished by such capabilities as satisfying ad hoc knowledge needs, performing knowledge derivation or discovery, direct accessibility by their decision-making users, user-specific customization of functionality and interfaces, and/or learning from prior decisional experiences.

Another expansion of the IS world is organizational computing (OC) which is concerned with computer-based systems that enable or facilitate activity involving multiple participants. These multiparticipant organizations range from dyads to groups to communities to complex enterprises. Examples of participants' joint activity include entertainment, education, commerce, design, research, and multi-participant decision making. Within the OC expansion, we find such topics as computer-mediated communication, computer-supported cooperative work, coordination systems, groupware, enterprise systems, and interorganizational systems. All of these contribute to and enrich the DSS subject by giving it a multi-participant dimension (Holsapple and Whinston 1996).

With the advent of the Internet and the Web, the IS discipline expanded to encompass what has come to be known as electronic commerce (and its electronic business counterpart). Not only has this expansion enriched transaction processing and organizational computing possibilities, it has added yet another dimension to the DSS realm. Electronic commerce is not simply about the consummation of transactions via the Internet, but also about supporting the decisions that underlie those transactions – plus online support for decisions leading to offline transactions (Holsapple and Singh 2000). Moreover, Internet-based support of collaborative, multiparticipant decision making is increasingly important for implementing electronic business strategies and operations, such as those dealing with supply chains and customer relationships (Holsapple and Jin 2007). Electronic commerce is itself undergoing expansions in such directions as mobile commerce and collaborative commerce, which even further intertwine with DSS theory and applications.

The latest, and perhaps all-encompassing, major expansion of the IS field is in the direction of pervasive computing. Emerging from a confluence of several developments, the era of anytime-anywhere computing is upon us – a vast array of computing capabilities embedded and connected within our surroundings. This formative trend toward pervasive computing poses many opportunities and challenges for IS researchers and practitioners: specifically, how to harness the potentials of pervasive computing to achieve higher productivity, greater agility, more innovation, enhanced reputation, and manageable risk – at individual, organizational, interorganizational, and national levels. Part of this quest involves the incorporation of pervasive decision support abilities into our surroundings. After all, survival and success in this increasingly turbulent, complicated, interdependent world demands astute decision making which, in turn, benefits from the DSS ability to relax cognitive, temporal, and economic limits of decision makers – amplifying decision makers' capacities for processing knowledge which is the lifeblood of decision making.

Figure 1 illustrates the foregoing expansions to the field of information systems. Decision support systems lie at the core of IS – a major step beyond MIS. Moreover, as the shading suggests, the DSS expansion involves substantial

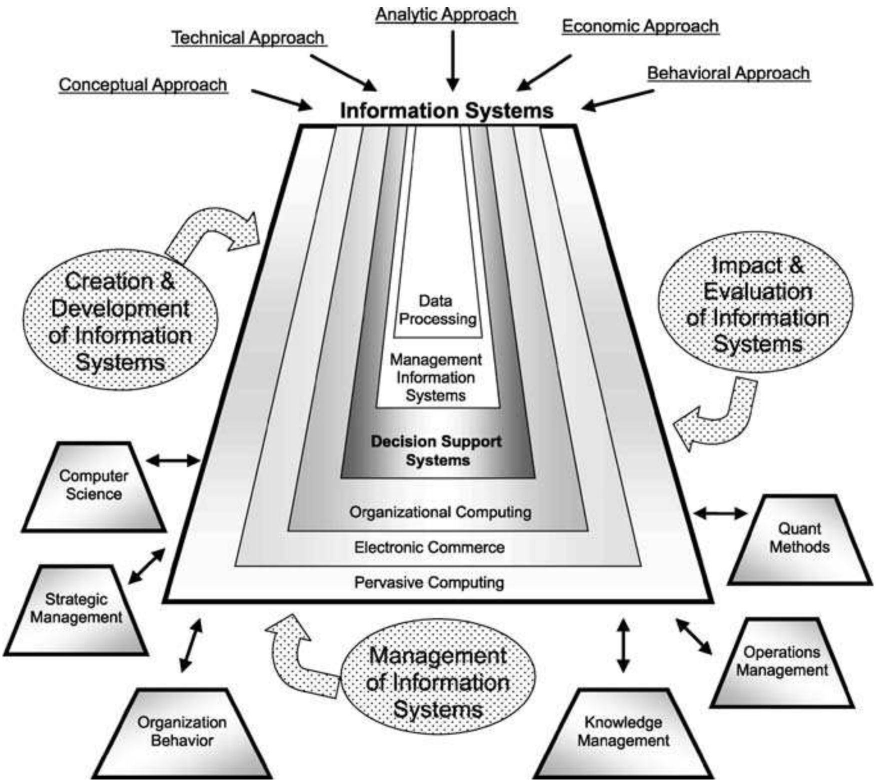


**Figure 1.** Decision support systems – indispensable elements at the core of the IS field

melding into OC, electronic commerce, and pervasive computing. Like each of the IS expansions, the study of DSSs can be approached from various angles including the technical, behavioral, economic, analytic, and conceptual. The major inter-related categories of IS issues apply just as much to decision support systems as to other expansions of the IS field: creation/development of DSS, management of DSS, and evaluation/impact of DSS. Moreover, all of the main reference disciplines for IS impact, and are impacted by, DSS advances. Six of these – from computer science to knowledge management – are shown in Figure 1. Modern decision support is inherently multi-disciplinary and involves innovation and creativity to integrate a range of skills and methods (Burstein and Widmeyer 2007).

Early detractors who did not appreciate the distinction between MIS and DSS have long since been answered – not only in the scholarly literature (e. g., Blanning 1983; Watson and Hill 1983), but also in practice – where DSS deployment is so widespread that it is nowadays taken for granted or not even noticed (Hall 2002). The principal business of numerous companies, whose shares are publicly traded, is the provision of decision support software and services. Every year brings forth an international conference devoted to decision support systems – sponsored by either the International Federation for Information Processing (Decision Support Systems Working Group 8.3) or International Society for Decision Support Systems (AIS SIGDSS). Tracks devoted to various DSS topics routinely appear in major conferences of the IS field (e. g., International Conference on Information Systems, Americas Conference on Information Systems), as well as major multidiscipline conferences such as the Annual Meeting of the Decision Sciences Institute and the Hawaiian International Conference on Systems Sciences. Benchmarking the publishing behaviors of tenured IS scholars at leading research universities reveals that *Decision Support Systems* is one of the most important journals in the entire information systems field (Holsapple 2008). While this journal routinely publishes research dealing with all facets of the IS field illustrated in Figure 1 (except, perhaps, for data processing and MIS), it has published more DSS-oriented research over the years than any other journal in the IS field.

Yet, even today, we sometimes see DSS referred to as a specialty topic in the IS field, while MIS is simultaneously treated as a dominant form of IS. The diversity of DSS research included in this ***Handbook*** is symptomatic of the vitality, significance, and scope of this major IS expansion. It is quite easy for someone who does/reads very little research in one of the IS expansions, in one of the IS issue categories, or along one of the IS approaches to overlook that IS facet – maybe even dismissing that facet as relatively unimportant for the IS discipline.

## The Growth of Decision Support Systems

As Figure 2 suggests, decision support systems have experienced a marked and uninterrupted increase in scholarly attention and importance over a twenty-five year period. According to Google Scholar (as of October 2007), the rate increases from less than three publications per week in 1980 to over 20 new DSS publications per day twenty-five years later. Citation levels for the most frequently referenced (as of October 2007) DSS publications in each year are shown in Figure 3. Of course, more recent publications have had less opportunity to be cited than earlier publications. Since 1990, every one of these modal publications has either been a book, a book chapter, or an article in *Decision Support Systems, Group Decision and Negotiation,* or a medical journal (e. g., *Journal of the American Medical Association, British Medical Journal, Archives of Internal Medicine*). While Google Scholar is not exhaustive, its IS-related database is much more complete than those of the ISI Web of Knowledge or ABI/INFORM.

An organization's portfolio of decision support systems, plus its practices for developing and managing these systems, affects both the processes and outcomes of individual and joint decision making. The chapters contained in the pages that follow reveal diverse perspectives on the nature of DSSs, depict various instances of melding with other IS expansions (e. g., with organizational computing, electronic commerce, pervasive computing), and demonstrate a pattern of

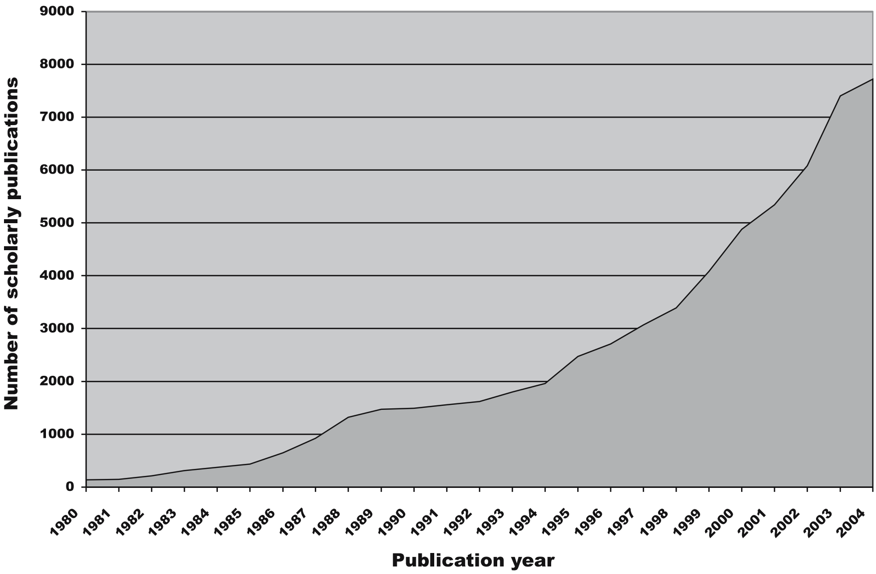


**Figure 2.** Trend of publications containing "decision support systems" (as tracked by Google Scholar)

continuing growth in DSS-related knowledge. They illustrate several of the approaches shown at the top of Figure 1, ranging from conceptual to technical to behavioral. They address all three of the major issues shown in Figure 1, from

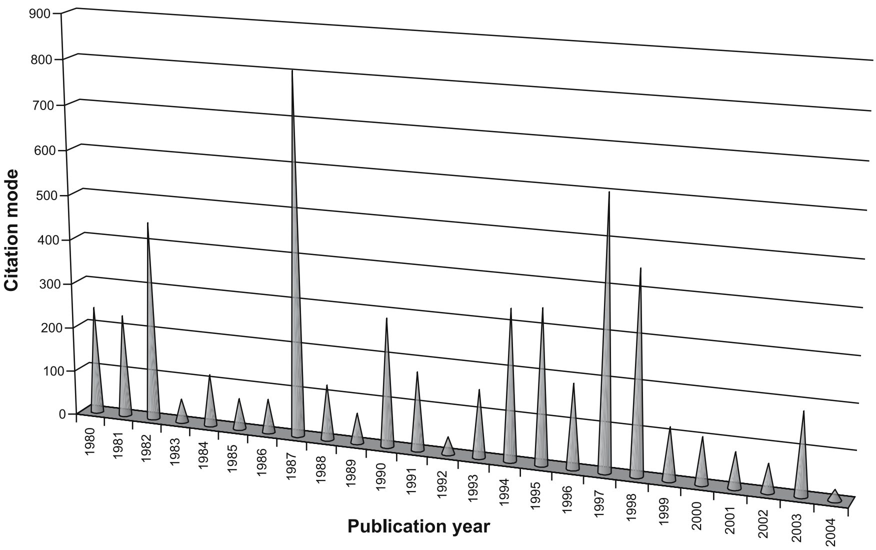


**Figure 3.** Citation modes for "decision support systems" publications (as tracked by Google Scholar)

foundations for DSS development, to managing DSS usage, to impacts of (and on) DSSs. The chapters not only describe and depict, they also stimulate and provoke.

This ***Handbook*** calls attention to the wide frontier of DSS research that continues to expand – making the case that IS scholars and those who evaluate them need to take into account both DSS research and leading forums for publishing DSS research. Decision support systems are not some side show, ancillary specialty topic, or moribund phenomenon. Rather, they comprise an active, fundamental expansion within the IS discipline – welling up with fresh insights that can contribute greatly to individual, organizational, and even national performance.

## Organization and Content

The ***Handbook on Decision Support Systems*** is organized into two volumes: *Basic Themes* and *Variations*. Although these two volumes are complementary and can be read straight through in a logical sequence, they can also be treated separately and their contents consulted as needed for specific DSS topics. The first volume presents basic themes that underlie and reveal the nature of decision support systems – ranging from the rationale of DSSs through the substance of DSSs to effects of DSSs. The second volume portrays many variations on these DSS themes – occurring in special contexts, across different scopes, in the course of development, for particular decisional applications, and along the horizons of emerging DSS directions.

## Volume 2: *Variations*

This volume is organized into five major parts. The first of these, Part VI, is concerned with decision support systems constructed for operation in contexts that impose various time or space demands. Its chapters begin with a consideration of decision support in turbulent, high-velocity environments. We then examine the support of decisions within real-time enterprises – with a particular focus on autonomic supply chain systems. Next up, there is a chapter that analyzes the important parts that DSSs can play in dealing with emergency situations. Because geographic aspects of a decisional context can be essential elements of effective decision support, we explore the nature and analysis of geographic information by DSSs. Combining space and time attributes, the concluding chapters of Part VI discuss decision support systems that address both physical mobility and real-time issues – one involving financial applications and the other concerned with transportation safety.

The possible scopes of decision support offered by DSSs can range widely – from local/personal to an enterprise scope to a trans-organizational, or even global, reach. Part VII treats these variations in scope. Following an examination of personal decision support systems, we consider DSSs that are known as information dashboards. These systems keep executives informed about the current status of key indicators of an enterprise's current situation and health, as a basis for helping them to be aware of opportunities and demands for decision making. Expanding the scope of such support, brings us to DSSs known for providing an enterprise's managers with business intelligence – often utilizing data warehouse and online analytical processing techniques – to find and solve problems involved in making decisions on behalf of the enterprise. Reaching beyond the enterprise boundary, we also scrutinize competitive intelligence systems. These are DSSs that focus on helping decision makers better understand the competitive landscapes in which their enterprises operate. Another chapter looks at the process scope of DSSs. Part VII closes with a discussion of decision support at the global scope, illustrated with the case of a global DSS for corporate financial planning.

Part VIII considers variations in the development and management of decision support systems. An organization's portfolio of decision support systems, plus its practices for developing and managing these systems, affects both the processes and outcomes of individual and joint decision making. Opening with a chapter about design features for DSSs, we then examine the activities of analysis and design that are involved in developing these systems – elucidating the role of the developer as a change agent. Once a DSS is in operation, it is important to evaluate its effectiveness as a basis for managing its life cycle. Following a chapter that covers DSS evaluation issues and methods, an enterprise perspective is adopted to offer guidance on planning an organization's portfolio of decision support systems. Part VIII closes with a chapter that traces the maturation of a DSS in terms of predicting, facilitating, and managing the evolution of knowledge with which it deals.

The enormous variation in decision support system applications is epitomized by the examples in Part IX. We commence with chapters describing the use of DSSs for supporting operations decisions, marketing decisions, and investment decisions. Then two case studies of DSSs are presented. One is concerned with a DSS that furnishes real-time business intelligence in the airline industry. The other involves a DSS devised for supporting security decisions involving bioterror preparedness and response. Decisions support systems are extremely important in the sectors of healthcare and natural-resource management. Ensuing chapters discuss advances and opportunities in these two sectors. While there is a tendency to think of DSSs being used in Europe, Austrasia, and North America, they are used on a world-wide basis. Descriptions of DSS experiences in South America and Africa illustrate this point. Part IX closes with a discussion of how knowledge management initiatives have evolved into enterprise decision support facilities at a major services firm.

While the DSS expansion of the IS field has attained a substantial critical mass in terms of both research and practice, it is also marked by continuing growth, by melding with other IS expansions, and by many heretofore unresolved questions (Shim et al. 2002). Part X presents a series of chapters that illustrate the variety of research efforts along the ever-expanding frontier of decision support systems. They are testimony to the vitality and continuing growth of DSS knowledge that make the study and application of decision support systems so integral to the IS field. The first three chapters investigate connections between organizational characteristics and decision support. Decision support is seen as an instrumental facet of compositional enterprise modeling. It is seen as significant for supporting inquiring organizations. It is envisioned as playing a helpful role for organizations (e. g., nations) that aspire to implement participatory democracy. Next we look at a couple of technical developments that are affecting what is possible with DSSs. One of these is concerned with the availability of massive volumes of real-time data; the other involves the incorporation of information visualization features into DSS interfaces. Two further chapters investigate the notion that systems can be built that enhance the creativity of decision makers. One does so by clarifying the concept of creative decision making, while the other reviews approaches and features of creativity support systems that could be used by decision makers. A final chapter introduces the notion strategic learning for DSSs and describes mechanisms whereby this can be achieved.

## Volume 1: *Basic Themes*

The chapters of Volume 1 are organized into five major parts. Part I examines foundations on which a broad and deep understanding of decision support systems can be built. The two primary dimensions of this foundation are decision making and knowledge. These dimensions are intricately related to each other (Bonczek et al. 1981; Holsapple 1995; Nicolas 2004; Zyngier et al. 2004). We begin with a chapter that discusses the nature and importance of decisional processes in today's turbulent, complex environment. The essential role of knowledge in decision making and sensemaking is highlighted. Knowledge is an antecedent of the ability to make sense of situations and of sound decision making in the course of dealing with those situations. Knowledge is the "stuff" of which decisions are made. Moreover, knowledge is produced in the course of sensemaking and decision making. Thus, knowledge occupies a central place in decision making. Because of this, ensuring the quality of that knowledge is an essential foundation for decision making. Against this background, we then address the key question of why it is that a decision maker needs any computer-based support at all. The answer to this question establishes the rationale for decision support, and we subsequently examine the role of knowledge management in providing such support. Part I closes by tracing the history of decision support systems as a stream of research and practice, plus the identification of important reference disciplines that impact and are influenced by DSS developments.

The eight chapters of Part II present decision support system fundamentals. This commences with an overview provided by a general-purpose architecture for understanding of DSS possibilities. These possibilities lead us to distinguish among various types of DSSs, based on the knowledge management techniques that they adopt or emphasize. Several of the best known types of DSSs are described in the ensuing chapters. The first is comprised of DSSs that stress the use of document management, which involves the representation and processing of knowledge in the guise of text/hypertext. Next, database-oriented decision support systems are considered, including those implemented for data warehouses. Our focus then turns to DSSs that manage knowledge represented in the guise of models and solvers. Perhaps the most common of these DSSs are those that perform online analytical processing (OLAP). Thus, a chapter is devoted to decision support via OLAP. This is followed by a consideration of DSSs that emphasize the spreadsheet technique for representing and processing knowledge – such systems are very widely deployed in practice. Another type of DSS involves those that concentrate on representing and helping to solve multi-criteria decision analysis problems. Part II closes with an examination of Web-based decision support systems. Expanding from the general-purpose DSS architecture and these fundamental types of DSSs, the next two parts of Volume 1 look at multi-participant decision support systems and artificially intelligent decision support systems.

Part III organizes an examination of DSSs that are meant to support the joint efforts of multiple participants engaged in collaborative decision making. We open with coverage of collaborative technologies that can form a backbone for multiparticipant decision support systems, followed by a discussion of motivational issues that need to be addressed if participants are indeed going to share knowledge with each other. A major category of multiparticipant DSSs involves those designed to support decisions made by a group of participants. In addition to characterizing the nature of these group decision support systems (GDSSs), we include a chapter identifying parameters that differentiate GDSSs from one another and discussing potential benefits of GDSSs. Another major category of multiparticipant DSSs is growing in importance. These are designed to support decisions made by participants in an organization (or virtual organization). Called an organizational decision support system (ODSS), such a facility is geared toward participants arranged into an infrastructure involving specialized knowledge-processing roles, linked by patterns of authority and communication relationships, and governed by possibly complex regulations. In addition to characterizing the nature of ODSSs, we include a chapter identifying parameters that can serve to leverage ODSS value and discussing potential benefits of ODSSs. Part III closes with an elucidation of systems that support negotiated decisions among participants.

Intelligent decision support systems employ techniques from the field of artificial intelligence to give DSSs behaviors that would be deemed as "intelligent" if observed in humans. In Part IV, we investigate several classes of such systems. One of these is comprised of systems that give advice to decision makers. They use reasoning knowledge and inference capabilities to help decision makers in much the same way as human experts/advisors can support decision making. Another class involves software agents, also called softbots or knowbots, which undertake autonomous behaviors. They have and process knowledge in ways that allow them to act as participants in decision making, or as assistants to decisional participants. The next chapter describes how some DSSs make use of artificial neural networks as means for knowledge representation, learning, and derivation. Yet another useful approach rooted in artificial intelligence is data mining. Incorporated into a DSS, a data mining capability discovers patterns (i. e., knowledge) embedded databases that may be of enormous size. In a kindred vein, we also consider the use of text mining for decision support purposes – discovering knowledge hidden in massive bodies of textual representations. Yet another chapter discusses the mining of processes via event logs for decision support purposes. Part IV closes with consideration of DSSs that can change their own behaviors based on experience. One approach, illustrated with a production planning application, entails DSS use of a genetic algorithm to adapt over time in order to provide improved decision support. Another involves DSS learning through the use of simulation and performance evaluation, and is illustrated via manufacturing, supply chain, and multi-agent pedagogy applications.

In Part V, our study of basic DSS themes concludes by concentrating on the effects of computer-based decision support systems. This includes an analysis of DSS benefits that have been observed over the years, plus an exploration of users' satisfaction with these automated decision aids. On the other hand, there is a chapter discussing existence of DSS failures – an essential awareness for avoiding repetition of negative effects in the future. A model of DSS critical success factors is developed for enhancing the likelihood of positive DSS effects. Aside from directly supporting a decision by furnishing needed knowledge to a decision maker, an indirect effect of DSSs may reside in the learning that its development and use foster on the part of individuals and organizations. Closing chapters of Part V suggest that learning at the individual and organizational levels can pay dividends in the future by enhancing users' dynamic capabilities for dealing with the circumstances that surround future decisional episodes.

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Frada Burstein and Clyde W. Holsapple (Editors),
*Handbook on Decision Support Systems*

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# PART VI

# Time and Space Issues for Decision Support

# CHAPTER 37
# Decision Support in Turbulent and High-Velocity Environments

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This chapter examines issues concerned with supporting managers and organizations with information and communication technologies as they decide and act in turbulent and high-velocity environments. In particular, the chapter identifies five key tensions in this context: (i) the tension between the need for quick decisions and the need for analytical decision processes; (ii) the tension involving managerial need for action and the need for the safest execution of decisions that may be bold and risky; (iii) the tension around empowering middle managers and management teams at various organizational levels in the midst of powerful and impatient top executives; (iv) the tension between programmed, quick-action learning loops and the increased requirement for emergence and improvisation; and (v) the tension between expending effort to eliminate the digital divide with other organizations versus finding expedient ways to communicate through heterogeneous digital infrastructures. Each of the tensions, and how it can be managed, is illustrated through a case example. The chapter ends by suggesting that the management of these critical tensions needs to be fused into the day-to-day fabric of management practices for decision support processes.

**Keywords:** Decision support; High-velocity environments; Turbulent environments; Managing tensions

## 1 Introduction

Organizations in turbulent and high-velocity business environments are facing rapid and discontinuous change in demand, competitions, technology, and/or regulations. Decision makers operating in such contexts must make high-quality decisions rapidly. Developments in information and communication technologies make it increasingly possible to support decision makers in such contexts better, faster, and at a lower cost. This provides organizations with new opportunities for near-real-time decision making, but also intensifies inherent tensions in decision-making processes that are not as obvious in less-turbulent and slow-moving environments. The aim of this chapter is to examine the issues around supporting managers and organizations in deciding and acting with the aid of information and communication technologies when operating in turbulent and high-velocity environments. This is done by identifying and discussing tensions that organizations must manage in this environment.

## 2 Decision Making in Turbulent and High-Velocity Environments

The external environment is a significant contingency for organizations (Daft and Lengel 1986, Daft et al. 1988). Several organization studies have used the environment as a contingency variable. Here, we focus on studies of organizations in turbulent and high-velocity environments, such as those of Eisenhardt and Bourgeois (Bourgeois and Eisenhardt 1987, 1988, Eisenhardt and Bourgeois 1988, 1990, Eisenhardt 1989, 1990). Huber (2003) argues that an increasing number of organizations will operate in turbulent and high-velocity environments. By high-velocity environments, Bourgeois and Eisenhardt mean environments "...in which rapid and discontinuous change occurs in demand, competition, technology, or regulation in such a way that information is often inaccurate, unavailable, or obsolete" and these environments "...involve continuous instability overlaid by sharp spikes of discontinuous change" (Eisenhardt and Bourgeois 1990, p. 74).

While environmental conditions have probably increased in velocity and turbulence since Bourgeouis and Eisenhardt conducted their studies, the underlying precariousness and tensions involved in decision making in such environments that they have uncovered remain – and are even more relevant today. Most important, theirs was one of the first and most insightful set of studies that showed how performance differences between organizations operating in high-velocity environments were related to how people decide and act. This chapter takes advantage of what they identified as key attributes of successful decision-making processes in high-velocity environments. Their focus on groups and teams of decision makers rather than on single decision makers makes their studies especially useful. As organizations must sense and respond faster, teams and groups are increasingly becoming key.

The literature on how organizations and managers operating in high-velocity environments must make decisions is not consistent, and suggestions for how to make decisions in such environments are sometimes even contradictory. For example, some studies suggest that management teams should conduct formal meetings and consider extensive evidence, while others suggest that too much information searching can lead to the loss of valuable opportunities. Organizations thus face conflicting demands to make decisions fast while evaluating extensive information. These and other conflicting demands can be articulated into a set of definable tensions.

Our reading of the literature suggests that organizations and decision makers in turbulent and high-velocity environments are able to manage at least five tensions. The literature also suggests that organizations and decision makers of less-successful organizations are not able to manage these tensions. The tensions are:

- The tension between the need for quick decisions and the need for analytical decision processes
- The tension around empowering middle managers and management teams at various organizational levels in the midst of powerful and impatient top executives
- The tension around the managerial need for action and the need for the safest execution of decisions that may be bold and risky
- The tension between programmed quick action learning loops and the increased requirement for emergence and improvisation
- The tension around expending effort to eliminate the digital divide with other organizations versus finding expedient ways to communicate through heterogeneous digital infrastructures

We now explore each of these tensions.

# 3 Managing the Five Tensions

## 3.1 Tension Between the Need for Quick Decisions and the Need for Analytical Decision Processes

The first tension is that successful organizations and decision makers in turbulent and high-velocity environments use "highly rational and analytic decision-making processes, but they execute those processes in a short time period'" (Eisenhardt and Bourgeois 1990, p 75). Information for strategic decisions in high-velocity environments is often incomplete, obsolete, and inaccurate. This means that, for example, a strategic decision based on a traditional industry analysis (e. g., Porter 1980) where an organization gathers a lot of data, formulates comprehensive alternatives, evaluates them, and then makes and implements (executes) a decision is not possible because the required information and time do not exist. Eisenhardt and Bourgeois found that successful firms' strategic decision processes are highly analytical and, in many cases, triggered by formal budgeting and control systems (i. e., triggered by using internal information systems for identifying changes in the external environment and in the organization's interactions with the external environment that require action). This is in line with findings that top managers use formal control systems interactively in different strategic settings to focus organizational attention and learning, and thereby shape the formation of new strategies (Simons 1995, Carlsson 2002).

The literature suggests that successful organizations and decision makers:

- Review quantitative measures on a regular basis
- Use different forms of modeling and simulations to varying degrees in order to run a business, especially quantitative analysis and simulations
- Analyze a relatively wide range of measures in an effort to establish a multifaceted perspective.

- Use more, not less, information, than lower-performing organizations and decision makers
- Use both internal and external information sources
- Develop more, not fewer, alternatives

All of these practices followed by more-successful organizations and decision makers suggest a highly analytical decision process. However, these appear to be at odds with some of the practices that have been reported in the popular trade press book "Blink: The Power of Thinking without Thinking" (Gladwell 2005). Gladwell articulates the power and virtues of rapid cognition that happens in the blink of an eye. He cites the example of how Cook County Hospital in Chicago changed the way they diagnosed heart attacks in the emergency room. They started to instruct doctors to gather less information on the patients, rather than more, and encouraged them to focus on only a few pieces of critical information related to patients' chest pains [e. g., blood pressure and electrocardiogram (ECG)] and to ignore all other information such as age, weight, and medical history. The result has been that Cook County Hospital is now one of the best hospital emergency rooms in the USA at quickly diagnosing chest pains.

The need for quick decision execution drives managers away from comprehensive analytics. The resultant tension needs to be managed effectively. Relying solely on gut feel and experience can be very dangerous. Overdone analytics can be paralyzing for rapid decisions. The key to managing this tension is to spend time understanding the critical issues and indicators around a decision context, and really focusing on the few ones that make most of the difference. Monitoring real-time information concerned with these critical indicators through electronic dashboards and scorecards, while not being tempted to monitor the less important ones, can be an effective way to manage this tension.

## 3.2 Tension from Empowering Middle Managers and Management Teams at Various Organizational Levels in the Midst of Powerful and Impatient Top Executives

The second tension is that successful organizations are led by decisive, powerful chief executive officers (CEOs) and top-management teams, yet management teams at different organizational levels may need to be equally empowered for effective decision making. According to studies by Eisenhardt and Bourgeois (1990), more-successful organizations have a balanced power structure. However, there is a natural need for top managers to make quick decisions, have the power to do so, and believe that their vantage point gives them a broader and wiser perspective on the decision context at hand from their interpretation, whatever a decision support system (DSS) model indicates. At the same time, top managers do know that managers at other levels or in different parts of the organization may have closer and more-informative contact with changes in the environment, and therefore need to be empowered to take action and provide input. This creates another tension around DSSs in high-velocity and turbulent environments. Knowledge sharing, as well as the coordination of various teams and groups, is crucial for the implementation of a solution to this tension. Team meetings (actual and virtual) for knowledge sharing and decision making are critical to easing this tension. These meetings should be characterized by open discussions and reasons for ideas should be discussed openly, but they need to be based on a common understanding of the status quo that is as current and close to real time as practically possible. One vehicle for enabling this is decision support via dashboards that are well integrated into the management practices of the organization. A successful example for accomplishing this is illustrated by the case of Western Digital Corporation, a manufacturer of disk drives, through its use of real-time dashboards across its supply chain, which stretches from the USA to Asia, and across various levels of management in the organization (Houghton et al. 2003).

Western Digital dashboards operate at three levels: the shop floor level (focused on shop floor supervisors), the factory level (focused on production managers with multiple product lines), and the corporate level (focused on senior executives). Although not electronically connected, the factory and corporate dashboard systems are connected through the data they share and the communications and interactions of the managers who use them. The dashboards are integrated into all managerial decision making and serve as the basis for coupling senior executive decisions with managerial input from other levels. This accelerates decision processes for instances that span multiple processes and departments, and allow managers to be sufficiently empowered to provide inputs. One purpose of providing key information via dashboards is to eliminate the separation of people in space and time, thereby allowing managers to be virtually in the room. This coordination is being accomplished at Western Digital by using corporate dashboards as the focal points of meetings among managers from sales and marketing, distribution, and the factory. This helps manage this second tension.

## 3.3 Tension between Managerial Need for Action and the Need for Safest Execution of Risky/Bold Decisions

The third tension is that more-successful organizations "...make bold, risky decisions that often challenged established industry norms, yet preserve safety by postponing decision implementation as long as possible through the use of carefully planned execution triggers" (Eisenhardt and Bourgeois 1990, p. 76). As Pfeffer (1992) points out: a decision by itself changes nothing; implementation (execution) often makes the difference. Successful organizations and managers act rationally, but seek innovation and risk. They build in execution triggers, which means that once a decision has been made, subsequent decisions are laid out. Coordinated plans are developed for implementation to be triggered by an event, schedule, or milestone. This is related to one of the purposes of decisions: mobilization (Brunsson 1989). A general problem in organizations is how to achieve coordinated and collective actions. The key is to secure commitment from actors, and hence link actors to action in advance. Decision making can be used as a way of establishing and maintaining commitments.

Once a decision has been made, a team tries to keep execution options open as long as possible. This requires good execution plans and the integration of different decisions and plans. At the same time, a team also tries to have other options – decisions and plans – available in case they have to make a different decision.

Organizations are making bold and risky decisions. One of the most problematic decision domains is merger and acquisition (M&A) decisions and the implementation of such decisions. During the last decade, the act of acquisition has become a prominent tool for corporate strategy worldwide (Sirower 2003). In 2005, the worldwide number of completed and pending M&As rose to 35,208. The number of M&A represents an overall transaction value of € 2,500 billion, a sum that amounts to some 25% of the total gross domestic product for the European Union or the US. Despite the popularity of M&As, history tells us that the endeavor is a risky and complicated process. For example, on separate surveys, KPMG and McKinsey report that 60% of M&As do not create shareholder value for the participating companies, nor do they increase growth appreciably (Bekier et al. 2001, KPMG 2001); and the business press states that "acquisition research studies indicate that between 60 and 80 percent are financial failures" (Norton 1998) and destroy shareholder wealth (Henry 2002). Hence, reality tells us that M&A decisions are often both bold and risky. The reality also tells us that the implementations of M&A decisions are far from safe.

The Mexican company, CEMEX (Cementos Mexicanos), has addressed the tension between the managerial need for action and the need for safest execution of decisions that may be bold and risky [the description of CEMEX is mainly based on Ghemawat and Matthews (2004) and Chung and Paddack (2003)]. For a sustained period, CEMEX achieved enviable growth results compared with its main competitors, becoming the world's leading producer of white cement. CEMEX's ambition to grow by acquisitions meant that it faced large challenges in making the correct acquisition decisions and in how to incorporate acquired companies into its existing operations (as many of the acquired companies were underperforming). Since the early 1990s CEMEX has made several major acquisitions, starting with acquisitions in Mexico and then internationally. Some of the acquisitions were highly controversial and on several occasions analysts questioned CEMEX's decisions. Analysts were saying, for example, that CEMEX overpaid and that CEMEX would not be able to manage companies in other regions well. Hence, it is safe to say that CEMEX's strategy required actions in terms of M&A, that many of its M&A decisions were bold and risky, and that the decisions required safe implementation. CEMEX managed this tension in several

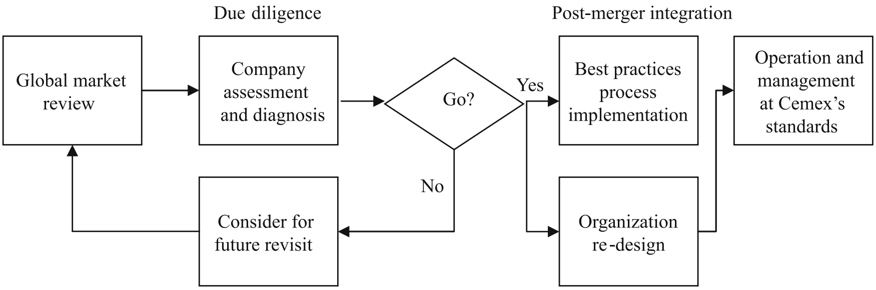


**Figure 1.** CEMEX's systematic institutional core process for acquisition (Chung and Paddack 2003, p. 23)

ways. Based on an early acquisition and as it moved to more-distant markets, the firm found that its M&A decision and implementation process had to be improved. Figure 1 depicts CEMEX's core process for acquisitions.

Over time, various stages in the M&A process became more formalized and, based on experiences, more attempts were made to standardize them. For example, to continue to be able to make bold and risky acquisition decisions better than its competitors were able to do, CEMEX used a larger number of dimensions and components in the process than its competitors did. A due-diligence process lasted for one to two weeks. For example, in the human resource component it looked at a larger number of dimensions than its competitors did, including dimensions such as age, education, labor union affiliations, training programs, years of employment of the prospect's employees, and government involvement. Such thoroughness reduced the likelihood of unpleasant surprises later in the process. Hence, CEMEX thought its due-diligence process was more systematic and specific than those of its competitors. CEMEX in its M&A decision process was also managing tension 1—the need for quick decisions and the need for analytical decision processes—very well.

CEMEX not only tried to manage its bold and risky M&A decision process, but also tried to manage the execution (implementation) of the acquisitions decisions. In 2001, CEMEX initiated the CEMEX Way, which was a firm-wide information and process standardization program. In this program, CEMEX created an information technology (IT) infrastructure and ensured that 60% of its business processes were managed in a Web-based environment. Identified best practices were incorporated into standard platforms and could be executed throughout the firm, as well as in acquired companies. One of the major benefits of the CEMEX Way was that CEMEX benefited from better control of the implementation process and, for example, could integrate an acquired company faster. Through standardized platforms and standardized IT-enabled processes, CEMEX was able to implement this process in acquired firms quickly and safely. For example, in just four months for a very large acquisition, as opposed to 18 months for its first acquisition.

Davenport and Harris (2007, p. 68) when describing the use of business analytics in M&A processes, say that “CEMEX, the global cement company, uses analytics to quantify expected benefits from increased market share and improved profitability by enforcing its processes and systems on the takeover target.”

## 3.4 Tension Between Programmed Quick Action Learning Loops and Increased Requirement for Emergence and Improvisation

Organizations in high-velocity and turbulent environments are faced with planning for programmed responses in a variety of contingency conditions, while leaving enough flexibility for improvised responses as new conditions emerge. In the context of DSSs, this creates a tension that needs to be wisely managed as part of the larger sense-and-respond cycle of an organization. On the one hand, the DSS has access to a set of existing models that can be queried in a what-if mode to help make better decisions. On the other hand, new conditions may emerge that require a course of action that is outside the scope of the programmed models, yet require a quick and informed decision.

A way to deal with this tension is perhaps best explained by using the concept of observe, orient, decide, act (OODA) loops and vigilant information systems (Figure 2). The concept of OODA loops was originated by US Air Force colonel John Boyd (Boyd 1986 quoted in Curtis and Campbell 2001) who wanted to understand how fighter pilots won air combat engagements (dogfights) against other pilots despite flying aircraft with inferior maneuverability. Boyd found that winning pilots were able to compress the entire cycle of activities that happen in

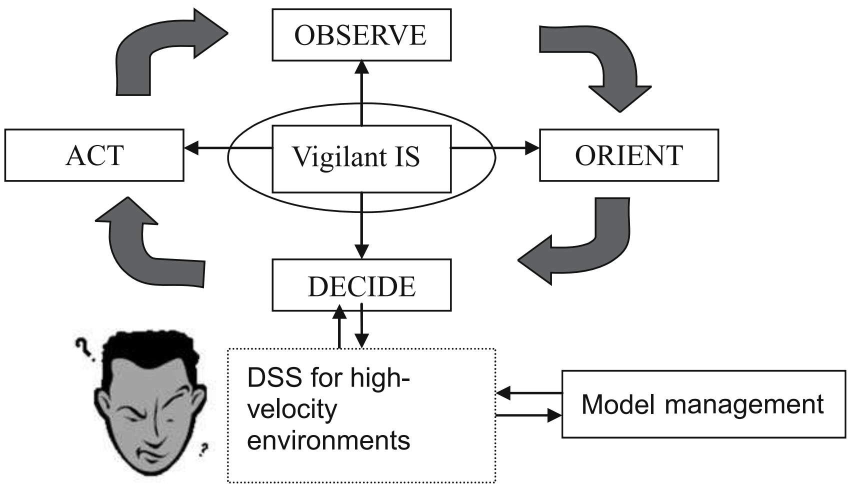


**Figure 2.** OODA loops and high-velocity DSSs

a dogfight and complete them more quickly than their adversaries. Boyd's OODA loop of activities is comprised of: *observation* (seeing the situation and adversary), *orientation* (sizing up vulnerabilities and opportunities), *decision* (deciding which combat maneuver to take), and *action* (executing the maneuver).

The OODA loop concept was popularized in business by Stalk and Hout (1990) and Haeckel and Nolan (1993):

- *Observation* (seeing change signals)
- *Orientation* (interpreting these signals)
- *Decision* (formulating an appropriate response)
- *Action* (executing the response selected).

The organization that can complete its OODA loops quickly when changes occur in business processes and in the environment is in a much better position to survive.

The class of systems that is appropriate for supporting fast OODA loops has been called vigilant information systems. Vigilance means being alertly watchful for any signals of change, detecting weak signals about emerging issues, and initiating further probing based on such detection. Vigilant information systems (Walls et al. 1992) allow information and business intelligence to be integrated and distilled from various sources and systems, detect changes, have active alert capabilities, aid issue diagnosis and analysis, and support communication for quick action. Effective vigilant information systems support both the *sense* portion of the OODA loop (observe, orient), as well as the *respond* portion of the OODA loop (decide, act). Thus, they provide a suitable interface to (or extension to) DSSs in high-velocity environments (Figure 2). However, OODA loops should not only be executed quickly, they should also be flexible and responsive to changes in the environment under unforeseen conditions.

The notions of improvisation in decision making, and how to use IT-enabled decision support capabilities to enable it intelligently, first appeared 20 years ago in the context of strategic decision making in developing economies where turbulent conditions are most pronounced. The cabinet of Egypt (El Sherif and El Sawy 1988) undertook a major effort to design and deliver decision support systems to aid the strategic decision making of the prime minister and the cabinet. The strategic issues and the decisions around them that the Egyptian cabinet had to deal with were typically complex, ill-structured, and accompanied by an overload of information of questionable reliability, with multiple and murky interpretations. Not only did the environmental conditions change quickly, but the decision makers discovered new aspects of the environment through the DSS that they had previously ignored or thought were different. Furthermore, the architecture and features of the DSS were designed to aid this. For example, in the design of a customs tariff policy formulation DSS in which decisions often had to be made very quickly due to shortages in critical goods or due to unforeseen crises, provisions were taken to quickly have the ability to surface the assumptions in the DSS model. There was even an assumption function key (similar to a help function key) that could be activated to show the assumptions and the reliability of the data around it explicitly, such that it could be easily challenged and changed if the environment structurally shifted. Thus the observe and orient part of the OODA loop was coupled to the decide and act portion in a way that enabled quick changes to be made to the DSS model while still executing the decisions in a systematic manner. The DSS thus helped manage this tension and permitted improvisation in a more orderly manner.

Another angle on managing this tension requires the notions of emergence to be taken into account (Majchrak et al. 2006). Majchrzak et al. identify several methods by which organizations effectively deal with emergence. These include building the ability continually to challenge information, assumptions, and interpretations into the structure of work; embracing new knowledge and skill sets; and the expectation of unpredictable inputs from the environment. Applying each of these best practices in the context of OODA loops suggests ways for managing the tensions between programmability and emergence in high-velocity DSSs. Thus, DSSs for high-velocity environments need to incorporate rapid ways of surfacing assumptions around decision models and be able to incorporate new parameters that did not previously exist when needed. This means a constant reevaluation of decision models when weak signals are sensed that may change them. Thus, DSSs for high-velocity environments also need to be tightly coupled to vigilant information systems. The lesson here is that the design of management dashboards needs to take into account this assumption surfacing capability.

## 3.5 Tension Between Efforts to Eliminate Digital Divide with Other Organizations Versus Finding Expedient Ways to Communicate Through Heterogeneous Digital Infrastructures

Organizations increasingly operate in environments in which the quality of their decisions is based on operational information that is aggregated from a number of partners and collaborating organizations. As it becomes more common to outsource entire business processes, very often halfway around the world, many more decisions are based on operational information and changes in conditions that are communicated via the IT infrastructures of partners outside the enterprise. Some of this information comes in the form of structured data from transactional systems, while some of it is in the form of unstructured data from a variety of heterogeneous digital infrastructures and people. The organization with the greatest need for speedy decisions in the ecosystem tends to be the one that tries to lead efforts to smooth out information delivery paths through better business processes and more digital pathways. It is also often the case that this is the one that has the most digitally intensive infrastructure for information transfer and communications. This creates a set of tensions: should the speediest organization try to get its partners to upgrade their digital infrastructure and digitize their data, or should it try to make do and find expedient ways to communicate through heterogeneous digital infrastructures? How should it manage the digital divide in the business ecosystem in which it operates so that the quality of the information supplied to its DSS is not compromised?

There are generally two types of solutions to this problem. The first type, which works best if the enterprise is a powerful player in the ecosystem (such as Walmart, Cisco, or CEMEX), is to lead and impose the need to have digital infrastructures in place for data and communication exchange with partners as a condition of doing business, while often assisting in setting it up and funding part of this effort. The second type of solution is to work with a patchwork of channels that have different levels of digitization and structure, and incrementally work to upgrade these over time, rather than trying to impose a total solution. While the first solution is most attractive for rapid DSSs, it is usually quite difficult to implement.

For example, IndyMac Bank and several other mortgage banks in the USA considered implementing an all-electronic mortgage initiative, but found many obstacles. IndyMac Bank discovered a digital divide between parts of the ecosystem, with some participants being highly electronic, while others were slow and paper based. They were unable to persuade title companies to digitize all of their data. Although digital title data is available in large metropolitan areas, the only way to title search in rural areas is to search through paper records in the courthouse. Furthermore, automating title searching may not be in the best economic interests of some ecosystem partners because they make more money from inefficient processes. Furthermore, they found industry reluctance to adopt the extended markup language (XML) standard for the transmission of transactional data between companies. This digital divide in the industry made it unlikely that the mortgage market could be fully digitized in the near future. The whole mortgage ecosystem must agree and act if the process is to be completely paperless. The only thing that firms like IndyMac Bank could do at this point was to work on the problem incrementally by automating additional portions of the mortgage process in paper-based form [e. g., optical character recognition (OCR) scanning of documents], eventually closing the digital divide. In the meantime, the tension between such heterogeneous portions of the value chain continues to contrast with the need for rapid DSSs.

## 4 Will Tensionitis Become a High-Velocity DSS Affliction?

Decision support in organizations is an ongoing process, rather than consisting of a single or few instances. Certainly, some decisions are more consequential than others and the quality of their outcomes may have much larger impacts, but decision processes are part of the fabric of organizations rather than isolated instances. Thus, it is important to create a practice framework that is robust across a whole range of decision instances. This framework should also encompass the links between decisions and actions horizontally across the entire organization and its supply chain, and vertically between various levels of management. As the Western Digital example above illustrates, when the environment speeds up and near-real-time decisions are not uncommon, the distinction between operational and strategic decisions becomes blurred. In these harsh conditions of high velocity and turbulence, it becomes critical to have a practice framework that guides decision support processes. The tension framework that we have presented is one way of doing that.

We have identified five different tensions in decision support processes that become more evident in the harsh environment of high velocity and turbulence. This does not mean that each of these tensions is equally critical in each decision instance, but that these tensions need to be considered. Their relative importance will be determined by managerial judgment in each context. This also does not mean that there are only five such tensions – there are probably more that we invite others to uncover.

The tendon is the structure in the human body that connects muscles to bones. There is a medical condition named tendonitis in which the tendon becomes inflamed for various reasons, and the action of pulling a muscle and movement becomes painful. Can we think of a similar situation in DSSs for high-velocity and turbulent environments, which for want of a better name we call tensionitis, in which the management of these tensions becomes dysfunctional and painful? How can we avoid this happening as the environment continues to speed up and increase in turbulence?

These are the tensions, contradictions, and paradoxes inherent to all organizational arrangements, and decision support processes are no exception. There are many ways of managing those tensions and contradictions in a spectrum that ranges from one-by-one resolution to an integrated portfolio of approaches. However, wherever on that spectrum an organization chooses to be, the critical issue is that the management of these tensions should be fused into the fabric of management practice and decision support. In high-velocity and turbulent environments, this fusion into day-to-day practice is especially important, as it is easy to lose sight of those tensions when the pace is frenzied, or conversely to develop an acute case of tensionitis.

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# CHAPTER 38
# Supporting Decisions in Real-Time Enterprises: Autonomic Supply Chain Systems[1]

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Supporting decisions in real time has been the subject of a number of research efforts. This paper reviews the technology and architecture necessary to create an autonomic supply chain for a real-time enterprise for supply chain systems. The technologies weaved together include knowledge-based event managers, intelligent agents, radio frequency identification, database and system integration, and enterprise resource planning systems.

**Keywords:** Real-time enterprises; Autonomic; Supply chain

## 1 Introduction

This chapter provides an overview of decision support applications for real-time enterprises and then provides a detailed investigation into supporting real-time supply chain decisions. The analysis of the real-time supply chain integrates a number of technologies into an overall architecture that treats the supply chain as an autonomic system – one designed with intelligence so that the *system* can respond to events and stresses placed upon it. The paper also examines the decision support system (DSS) roles of such autonomic systems, which ultimately provide support, despite the substantial capabilities built into the system architectures.

The chapter is structured as follows. Section 2 investigates the supply chain and use of different technologies in the supply chain. Section 3 reviews some of the previous research in supporting decisions in real-time enterprises in a variety of industries. Section 4 summarizes some of the key technologies supporting supply chain decisions in real-time enterprises. Section 5 drills down using some examples of the use of the autonomic supply chain. Section 6 briefly summarizes the paper, discusses some extensions, and reviews the paper's contributions.

[1] The author would like to acknowledge the helpful comments of the referees in the development of this paper.

# 2 Supply Chains

This section presents some analysis of the importance of supply chains in business and the role of technologies in existing supply chains. In addition, it presents some empirical evidence that supply chains, in real-world settings, need additional technology.

## 2.1 The Importance of Supply Chains

Robert Rodin, former chief executive office (CEO) of Marshall Industries noted, "Today business is about my supply chain, versus your supply chain." Accordingly, the very survival of multiple related industries is concentrated in groups of firms competing against other groups of firms. It is not just one firm against another. This has been reiterated by others (e. g., SAP 2001). As a result, members of supply chains need to be able to work together. Processes and technologies need to be integrated within firms and across firms in the supply chain. Furthermore, since it is a matter of survival, often the system must work in real time, thus requiring integrated data and processes that facilitate and enable real-time integration.

In addition, for the system to respond to a range of environmental events, the whole system must respond. As a result, the system needs to be adaptive to events that affect the system. Accordingly, knowledge about events and how to respond to those events needs to be embedded in the supply chain system.

## 2.2 Supply Chains Need Technology

From a technology perspective, a first concern is: do existing supply chains see a need for technology to facilitate integration and support of real-time decisions making? As seen in Table 1, the Aberdeen Group's (2006) survey of over 150 companies found that only 10% of the firms surveyed felt that they had the right technology in place for the supply chain.

**Table 1.** Extent to which supply chain technology meets needs

| | |
|---|---|
| Technology meets our needs | 10% |
| Our technology needs improvement | 44% |
| We lack the technology we need | 46% |

Source: Aberdeen Group (2006)

For example, we can see that 90% of the firms do not have the technology that they need. Accordingly, one of the purposes of this paper is to identify the appropriate technologies and outline an architecture that can facilitate a range of technologies that meet supply chain needs.

Aberdeen's survey was based on a sample of 16% consumer goods and distribution, 15% high tech, 13% apparel, 10% aerospace and defense, and 10% construction/engineering, and included firms from other industries including retail, industrial manufacturing, and chemicals/pharmaceuticals. Roughly 30% of respondents were from enterprises with annual revenues of $1 billion or greater, 48% from enterprises with revenues between $50 million and $999 million, while 22% of respondents were from businesses with annual revenues of less than $50 million.

## 2.3 Supply Chains as Real-Time Enterprises

In a real-time supply chain, the supply chain is automated end-to-end. Unfortunately, few supply chains are automated to leverage real-time capabilities. For example, the results of a survey by the Aberdeen Group (2006) regarding the extent to which supply chains are automated and integrated are summarized in Table 2. Currently only 6% of supply chains are highly automated. Virtually all supply chains are fragmented and not integrated at some level. This means that there is substantial opportunity to evolve those supply chains to include appropriate technologies so that they become real-time systems.

However, even if the supply chain is automated, what should that automation look like, how would we expect it to be automated, and how might it be automated in the future? Even if it is automated, how do we ensure that the system is adaptive to the wide range of events that can occur in supply chains? How can enterprises detect and get rid of fragmentation? The next section will examine some of the previous research in real-time enterprises to see where opportunities for supply chain technology applications might exist.

**Table 2.** Technology maturity in supply chains

| | |
|---|---|
| Highly automated | 6% |
| Some end-to-end and cross-functional process automation | 19% |
| Department-level automation | 20% |
| Fragmented information technology (IT) approach | 29% |
| Mostly manual and spread sheet driven | 26% |

Source: Aberdeen Group (2006)

## 3 Previous Research on Real-Time Enterprises

Previous research on supporting decisions in real-time enterprises has focused on a range of industries and approaches. The industries provide the basis on which to understand how technology can be leveraged to bring real-time decision making to the enterprise. This section reviews and briefly summarizes some sample applications along with the key supporting technologies used in the applications. This review is focused on those real-time applications and their use of technologies, in contrast to, e. g., pricing algorithms, etc., where the dominant concern is economics. Our concern is with those applications where, at some level technology plays a critical role in the real-time aspect of the enterprise.

### 3.1 Electric Power

Bergey et al. (2003) investigated a system for the electric power districting problem, in order to balance the supply and demand for electricity in real time. As a result, electricity must be scheduled and dispatched to all generators connected to the network in real time. They proposed a solution that allowed *visualization* to help decision makers. Alvarado (2005) investigated the use of a decision support system to facilitate the control of power systems using real-time pricing for electricity. By using real-time price changes, the plan was to influence real-time electricity use.

### 3.2 Electronic Markets

Aron et al. (2006) discussed how the use of *intelligent agent* technologies analyzing real-time data in order to help electronic markets evaluate buyers, and customize products and prices in real time. Karacapilidis and Moraitis (2001) developed an intelligent agent-based architecture where personal software agents perform buyer and seller tasks in electronic markets and auctions.

### 3.3 Health Care

Duda and Heda (2000) investigated business processes in managed health care businesses to attain a real-time response. They find that *technology integration* across multiple databases and systems is a critical part of the design. Forgionne and Kohli (2000) discussed a decision support system for health care, designed to improve decision making through integration across multiple systems. They developed a system with integrated databases and intelligent systems used to facilitate decision making. Wu et al. (2005) examine the importance of tracking individual items, ranging from equipment to drugs to people, using radio frequence identification.

## 3.4 Nuclear Power

Papamichical and French (2005) discussed a system designed to operate in real time in the nuclear power industry, in case of radiation accidents, by decreasing the number of alternatives to be considered to a reasonable number. Using accident-based events, they developed a knowledge-based system based on multi-attribute utility theory, to determine how to reduce the number of alternatives and solution speed. *Knowledge about events* was generated along with corresponding knowledge about alternatives to help manage these events.

## 3.5 Telemarketing

Ahn and Ezawa (1997) developed a system based on Bayesian learning to support real-time telemarketing operations. The intelligent system was designed to support decision making about different kinds of offers to make and whether or not to go to the next customer or promote another product. That is, knowledge about one event provided insight into a chain of reasoning about the customer. Again, *knowledge about events* is captured and used to help manage the process.

## 3.6 Transportation

Balbo and Pinson (2005) developed a decision support system designed to monitor transportation systems. If there was a disturbance on a public transportation line then the system uses knowledge to follow the disturbance as it evolves. They also proposed a *multiple-intelligent-agent*-based approach that facilitated disturbance processing.

Beroggi and Wallace (1994) developed a prototype system aimed to facilitate real-time control of the transportation of hazardous materials. Their system was designed to support risk assessment and route guidance for safety and cost, using a hypertext tool that allowed knowledge capture and reuse. They were concerned with communication of location types of information using hypertext. Such an approach facilitated visualization and management of *knowledge about key events*.

## 3.7 Supply Chain

Supply chain is a rapidly emerging and new application area for real-time systems. Kimbrough et al. (2002) were among the first to use *intelligent agents* to model the supply chain. Babaioff and Walsh (2005) examined the use of intelligent agents to facilitate auction-based choices. Liu et al. (forthcoming 2007) modeled event management for the supply chain. Yao et al. (2007) have examined key parameters associated with supply chain *process integration* associated with issues such as vendor-managed inventories.

## 3.8 Summary of Selected Research

A summary of this research is provided in Table 3. As seen in these many applications, a broad base of technologies has been analyzed in previous research, from many industries, in an attempt to facilitate decision making in real-time enterprises. At the heart of many of these applications are intelligent systems and integration across multiple databases and systems. Furthermore, the notion of knowledge-based event or disturbance processing is consistent with a system that responds to a set of events that can influence or disrupt the supply chain. For all intents and purposes, many of the systems contain knowledge-based event managers that monitor and respond to events or sets of events, using knowledge with which they have been provided. Those event managers have been referred to as intelligent agents and event managers. Because their purpose is to manage events we will continue to refer to them as event managers.

This summary illustrates some limitations of the existing literature. Firstly, in earlier applications there was apparently limited need to gather data and control individual objects. As we will see below, that is not the case in the supply chain, where information about many different objects can be used to facilitate and control the supply chain. As a result, object identification becomes an important issue. Secondly, each of the applications was in a single industry, as a result there was limited need for integration. Since these previous real-time applications employ these technology approaches, the real-time enterprise supply chain architecture discussed here also will employ many of these same technologies. Thirdly, at least in the literature examined here, visualization has received at most limited attention. However, technologies such as object identification and real-time data facilitate visualization to aid people's use of the overall systems. Ultimately, this whole collection of technologies will be assembled for the development of autonomic supply chains.

**Table 3.** Summary of selected research

| Industry | Real-time data | Object identi-fication | Visuali-zation | System/ process integration | Intelligent agents | Event managers |
|---|---|---|---|---|---|---|
| Electric power | X | | X | | | |
| Electronic markets | X | | | | X | |
| Health care | X | X | | X | X | |
| Nuclear power | X | | | | | X |
| Telemarketing | | | | | | X |
| Transportation | X | | | | X | X |
| Supply chain | | X | | X | X | X |

# 4 Technology to Support Supply Chain Decisions: Autonomic Supply Chains

As seen in the literature review a number of technologies have been employed in developing real-time enterprises. Similarly, a broad range of information technologies can be used to facilitate decision support in real-time enterprises for the supply chain. Although the term autonomic supply chain has received attention (e. g., Gill 2003 and Grosson 2004), there is limited research establishing what constitutes the concept. For the supply chain to attain a level of autonomy to provide a high level of support, data and processes across different partners in the supply chain must be able to be integrated. Furthermore, to provide data about the flow of individual objects through the supply chain, a technology such as radio frequency identification (RFID) is needed. These technologies are summarized in the following table. Ultimately, the basis for the choice of these technologies is generated by the notion of autonomic computing in the supply chain (Table 4).

**Table 4.** Autonomic supply chain and technology components

| Autonomic systems | Technology |
|---|---|
| Real-time supply chain data | Enterprise resource planning (ERP) |
| Real-time object identification | Radio frequency identification (RFID) |
| Seeing the data and supply chain in real time | Visualization |
| Real-time integration of data and processes | Extensible markup language (XML)/electronic data interchange (EDI) |
| Real-time decision making | Intelligent agents |
| Real-time event monitoring | Event managers |

## 4.1 Autonomic Systems

The overriding structure of the real-time enterprise supply chain architecture used in this paper is autonomic computing. The term autonomic derives from the body's autonomic nervous systems, so systems can work by themselves, as the nervous system does without conscious human intervention. The notion of autonomic computing was originally proposed so that computers could be more independent and intelligent, operating with minimal human interaction (http://www.research.ibm.com/autonomic/). Initially, it appears that the focus of such systems was on large mainframe systems, and then later networks. IBM, Siemens, Cisco, and other firms have argued that computing systems need to be more autonomic, so that systems can fend for themselves, rather than requiring substantial human direction. Substantial human intervention is too costly and too slow.

The translation of notions of autonomic computing to autonomic supply chains requires a number of elements in order to be executed in a supply chain environment, including the following abilities:

- to obtain data in real time to facilitate decision making
- to provide information on the objects being processed by the system
- to allow humans to visualize the system to help them reduce complexity
- to integrate across different systems so that systems can work together,
- to operate intelligently, in the numerous simultaneous settings that occur in supply chains
- to monitor its own operation and decide what to do if particular prespecified events occur

We will examine each of these components as part of generating the overall system architecture.

## 4.2 Real-Time Data Generation: Enterprise Resource Planning (ERP) Systems

Real-time data for autonomic systems means real-time data throughout. Much supply chain data is ultimately captured using an ERP system. Accordingly, ERP systems are at the center of much of the real-time data generation for decision making. For example, key data generated or maintained for the supply chain in the ERP system are qualified vendor lists, orders, goods received given the orders, transportation vendors, etc. Holsapple and Sena (2005) discussed some of the relationships between ERP and decision support.

Ultimately, this data, updated in real time, is the basis of planning in both the enterprise and the supply chain. Often there is sharing of ERP data to facilitate data exchange. This often occurs by making the data available to others in the supply chain through a data warehouse, accessible from the Internet. For example, retailers can make sales data available to vendors so that the vendors can use it for planning or management of the inventory. The need for data exchange leads to the integration of data and processes among supply chain organizations.

However, real-time data from sources other than an ERP system may be necessary. One of the primary sources of real-time data is individual object identification information, including RFID.

## 4.3 Real-Time Object Identification: RFID

RFID allows enterprises to uniquely identify and track supply chain objects at different levels, including train cars, trucks, pallets, cases, or even individual product items. RFID provides a unique identifier for whatever the tag is attached

**Table 5.** Extent to which RFID is embedded in the supply chain by two large retailers

| Company/date | RFID-enabled suppliers | RFID-enabled stores | RFID-enabled distribution centers |
|---|---|---|---|
| Wal-Mart[a] (April 2006) | 300 | 500 | 5 |
| Metro[b] (August 2005) | 33 | 13 | 9 |

[a] Haskins (2006)
[b] Ton et al. (2005)

to or embedded within, in real time. Readers at garage doors determine when a truck enters or leaves the garage. Readers at the rear of a truck can capture movement of goods onto or off a truck, depending on the object of interest.

Two retail leaders in the use of RFID in the supply chain are Wal-Mart and Metro. The extent to which they have embedded RFID into their supply chains is summarized in Table 5. RFID participants include the suppliers, the stores, and the stores distribution centers. As a result, the location and passage of RFID objects can be traced throughout the entire supply chain. Some retailers, including Tesco (Nielsen 2005), have had difficulties, often beyond their control, which have limited their ability to implement RFID.

Accordingly, if they are present, RFID tags can be used to find whatever has been labeled using the RFID tag at various points in the supply chain. This can help to minimize misplaced inventory, and the corresponding lost sales, etc., that accompany that inventory as it sits, lost, covered and unused in storage. RFID can also be used to minimize the leakage of goods.

Most RFID tags are passive, having no power source, and limited range, but a unique identifying code. However, because of their unique identifier, passive RFID tags allow the objects that they represent to become *responsive*. The tagged goods are not intelligent per se, however, when queried they can signal their presence. Object responsiveness is critical for an autonomic supply chain.

In contrast to passive tags, active tags have their own power source, and while operating over a longer range they are larger and more expensive. Rather than just being responsive, active tags can facilitate *intelligence*, since each object can interact with other objects. For example, tagged chemicals could respond to each other, to note, for example, that they could spontaneously combust or that the goods they carry have expired. Intelligent tags can also keep a history of events faced by the object, for example, temperature changes, thus facilitating intelligence at the object level. Even knowledge-based systems can be generated and used at the object level.

In an autonomic supply chain responsive or intelligent objects meet the need for objects in the system to provide information back to the system. In some applications, more-intelligent objects can be more helpful than others (e. g., if they could spontaneously combust). However, in most applications, responsiveness is likely to be sufficient. Although this section has focused on RFID, other technologies, such as satellite communications, are also emerging for object identification.

## 4.4 Seeing the Data and Supply Chain in Real Time: Visualization

Individual object identification (e. g., RFID) can facilitate visualization, which can be used to address the complexity that comes with multiple-agent systems. As a result of the ability to keep track of individual items, the visibility of goods is strengthened. So much so that in one discussion, the CEO of a company noted (Rhode 2004), "I can actually sit in my office and follow where all of the pallets are going." Whether or not the CEO should be concerned about specific pallets is another issue, but we can see that RFID can definitely facilitate visibility. Furthermore, this technology is consistent with previous research in real-time systems that promotes the use of visualization maps of the flow of goods marked with RFID to determine where bottlenecks are slowing processes down. In so doing they can determine where bottlenecks are and work to mitigate them in real time.

## 4.5 Real-Time Integration of Data and Processes: Electronic Data Interchange (EDI) and Extensible Markup Language (XML)

Supply chains cross many boundaries, both inter- and intra-firm. Accordingly, information must cross those boundaries, systems must to talk to systems, and processes must be integrated across those boundaries. Furthermore, for data flow to occur in real time, these systems must be integrated.

Beyond allowing access of others to internal systems, such as data warehouses, there are a number of technologies that can be used to facilitate system-to-system integration. Historically, large firms have relied on EDI using value-added networks (VANs), pricing smaller firms out of EDI integration. However, Hamblen (2002) noted that recently Wal-Mart had adopted Internet-based EDI, with software costing potential integration partners only $300 per year, making data integration a cost-effective capability.

XML offers another technological capability to facilitate data integration. XML does not require classic value-added networks that were used to support EDI. Further, there is substantial flexibility in the definition of XML standards, since XML does not specify the semantic content of the exchanged data. In addition, although EDI is more batch focused, XML is more amenable to facilitating real-time interactions, and companies can continually go back and forth with XML conversations.

However, the development of semantic standards that can be used across the supply chain or industry is critical to XML use. Metadata management at the enterprise, supply chain, and industry level is required. Common definitions must be created so that XML-based exchanges result in real information exchanges.

However, data integration is only part of the story. In addition, processes need to become integrated and managed. For example, RosettaNet (http://www.rosettanet.org/Rosettanet/Public/PublicHomePage) provides a set of standards designed to facilitate the exchange of process information along the supply chain. For the semiconductor industry, RosettaNet defines about 1000 dictionary items defining different product types, ultimately laying out a semantic map of the products so that users' systems can talk the same language. RosettaNet also defines partner interface processes (PIPs). PIPs are XML-based system-to-system dialogs that define data exchange between partners. They have also defined over 100 different PIPs, and have standardized or plan to standardize the exchange of information between different members of the supply chain. PIPs do not really care about processes leading up to the exchange, as long as that data exchange continues. However, data exchange and process impact are laid out along with the exchange. Although RosettaNet is specifically for the semiconductor industry and not appropriate for the other industries, the same conceptual approach would be appropriate, providing standard information exchanges across the supply chain.

In the retail supply chain, Procter and Gamble also uses XML and EDI to accept invoices for payment (http://www.pgsupplier.com/AP_General_Information.htm), however, they prefer a change in the overall process of invoices. In particular, they prefer to either pay off their invoices based on computing the amount of the inventory they have used or the amount of inventory that they receive, speeding the process even more. This illustrates that, in some situations, processes along with technology can drive change. However, technology must accommodate the exchange of information and integration of processes.

## 4.6 Real-Time Decision Making: Intelligent Agents

One of the ways to make systems autonomic is to employ intelligent agents to perform many of the system tasks. But an even more important factor leading to the use of intelligent agents is simply the sheer number of activities happening at any one time and the number of items in play in the supply chain. For example, when Gillette announced that it was going to use RFID, they purchased 500,000,000 tags (Schwartz 2003). Humans cannot keep track of 500,000,000 different items, so necessarily, intelligent computer agents are required.

Using intelligent agents in the supply chain is not a far-fetched tale for the real world. For example, as discussed in Thomas (2002), SAP, the large ERP software vendor is pursuing the use of intelligent agents: "SAP announced the enhancement of … (its supply chain management software) through the use of new intelligent agent technology." SAP (2001) further notes that

> … intelligent agents will automatically trigger a variety of problem resolution techniques resulting in the optimization of the adaptive supply network. Intelligent agents are the next stage of adaptive planning and execution. … The ultimate goal is to create a truly adaptive supply network that can sense and respond to rapidly evolving conditions so that partners can intelligently cooperate to keep demand and supply in close alignment and efficiently coordinate the fulfillment process. We believe that intelligent agents will be key to resolving the increasing challenges companies are faced with in participating and managing global adaptive supply networks.

Intelligent agents can be used to provide a number of capabilities to the supply chain. Cisco Systems was one of the first firms to adopt intelligent agents in a number of supply chain activities (Cisco Systems, no date):

- Configuration agents – verify configurations
- Pricing agents – search for product prices
- Lead-time agent – check lead times
- Order status agent – monitor the status of orders
- Invoice agent – view invoices, credit memos and debit memos
- Orders extract agent – take order information at Cisco and download for local use

Intelligent agents could also be employed in circumstances similar to those of other real-time enterprise applications. For example, intelligent agents could be used in bids to determine where goods might be manufactured. Further, intelligent agents could be used to schedule production activity or transportation activity.

## 4.7 Real-Time Event Monitoring: Event Managers

As with applications in other real-time systems such as traffic or nuclear power supply chain systems need to define events that can happen and how to manage the supply chain if these events do happen. For example, if a supplier cannot provide a particular shipment of raw materials, what should happen? In this case, we might have an intelligent agent that is notified and takes responsibility for choosing another supplier. As another example, if there is a weather event, and a shipment is interrupted, what should happen? In this case, an intelligent agent can be charged with finding another supplier or another approach to shipment, or possibly contacting another intelligent agent that might try to rearrange the production at a particular facility to accommodate the late shipment.

Using a knowledge base, event managers can be established not just for independent events, but also chains of events. For example, if a weather event occurs, interrupting a shipment, that then triggers a sequence of other events. The event manager can be built to include knowledge about these chains and sets of dependent events, not just independent events. Event managers are generally intelligent agents designed to process streams of events.

Event management allows for the development of a system that will be adaptive to events happening in the world around it. However, it can only be as adaptive as the event knowledge and contingencies that are captured and maintained within it. Organizational and supply chain knowledge is captured and used to understand what to do in the case of each of a set of contingent events. For an autonomic system creating a knowledge base of events and the contingencies associated with each of those events is a critical step that enables the system to become autonomic.

Research is beginning to be focused on event management. For example, Lui et al. (2007) propose using a Petri net approach to model a real-time event supply chain.

## 4.8 Autonomic Supply Chain Architecture: Summary

These technologies are brought together under the label of autonomic supply systems for real-time enterprises. ERP systems provide a central source of data for the system. XML and PIPs (or equivalents) are used to integrate data flows across the multiple actors. RFID is used to attach a unique identification to each object so that it can be followed throughout its life in the supply chain. RFID can be attached to virtually all objects of interest in the supply chain: trucks, pallets,

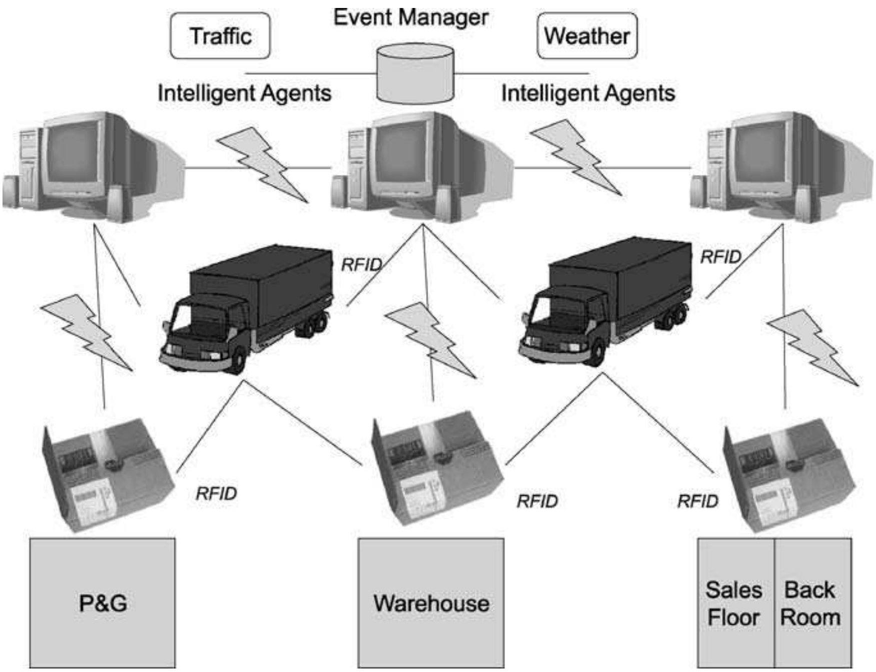


**Figure 1.** Autonomic supply system architecture

cases, and items. RFID can be used to facilitate visualization and responsiveness. Intelligent agents gather and process information about the objects so the system can be autonomous. Intelligent agents are linked to a knowledge-based event manager that helps the system respond to changes and perturbations in the environment. Event managers capture knowledge about contingent events and event sets, and use that knowledge to help manage the system in real time in response to events that occur. This architecture is summarized in Figure 1.

Although the focus of autonomic systems is on working autonomously, the systems still need to provide the basis for supporting human-based supply chain decisions. Visualization allows users to see product bottlenecks and other types of problems. Intelligent agents inform users of problems and potential solutions, and help the system respond to problems that are encountered. Event managers provide information about discrete events and potential solutions, and inform users about event disruptions that require intervention. However, the huge magnitude of millions of objects interacting, and the requirement that the system function in real time requires a certain extent of autonomy.

# 5 Supply Chain Monitoring and Management: Examples

The purpose of this section is to illustrate the use of an autonomic supply chain with some extrapolated example applications of support from such systems.

## 5.1 Example: The Case of Procter and Gamble

Procter and Gamble has generated a vision of what they think supply chain systems that are designed to support decisions will look like. This section briefly summarizes and extends that vision, as discussed in Anthes (2003).

The example starts in 2008, when Procter and Gamble has plans to shorten the replenishment cycle for a box of detergent from four months to one day. Whether or not that arget is reached is not the issue. Although such a radical change may not occur by 2008, even reducing the cycle to a week or two would be a huge change in the way they will do business, and the corresponding inventory in the supply chain.

In 2008, Procter and Gamble will have a number of highly flexible production facilities that have rapid turnaround capabilities. DSSs will support the decision of where goods will be produced. In particular, intelligent software agents will help determine what is produced in those facilities and help facilitate supply of those facilities. Intelligent agents will bid for different jobs, based on each production facility's current and future commitments. Computer-based agent bidding should speed the production allocation process.

Event managers will monitor data on a wide range of different events. For example, intelligent agents will monitor conditions so that, if supplies are delayed due to weather or traffic or major strikes or other causes, the agents will be able to create alternative delivery schedules to ensure that the production facilities get the appropriate supplies in sufficient quantities. Event managers will monitor that flow of event information and help determine what needs to be done in response to those events. Humans will facilitate solutions to anomalies.

In the long run, Procter and Gamble anticipates that RFID technology will be embedded on trucks, pallets, cases, and at the individual item level. Data will be integrated along the entire supply chain, allowing true vendor-managed inventory. Goods will become responsive and unique objects. Thus, it will be easy to determine the location of particular goods in the supply chain. As a result, the distribution chain through to stores will provide Procter and Gamble with substantial real-time information about the movement and sales of goods sent to them. For example, Procter and Gamble might track how long goods stay in the back room or on the selling floor. When goods are sold, Procter and Gamble will know about it in real time so that they will be able to track their sales over time. Shelves will become intelligent and ultimately report their needs directly back to Procter and Gamble. They will be able to monitor the goods on them and track when the shelves need to be replenished. When the number of units becomes low enough, the shelves can request replenishment to the back room, the warehouse, or even Procter and Gamble. Procter and Gamble will know which retailers have the lowest inventories and which need immediate inventory replenishment. Accordingly, as goods are produced, Procter and Gamble will dispatch the shipments to those customers where the inventories are low, and they will know how much to produce. As a result, stores will increasingly become smart stores and the supply chain will become autonomic.

Because a range of objects will be embedded with RFID technology, visualization will be able to see where those objects are, and manage accordingly. Accordingly, tagging and visualization will eliminate many information asymmetries in the supply chain.

In such a vision, objects become responsive, shelves become intelligent, stores become smart, and the entire supply chain together becomes responsive to the environmental strains put upon it, in order to create an autonomic supply chain.

## 5.2 Example: Tainted Dog Food and Spinach

In late 2006 and early 2007 there were at least two incidents of problems with products in the food supply chain. Apparently tainted ingredients in dog food poisoned and killed a number of dogs, while tainted spinach apparently made a number of people in the United States and Canada sick. How might an autonomic supply chain support mitigating those problems?

The ERP system would provide order and shipment information relating to the particular vendors that were responsible for the tainted goods. Given identification of a particular batch of tainted goods, RFID could help us to determine the specific vendor or shipments that were affected. Furthermore, with RFID information, any other shipments from identified vendors could be rapidly found and examined. Data about vendors and shipments on a map would greatly facilitate visualization of the flow of tainted goods, allowing us to trace them back to the source or sources. Accordingly, integrated data would allow us to gather data rapidly from multiple sources to facilitate the generation of data for visualization. Event managers could lay out the steps necessary to respond to receiving tainted goods. For example, they could indicate the need to contact the authorities, allow the search for alternative sources of goods, and any other activities that need to be pursued.

# 6 Summary and Extensions

This paper has summarized some of the applications that illustrate decision support for real-time enterprises. In addition, it has also laid out an architecture for an autonomic system approach to supply chains. To build a system that can act on its own requires substantial ground work. In the architecture described herein, we have discussed multiple integrated systems, with integration across organizational lines to include processes. In addition, we have discussed intelligence built into the system at a number of points. Using RFID, objects can be intelligent, and at a minimum, responsive. Furthermore, intelligent agents acting autonomously can perform specific duties assigned to them. Finally, event managers can coordinate the overall system in response to particular events. Knowledge about a wide range of events is built into the event manager, which is responsible for marshalling resources to solve particular problems to help the system adapt to the requirements placed on it. Visualization technologies that allow the location of different objects to be traced can play a key role in assisting people to see where problems are located to facilitate their resolution.

## 6.1 Extensions

How can the discussion in this paper be extended? First, the set of technologies reviewed might be extended within categories. For example, object identification could be extended from RFID to include satellite-based technologies that are more widely accessible from longer distances. Second, additional categories of technologies might be included beyond those of visualization, integration, real-time data, intelligent agents, and event data and managers. For example, organizational simulation models might be added to facilitate problem analysis and solution. Third, the architecture presented here is more aimed at generating data and running a supply chain on a day-to-day basis. In addition, there could be a focus on simulating the supply chain to understand what could and what is most likely to happen. For example, so-called mirror worlds provide the opportunity to model organizations and anticipate the future (Gelentner 1992 and O'Leary 2006). Perhaps the supply chain could be a good domain for a mirror-world application. Fourth, in order to have information all along the supply chain, there must be information sharing. Unfortunately, there are more than just technical issues associated with information sharing, such as trust, etc. (e. g., Li and Lin 2006).

## 6.2 Organizational Issues[2]

The scope of this paper has been to generate a technological architecture for an autonomous supply chain to facilitate real-time enterprises. However, making a supply chain work ultimately requires more than just a strong technological structure. Over the years many frameworks have been provided to analyze the successful use of the technologies have been generated. For example, Bradach (1996) discusses the well-known seven Ss, development by Waterman et al. (1980): strategy, structure, systems, style, skills, staff, and shared values need to be aligned with any technology implementation. Ignoring any one of these can lead to a solution that will not work. Again, systems are only one of the seven Ss. Other models also could be used to elicit other factors, including that of Pfeffer (1994).

Furthermore, as we expand this analysis to supply chain issues with multiple interacting partners, other issues such as incentives and trust become important. If supply chain partners do not trust each other then even the most basic integration and real-time data flows become problematic. If partners have no incentives to bring their technology into concert with others in the supply chain, the rest of the supply chain will suffer.

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# CHAPTER 39
# Decision Support for Emergency Situations

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Emergency situations occur unpredictably and cause individuals and organizations to shift their focus and attention immediately to deal with the situation. When disasters become large scale, all the limitations resulting from a lack of integration and collaboration among all the involved organizations begin to be exposed and further compound the negative consequences of the event. Often in large-scale disasters the people who must work together have no history of doing so; they have not developed a trust or understanding of one another's abilities, and the totality of resources they each bring to bear have never before been exercised. As a result, the challenges for individual or group decision support systems (DSS) in emergency situations are diverse and immense. In this contribution, we present recent advances in this area and highlight important challenges that remain.

**Keywords:** Emergency situations; Crisis management; Information systems; High reliability; Decision support

## 1 Introduction

Emergency situations, small or large, can enter our daily lives instantly. A morning routine at home all of a sudden turns into an emergency situation when our five-year-old on her way to the school bus trips over a discarded toy, falls and hurts herself. At work, the atmosphere in the office turns grim when the news breaks that the company is not meeting its expected earnings for the second quarter in a row and, this time, the chief executive officer (CEO) has announced that hundreds of jobs are on the line. Emergency situations can be man-made, intentional, or accidental. Especially hard to plan for is the rare and violent twist of nature, such as the Sumatra-Andaman earthquake of December 26, 2004, with an undersea epicenter off the west coast of Sumatra, Indonesia, triggering a series of devastating tsunamis that spread throughout the Indian Ocean, killing approximately 230,000 people.

By definition, emergency situations are situations we are not familiar with – nor likely to be familiar with – and by their mere happening create acute feelings of stress, anxiety, and uncertainty. When confronted with emergency situations, one must not only cope with these feelings, but also make sense of the situation amidst conflicting or missing information during very intense time periods with very short-term deadlines. The threat-rigidity hypothesis, first developed by Staw, Sandelands, and Dutton (1981) and further discussed by Rice (1990), states that individuals undergoing stress, anxiety, and psychological arousal tend to increase their reliance on internal hypotheses and focus on dominant cues to emit well-learnt responses. In other words, the potential decision response to a crisis situation is to go by the book, based on learned responses. However, if the response situation does not fit the original training, the resulting decision may be ineffective, and may even make the crisis situation worse (e. g., the 9/11 emergency operators telling World Trade Center occupants to stay where they were, unless ordered to evacuate). In order to counter this bias, crisis response teams must be encouraged and trained to make flexible and creative decisions. The attitude of those responding to the crisis and the cohesive nature of the teams involved is critical to the success of the effort (King 2002). In an emergency the individuals responding must feel they have all the relevant observations and information that is available in order to make a decision that reflects the reality of the given situation. Once they know they have whatever information they are going to get before the decision has to be made, they can move to sense-making to extrapolate or infer what they need as a guide to the strategic/planning decision, which allows them to create a response scenario, which is a series of integrated actions to be taken. It has also been well-documented in the literature that the chance of defective group decision making, such as groupthink (Janis 1982), is higher when the situation is very stressful and the group is very cohesive and socially isolated. Those involved in the decision are cognitively overloaded and the group fails to adequately determine its objectives and alternatives, fails to explore all the options, and also fails to assess the risks associated with the group's decision itself. Janis also introduced the concept of hypervigilance, an excessive alertness to signs of threats. Hypervigilance causes people to make "ill-considered decisions that are frequently followed by post-decisional conflict and frustration" (Janis 1982). As a result, the challenges for individual or group decision support systems (DSS) in emergency situations are diverse and immense. In contrast, individuals performing in emergency command and control roles who may have expertise in the roles they have undertaken, and who have feelings of trust for others performing related and supporting roles (such as delivering up-to-date information), are likely to be able to go into a state of cognitive absorption or ***flow*** that captures an individual's subjective enjoyment of the interaction with the technology (Agarwal and Karahanna 2000), where they cope well with states of information overload over long periods of time and make good decisions, even with incomplete information. The knowledge that one is making decisions that involve the saving of lives appears to be a powerful motivator.

## 2 A Model for Emergency Management Processes

Many events in organizations are emergencies but are sometimes not recognized as such because they are considered normal problems: developing a new product, loss of a key employee, loss of a key customer, a possible recall on a product, the disruption of an outsourced supply chain, etc. Developing a new product is probably influenced by a belief that, if it is not done now, some competitor will do it and that will result in the obsolescence of the company's current product. Because the time delay in the effort for developing a new product is often much longer than what we think of as an emergency, we tend not to view many of these occurrences as emergency processes. This is unfortunate because it means that organizations, private or public, have many opportunities to exercise emergency processes and tools as part of their normal processes. One of the reoccurring problems in emergency preparedness is that tools not used on a regular basis during normal operations will probably not be used or not be used properly in a real emergency. The emergency telephone system established for all the power utility command centers to coordinate actions on preventing a wide-scale power failure was developed after the first Northeast blackout in the U.S. It was not used until after the power grid completely failed and resulted in the second failure almost a decade later, and then not until 11 hours after the start of the failure process. Employees had forgotten it existed.

Sometimes our view of the emergency management effort is too simplified and farmed out in separate pieces to too many separate organizations or groups. In emergency management, the major processes and sub-processes are:

- Preparedness (analysis, planning, and evaluation)
  - Analysis of the threats
  - Analysis and evaluation of performance (and errors)
  - Planning for mitigation
  - Planning for detection and intelligence
  - Planning for response
  - Planning for recovery and/or normalization
- Training
- Mitigation
- Detection
- Response
- Recovery/normalization

These segments of the process are cyclic, overlap, require integration, collaborative participation, involvement of diverse expertise and organizational units, as well as constant updating. These processes give us a structure for identifying and categorizing the various information and decision needs DSS must provide for in emergency situations.

Emergency situations typically evolve during an incubation period in which the emergency (often unnoticed) builds up to ultimately lead to an acute crisis when the last defenses fall or when the circumstances are just right. For organizations, it is therefore crucial to focus on this phase and try to reduce the consequences or prevent the emergency from developing at all. During the *preparedness*, *mitigation*, and *detection* phases, it is important to prepare for the eventuality of an emergency by understanding the vulnerabilities of an organization, analyzing early warning signals which may point at threats to which the organization may already be or become exposed, and by taking precautionary measures to mitigate the possible effects of the threats. Developing emergency plans is one of the key activities in the *preparedness* phase. It should be clear that planning is critical and it is something that must go on all the time, especially since the analysis and evaluation processes must be a continuous processes in any organization that wants to be able to manage the unexpected in a reliable and responsive manner. *Mitigation* goes hand in hand in with *detection*, and what we do in mitigation is often influenced by the ability to detect the event with some window of opportunity prior to the event. The *response* phase is a very different phase during which the initial reaction to the emergency is carried out and the necessary resources are mobilized, requiring an intense effort from a small or large number of people dealing with numerous simultaneous emergencies of different scope and urgency. During the *recovery* phase, the pace of the action has slowed down from the hectic response phase, and there may be a need for complex planning support to relocate thousands of homeless families, to decide on loans for businesses to be rebuilt, or to start with the most urgent repairs of damaged public infrastructure. However, given a pandemic like the avian flu, the distinction between response and recovery becomes somewhat meaningless. Clearly the scale of the disaster can produce considerably complex and difficult situations for the recovery phases as evidenced by both 9/11 and Katrina.

The remainder of this chapter is structured according to the DSS needs for the various emergency management processes. In the following section, we introduce high-reliability organizations, a remarkable type of organization that seems to be well prepared and thrives well even though it deals with high-hazard or high-risk situations routinely. Concluding from this strand of research that mindfulness *and* resilience are key aspects of emergency preparedness, we discuss information security threats and indicate how DSS may help organizations to become more mindful and prepared. In section 4, we focus on DSS for emergency response, and present a set of generic design premises for these DSS. As a case in point, we discuss a DSS for nuclear emergency response implemented in a large number of European countries. In section 5, we focus on the recovery phase, and we highlight the role and importance of humanitarian information and decision support systems. We describe the example of Sahana, an open-source DSS developed since the 2004 tsunami disaster in Sri Lanka. We conclude in section 6 by summarizing our main findings.

# 3 DSS for Emergency Preparedness and Mitigation

## 3.1 Mitigation in High-Reliability Organizations

Some organizations seem to cope very well with errors. Moreover, they do so over a very long time period. Researchers from the University of California in Berkeley called this type of organization high-reliability organizations (HROs): "*How often could this organization have failed with dramatic consequences? If the answer to the question is many thousands of times the organization is highly reliable*" (Roberts 1990). Examples of HROs are nuclear power plants, aircraft carriers, and air-traffic control, all of which are organizations that continuously face risk because the context in which they operate is high hazard. This is so because of the nature of their undertaking, the characteristics of their technology, or the fear of the consequences of an accident for their socio-economic environment. The signature characteristic of an HRO, however, is not that it is error-free, but that errors do not disable it (Bigley and Roberts 2001). For this reason, HROs are forced to examine and learn from even the smallest errors they make.

Processes in HROs are distinctive because they focus on failure rather than success: inertia as well as change, tactics rather than strategy, the present moment rather than the future, and resilience as well as anticipation (Roberts 1990, Roberts and Bea 2001). Effective HROs are known by their capability to contain and recover from the errors they make and by their capability to have foresight into errors they might make. HROs avoid accidents because they have a certain state of mindfulness. Mindfulness is described as the capability for rich awareness of discriminatory detail that facilitates the discovery and correction of potential accidents (Weick 1987). Mindfulness is less about decision making and more about inquiry and interpretation grounded in capabilities for action. Weick et al. (1999) mention five qualities that HROs possess to reach their state of mindfulness, also referred to as high-reliability theory (HRT) principles (Van Den Eede and Van de Walle 2005), and shown in Figure 1. It is sometimes stated in a joking manner that long term survival of firms is more a function of those firms that make the smallest number of serious errors and not those that are good at optimization. Some of the recent disasters for companies in the outsourcing of supply chains may be

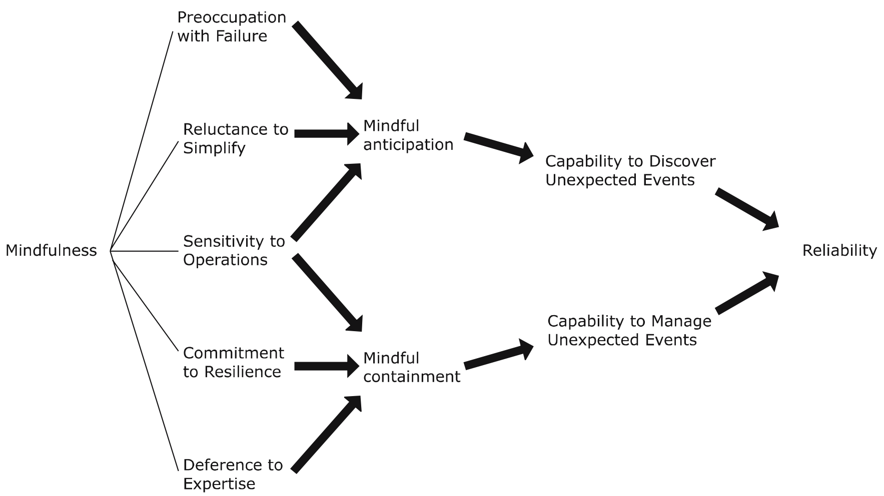


**Figure 1.** A mindful infrastructure for high reliability (adapted from Weick et al. 1999)

a new example of this folklore being more wisdom than it is currently believed. The more efficient the supply chain (thereby providing no slack resources), the more disaster prone it is (Markillie 2006).

As Figure 1 indicates, reliability derives from the organization's capabilities to discover as well as manage unexpected events. The discovery of unexpected events requires a mindful anticipation, which is based in part on the organization's preoccupation with failure. As an illustrative case of a discipline that is very concerned with the discovery of unexpected events and the risk of failure, we will next discuss how information security focuses on mindfulness in the organization.

## 3.2 Mindfulness and Reliability in Information Security

Information security is a discipline that seeks to promote the proper and robust use of information in all forms and in all media. The objective of information security is to ensure an organization's continuity and minimize damage by preventing and minimizing the impact of security incidents (von Solms 1998, Ma and Pearson 2005). According to Parker, information security is the preservation of confidentiality and possession, integrity and validity, and the availability and utility of information (Parker 1998). While no standard definition of information security exists, one definition used is as follows: *Information security is a set of controls to minimize business damage by preventing and minimizing the impact of security incidents.* This definition is derived from the definition in the ISO 17799 standard (ISO 17799 2005) and accepted by many information security experts. The ISO 17799 is defined as a comprehensive set of controls comprising best practices in information security and its scope is to give recommendations for information security management for use by those who are responsible for initiating, implementing, or maintaining security in their organization. The ISO 17799 standard has been adopted for use in many countries around the world including the U.K., Ireland, Germany, The Netherlands, Canada, Australia, New Zealand, India, Japan, Korea, Malaysia, Singapore, Taiwan, South Africa, and others.

Security baselines have many advantages in the implementation of information security management in an organization, such as being simple to deploy and using baseline controls, easy to establish policies, maintain security consistency, etc. However, such a set of baseline controls addresses the full information systems environment, from physical security to personnel and network security. As a set of universal security baselines, one of the limitations is that it cannot take into account the local technological constraints or be present in a form that suits every potential user in the organization. There is no guidance on how to choose the applicable controls from the listed ones that will provide an acceptable level of security for a specific organization, which can create insecurity when an organization decides to ignore some controls that would actually have been crucial. Therefore, it is necessary to develop a comprehensive framework to ensure that the message of commitment to information security is pervasive and implemented in policies, procedures and everyday behavior (Janczewski and Shi 2002) or, in other words, create organizational mindfulness. This framework should include an effective set of security controls that should be identified, introduced, and maintained (Barnard and von Solms 2000). Elements of those security controls are, respectively, a baselines assessment, risk analysis, policy development, measuring implementation, and monitoring and reporting action.

One very good reason why emergency management has progressed very rapidly in the information field is that there is a continuous evolution of the threats and the technologies of both defense and offense in this area, coupled with the destruction of national boundaries for the applications that are the subject of the threats. Today we have auditors who specialize in determining just how well prepared a company is to protect its information systems against all manner of risks. Even individuals face the problem that their identities can be stolen by experts from another country, who then sell them to a marketer in yet another country, who then offers them to individuals at a price in almost any country in the world. In the general area of emergency management, maybe we need to all learn that it is time to evolve recognized measures of the degree of emergency preparedness for a total organization rather than just its information systems (Turoff et al. 2004).

## 3.3 Decision Support Systems for Information Security Mindfulness

Group decision support systems (GDSS) have proven to efficiently facilitate preference and intellective tasks via anonymous exchange of information supported by electronic brainstorming and to reduce process losses in face-to-face meetings (Nunamaker et al. 1991), as well as distributed meetings (Turoff and Hiltz 1984, Hiltz et al. 2005). In a recent field study, a synchronous GDSS was used to support the exchange of information among senior managers of a large financial organization during a risk management workshop (Rutkowski et al. 2006). This workshop was held to generate and identify an exhaustive set of risks related to information security. From the large number of risks generated in this first phase, a smaller number of risks was selected and assessed in terms of their expected utility (amount of damage), calculated from their expected impact and probability of occurrence. The most relevant risks were then discussed in the last phase of the workshop in order to build business preparedness scenarios to be activated should one of the identified risks actually materialize. The findings of this study indicated that the use of the GDSS increased the overall level of mindfulness among the participants on the importance of addressing risks in the organization. The anonymous input and exchange of information while using the GDSS encouraged participants to freely express their private opinion about very sensitive information in the organization. Overall, it was found that the managers involved in this study obtained a higher feeling of control and appropriation of the decision taken toward the business continuity scenarios to be built. Similarly, the fuzzy decision support system FURIA (fuzzy relational incident analysis) allows individual group members to compare their individual assessment of a decision alternative or option (such as an information security risk) to the assessments of the other group members so that diverging risk assessments or threat remedies can be identified and discussed (Van de Walle and Rutkowski 2006). At the core of FURIA is an interactive graphical display visualizing group members' relative preference positions, based on mathematical preference and multi-criteria decision support models (Fodor and Roubens 1994).

# 4 DSS for Emergency Response

## 4.1 Design Principles for Dynamic Emergency Response Systems

Implicit in crises of varying scopes and proportions are communication and information needs that can be addressed by today's information and communication technologies. What is required is organizing the premises and concepts that can be mapped into a set of generic design principles, in turn providing a framework for the sensible development of flexible and dynamic emergency response information systems. Turoff and coworkers (Turoff et al. 2004) systematically develop a set of general and supporting design principles and specifications for a dynamic emergency response management information system (DERMIS) by identifying design premises resulting from the use of the emergency management information system and reference index (EMISARI), a highly structured group communication process that followed basic concepts from the Delphi method (Linstone and Turoff 1973), and design concepts resulting from a comprehensive literature review. In their paper, Turoff et al. (2004) present a framework for the system design and development that addresses the communication and information needs of first responders as well as the decision-making needs of command and control personnel. The framework also incorporates thinking about the value of insights and information from communities of geographically dispersed experts and suggests how that expertise can be brought to bear on crisis decision making. Historic experience is used to suggest nine design premises, listed in Table 1. These premises are complemented by a series of five design concepts based upon the review of pertinent and applicable research. The result is a set of general design principles and supporting design considerations that are recommended to be woven into the detailed specifications of a DERMIS. The resulting DERMIS design model graphically indicates the heuristic taken by this paper and suggests that the result will be an emergency response system flexible, robust, and dynamic enough to support the communication and information needs of emergency and crisis personnel on all levels. In addition it permits the development of dynamic emergency response information systems with tailored flexibility to support and be integrated across different sizes and types of organizations.

**Table 1.** DERMIS design premises (Turoff *et al.* 2004)

| |
|---|
| **P1 System training and simulation**. Turoff et al. argue that finding functions in the emergency response system that can be used on a daily basis is actually much more effective than isolated training sessions. Indeed, if the system is used on a day-to-day basis, this will partly eliminate the need for training and simulation, as those who must operate the system gain extensive experience with the system just by using it. |
| **P2 Information focus.** During a crisis, those who are dealing with the emergency risk are flooded with information. Therefore, the support system should carefully filter information that is directed towards actors. However, they must still be able to access all (contextual) information related to the crisis as information elements that are filtered out by the system may still be of vital importance under certain unpredictable circumstances. |
| **P3 Crisis memory**. The system must be able to log the chain of events during a crisis, without imposing an extra workload on those involved in the crisis response. This information can be used to improve the system for use in future crises, but it can also be used to analyze the crisis itself. |
| **P4 Exceptions as norms**. Due to the uniqueness of most crises, usually a planned response to the crisis cannot be followed in detail. Most actions are exceptions to the earlier defined norms. This implies that the support system must be flexible enough to allow reconfiguring and reallocation of resources during a crisis response. |
| **P5 Scope and nature of crisis**. Depending on the scope and nature of the crisis, several response teams may have to be assembled with members providing the necessary knowledge and experience for the teams' tasks. Special care should also be given to the fact that teams may only operate for a limited amount of time and then transfer their tasks to other teams or actors. The same goes for individual team members who may, for example, become exhausted after many hours of effort, necessitating passing on the role to trusted replacements. |
| **P6 Role transferability.** Individuals should be able to transfer their role to others when they cannot continue to deal with the emergency. For the support system, this means that clear descriptions of roles must be present and explicit in the software, as well as a description of the tasks, responsibilities, and information needs of each role. |
| **P7 Information validity and timeliness**. As actions undertaken during crises are always based on incomplete information, it is of paramount importance that the emergency response system makes an effort to store all the available information in a centralized database which is open equally to all who are involved in reacting to the situation. Thus, those involved in the crisis response can rely on a broad base of information, helping them making decisions that are more effective and efficient in handling the crisis. When they suddenly need unexpected information (something that neither the system nor others predicted they would need) they need to be able to go after it and determine if it exists or not, and who can or should be supplying it. |
| **P8 Free exchange of information**. During crisis response, it is important that a great amount of information can be exchanged between stakeholders, so that they can delegate authority and conduct oversight. This, however, induces a risk of information overload, which in turn can be detrimental to the crisis response effort. The response system should protect participants from information overload by assuming all the bookkeeping of communications and all the organization that has occurred. |

**Table 1.** Continued

| |
|---|
| **P9 Coordination**. Due to the unpredictable nature of a crisis, the exact actions and responsibilities of individuals and teams cannot be pre-determined. Therefore, the system should be able to support the flow of authority directed towards where the action takes place (usually on a low hierarchical level), but also the reverse flow of accountability and status information upward and sideways through the organization. |

## 4.2 Emergency Response for Industrial Disasters: The Chernobyl Nuclear Disaster

Several large-scale industrial disasters causing considerable loss of human life and damage to the environment have occurred in the recent past. On December 3, 1984, in Bhopal a Union Carbide chemical plant leaked 40 tons of toxic methyl isocyanate gas, killing at least 15,000 people and injuring about 150,000 more. A lesser known example but with an even larger impact occurred in Henan Province in China, where the failing of the Banqiao and Shimantan reservoir dams during typhoon Nina in 1975 killed 26,000 people while another 145,000 died during subsequent epidemics and famine. In that disaster, about six million buildings collapsed and in total more than 10 million residents were affected. However, of all industrial disasters in recent times, the 1986 Chernobyl nuclear disaster probably brings to mind the most apocalyptic visions of worldwide devastation.

The world's largest nuclear disaster occurred on April 26, 1986, at the Chernobyl nuclear power plant in Pripryat, Ukraine in the former Soviet Union. The cause of the disaster is believed to be a reactor experiment that went wrong, leading to an explosion of the reactor. As there was no reactor containment building, a radioactive plume was released into the atmosphere, contaminating large areas in the former Soviet Union (especially Ukraine, Belarus and Russia), Eastern and Western Europe, Scandinavia, and as far away as eastern North America, in the days and weeks following the accident. In the days following the accident, the evidence grew that a major release of nuclear material had occurred in the Soviet Union, and measures were taken by governments in the various affected countries to protect people and food stocks. In the Soviet Union, a huge operation was set up to bring the accident under control and extinguish the burning reactor, and about 135,000 people were evacuated from their homes. The number of confirmed deaths as a direct consequence of the Chernobyl disaster is only 56, most of these being fire and rescue workers who had worked at the burning power plant site, yet thousands of premature deaths are predicted in the coming years.

Nuclear power plants have been put forth as examples of what an HRO should be and yet we still see events like Chernobyl and Three-Mile Island. Some believe the root cause of Chernobyl was the lack of local authority of the professional operators of the plant to veto decisions by the higher ups that decided to take the plant operation outside the limits of the original performance specifications for the technology. Consider the comparison where a commercial airplane pilot in most countries has the right to veto the flight of the plane if he or she feels something is not right with respect to the readiness state of the aircraft. This was the case on August 14, 2006, shortly after the foiled airline terrorism plot in the U.K., when British Airways flight BA179 from Heathrow Airport to New York turned back after an unattended and ringing cell phone was discovered on board. The pilot went against the advice of British Airways' own security team and decided "to err on the side of caution" (U.K. Airport News 2006). This example contrasts the lack in the Chernobyl power plant procedures of any clear process plan for the human roles in the plant when there is any uncertainty about decisions to be made, the accountability for those decisions, and the need for oversight. In emergencies with well laid out preparedness plans there is always the need for a command and control structure where those role functions have to be very clear to all who are involved.

## 4.3 RODOS, the Real-Time Online Decision Support System for Nuclear Emergencies

The different and often conflicting responses by the different European countries following the Chernobyl disaster made it clear that a comprehensive response to nuclear emergencies was needed in the European Union. Funded by the European Commission through a number of three-year research programs (so-called framework programs), a consortium of European and formerly Soviet Union based universities and research institutions worked together to develop a real-time online decision support system (from which one can form with some creativity the acronym RODOS) that "could provide consistent and comprehensive support for off-site emergency management at local, regional and national levels at all times following a (nuclear) accident and that would be capable of finding broad application across Europe unperturbed by national boundaries" (Raskob et al. 2005, French et al. 2000, French and Niculae 2005, Ehrhardt and Weiss 2000). The objective was that RODOS would (Niculae 2005):

- provide a common platform or framework for incorporating the best features of existing DSS and future developments;
- provide greater transparency in the decision process as one input to improving public understanding and acceptance of off-site emergency measures;
- facilitate improved communication between countries of monitoring data, predictions of consequences, etc., in the event of any future accident;
- promote, through the development and use of the system, a more coherent, consistent and harmonized response to any future accident that may affect Europe.

The overall RODOS DSS consists of three distinct subsystems, each containing a variety of modules:

- **Analyzing** subsystem (ASY) modules that process incoming data and forecast the location and quantity of contamination including temporal variation. These modules contain meteorological, atmospheric dispersion, hydrological dispersion, deposition and absorption, health effects, and other models. The ASY modules predict the evolution of the situation according to the best scientific understanding of the processes involved.
- **Countermeasure** subsystem (CSY) modules that suggest possible countermeasures, check them for feasibility, and calculate the expected benefit in terms of a number of criteria.
- **Evaluation** subsystem (ESY) modules that rank countermeasure strategies according to their potential benefit and preference judgments provided by the decision makers.

The interconnection of all program modules, the input, transfer and exchange of data, the display of the results and its modes of operation (interactive and automatic) are controlled by the RODOS **operating system** (OSY), a layer built upon the UNIX operating system of the host computer. Interaction with users and display of data takes place via a **graphical subsystem** (GSY), which includes a purpose-built geographical information system (RoGIS). This would display demographic, topographic, economic and agricultural data along with contours of measured or predicted radiological data. These displays seek to ensure that the output can be used and understood by a variety of users who may possess qualitatively different skills and perspectives (Marsden and Hollnagel 1996). In the early phases of an accident, local decisions are likely to be the responsibility of local plant management. However, regional emergency planning officers and senior officers in the emergency services need to be immediately concerned with oversight, analyzing if there are sufficient resources to meet the demand, seeking out re-supply when necessary, and stepping into arrange maintenance and logistic support. In later phases, regional and national politicians would be involved depending on how serious the accident is.

RODOS is a real-time, online system connected to meteorological and radiological data networks; thus including several communication modules. Its database formats are defining the basis for data exchange on a European scale. All data required by the modules to process information are stored in databases, of which there are three main categories in RODOS:

- a database storing program data that include input and output data required by or produced by different modules, intermediate and final results, temporary data, etc.;
- a real-time database containing information coming from regional or national radiological and meteorological networks and
- a geographical database containing geographical and statistical information for the whole of Europe.

The system is designed to be flexible in order to work equally well under various circumstances. Therefore, the content of the subsystems and the databases vary depending on the specific application of the system, i. e., the nature and characteristics of any potential nuclear accident, different monitoring data, national regulations, etc. The RODOS models and databases can be customized to different site and plant characteristics as well as to the geographical, climatic, and environmental variations across Europe. The current version of the RODOS system is installed in national emergency centers for use in Germany, Finland, Spain, Portugal, Austria, the Netherlands, Poland, Hungary, Slovakia, Ukraine, Slovenia, and the Czech Republic. Installation is under consideration in several other countries such as Romania, Bulgaria, Russia, Greece, and Switzerland. As a consequence, RODOS today is the virtually centralized resource for all relevant information that may be needed in any potential nuclear plant crisis in the European Union. Clearly, RODOS would be very useful in the event of a terrorist action to release a radioactive substance through a dirty bomb. However, there is no publicly stated mission of RODOS to provide this aid to those that would be most concerned with that type of event. We hope this is not an example of the lack of integration across governmental organizations responsible for this other problem.

# 5 DSS for Emergency Recovery

## 5.1 Emergency Recovery

On August 28 2005, hurricane Katrina hit the Gulf Coast, wreaking havoc in the states of Louisiana, Mississippi, and Alabama. Many areas of New Orleans were flooded and winds of more than 100 mph (160 km/h) tore off parts of the roof of the Superdome stadium where some 9,000 people who were unable or unwilling to leave the city were taking refuge. Power lines were cut, trees felled, shops wrecked, and cars hurled across streets strewn with shattered glass. In the following days, the scale of the devastation caused by Hurricane Katrina and the subsequent flooding became clearer. About 80% of the low-lying city was under water. Helicopters and boats were picking up survivors stranded on rooftops across the area – many were to spend several more days there. On September 1, with the lack of any local command and control facility, New Orleans appeared to descend into anarchy, with reports of looting, shootings, carjacking, and rapes. The local police force, reduced in number by 30%, was ordered to focus its efforts on tackling lawlessness. Anger mounted over the delay in getting aid to people in New Orleans and what was seen as an inadequate response from the federal government. In the following days, the relief effort was stepped up. Evacuations continued as military convoys arrived with supplies of food, medicine and water. Finally, on September 3, more than 10,000 people were removed from New Orleans – the Superdome stadium and the city's convention center were cleared. The U.S. appealed for international aid, requesting blankets, first aid kits, water trucks, and food. One year later, the scale and costs of the recovery efforts were impressive. FEMA (the Federal Emergency Management Agency) has paid out more than $13.2 billion under the National Flood

Insurance Policy to policyholders in Louisiana. The U.S. Small Business Administration (SBA) approved more than 13,000 disaster assistance loans to business owners totaling $1.3 billion and 78,237 loans to renters and homeowners totaling more than $5 billion. FEMA issued 1.6 million housing assistance checks totaling more than $3.6 billion to Louisiana victims, in the form of rental assistance and home repair or replacement grants (FEMA News Release, 2006).

On the other side of the planet, aid was badly needed for those countries affected by the 2004 tsunami (mostly Indonesia, Sri Lanka, Thailand, and India) which had inflicted widespread damage to the infrastructure, leading to a shortage of water and food. Due to the high population density and the tropical climate of the region, epidemics were a special concern and bringing in sanitation facilities and fresh drinking water as soon as possible was an absolute priority. In the days and weeks following the tsunami, governments all over the world committed to more than $7 billion in aid for the affected countries, followed by donations from large companies and many smaller local private initiatives.

No matter how impressive the scope of the final efforts, Katrina demonstrated what happens when local command and control systems are lost and no realistic and workable plans exist for integration between the city, state, federal, and private sector response capabilities. The international response to the 2004 Indian Ocean tsunami was nothing less than chaotic in the most crucial first days following the disaster. When disasters become large in scale all the limitations resulting from a lack of integration and collaboration among all the involved organizations begin to expose themselves and further compound the negative consequences of the event. Often in large-scale disasters the people who must work together have no history of doing so, they have not developed a trust or understanding of one another's abilities, and the totality of resources they each bring to bear were never before exercised. While a new organization is stumbling around trying to form itself into something that will work, the disaster does not wait for them.

## 5.2 Emergency Recovery Following Major Disasters: Humanitarian Information Systems

In times of major disasters such as hurricane Katrina or the 2004 tsunami, the need for accurate and timely information is as crucial as is rapid and coherent coordination among the international humanitarian community (Bui and Sankaran 2001, Currion 2006). Effective humanitarian information systems that provide timely access to comprehensive, relevant, and reliable information are critical to humanitarian operations. The faster the humanitarian community is able to collect, analyze, disseminate and act on key information, the more effective the response will, the better needs will be met, and the greater the benefit to affected populations. In 2005 ECHO, the European Commission Directorate-General for Humanitarian Aid, announced its decision to approve a total amount of 4 million Euros to support and enhance humanitarian information systems essential to the coordination of humanitarian assistance (ECHO 2005). Specifically, it was decided to improve information management systems and services of the United Nations Office for the Coordination of Humanitarian Affairs (OCHA). OCHA was established in 1991 with a specific mandate to work with operational relief agencies to ensure that there are no gaps in the response and that duplication of effort is avoided. OCHA's information management extends from the gathering and collection of information and data, to its integration, analysis, synthesis, and dissemination via the Internet and other means.

To respond to information needs, OCHA has developed humanitarian information systems which include ReliefWeb, the regional information networks (IRIN), information management units (IMUs) and humanitarian information centers (HICs). These services have established solid reputations in the provision of quality information and are recognized as essential in the coordination of emergency response among partners in the humanitarian community. Common in the success of these systems, or information services, is that the information provided is based upon a solid information exchange network among all partners in the humanitarian community. ReliefWeb (http://www.reliefweb.int) is the world's leading online gateway to information on humanitarian emergencies and disasters. Through ReliefWeb, OCHA provides practitioners with information on both complex emergencies and natural disasters worldwide from over 1,000 sources, including UN, governments, nongovernmental organizations (NGOs), the academic community, and the media. ReliefWeb consolidates final reports, documents, and reports from humanitarian partners, providing a global repository one-stop shop for emergency response information. IRINs gather information from a range of humanitarian and other sources, providing context and reporting on emergencies and at-risk countries. IMUs and HICs collect, manage, and disseminate operational data and information at the field level, providing geographic information products and a range of operations databases and related content to decision makers in the field as well as headquarters. Other OCHA humanitarian information systems that provide complementary information services to meet the full range of information needs as described above include OCHA Online, the Financial Tracking System (FTS), and the Global Disaster Alert System (GDAS).

In the U.S., the Humanitarian Information Unit (HIU) was created in 2002 by Secretary of State Powell as "a U.S. Government interagency nucleus to identify, collect, analyze and disseminate unclassified information critical to USG preparations for and responses to humanitarian emergencies worldwide." In 2004, the task "to promote best practices for humanitarian information management" was added to the HIU's mission statement. The role of the HIU is to provide critical and reliable information quickly and efficiently to U.S. government organizations involved in providing humanitarian assistance in response to disasters and emergencies overseas. The HIU has developed products for the Secretary of State, the administrator of the U.S. Agency for International Development (USAID) and the National Security Council. These products are almost always created to be unclassified, so that they can be shared easily with other audiences within the international humanitarian community: the UN, NGOs, the media, the public, etc. Another role of the HIU is to develop, test, and promote new technologies for better humanitarian information management. The HIU has been in the forefront of using and promoting geographic information systems (GISw) and satellite imagery, both for strategic and operational uses and applications. In addition, the HIU has tested and promoted the use of personal digital assistants (PDAs), global positioning systems (GPSs), and digital cameras on humanitarian field assessments. The HIU has also used collaboration tools and content management software to improve interagency collaboration and information sharing. VISTA is an example of a new web-based visualization tool that not only provides situational awareness, but facilitates humanitarian situational analysis as well (King 2006).

## 5.3 The Sahana Open-Source Humanitarian Information and Decision Support System

Sahana is a web-based collaboration tool that addresses the common coordination problems during a disaster from finding missing people, managing aid, managing volunteers, tracking relocation sites, etc., between government groups, the civil society (NGOs), and the victims themselves. Sahana is an integrated set of pluggable, web-based disaster management applications that provide solutions to large-scale humanitarian problems in the aftermath of a disaster. The main applications and problems they address are as follows:

- *Missing person registry*: helping to reduce trauma by effectively finding missing persons;
- *Organization registry*: coordinating and balancing the distribution of relief organizations in the affected areas and connecting relief groups, allowing them to operate as one;
- *Request management system*: registering and tracking all incoming requests for support and relief up to fulfillment and helping donors connect to relief requirements;
- *Camp registry*: tracking the location and numbers of victims in the various camps and temporary shelters set up all around the affected area.

The development of Sahana, a free and open-source disaster management system distributed under terms of the GNU lesser general public license, was triggered by the tsunami disaster in 2004 to help coordinate the relief effort in Sri Lanka (Sahana 2006). It was initially built by a group of volunteers from the Sri Lankan information technology (IT) industry and spearheaded by the Lanka Software Foundation. An implementation of Sahana was authorized and deployed by CNO (the main government body in Sri Lanka coordinating the relief effort) to help coordinate all the data being captured. Development of Sahana continues today to make the system applicable for global use and to be able to handle any large-scale disaster. Sahana has been deployed successfully in the aftermath of several large natural disasters, for instance following the large earthquake in Pakistan in 2005, and the mudslide disaster in the Philippines and the Yogjakarta earthquake, both in 2006. The long term objectives of Sahana are to grow into a complete disaster management system, including functionality for mitigation, preparation, relief, and recovery. The current status, ongoing development, and future goals are intensively discussed in two web-based communities, the Sahana wiki pages (Sahana 2006) and the Humanitarian-ICT Yahoo! group (Humanitarian-ICT 2006).

# 6 Conclusion

Using standard emergency management terminology, we have in this chapter categorized DSS for emergency situations according to the different phases of crisis preparedness, response and recovery. We have presented DSS that have been developed or implemented in response to some of the worst emergency situations our society has been confronted with in recent times, such as the Chernobyl, Indian Ocean tsunami, and hurricane Katrina disasters. Serving as a foundation for this overview, we started by introducing high-reliability organizations, as these seem to be dealing remarkably well with emergency situations on a daily basis. In this conclusion, we stress once again the need for such organizations to support and sustain efficient emergency response and recovery efforts, and summarize some of the key aspects of DSS we believe are crucial for high-reliability emergency management.

## 6.1 Role Multiplicity

In any emergency effort to allocate a particular resource, there are many specific roles involved and it must be clear to everyone involved who is the person that is performing a specific role at a specific time. These fundamental role functions are:

- *Requesting*: individuals who are requesting the resource and are trusted by the others to know that this request is a valid one.
- *Observing or reporting*: those trained to be able to make observations about the situation and report information that will be useful to others in carrying out their tasks.
- *Allocating*: The persons allocating the resource to meet the requests being made must make judgmental decisions on the priority of each request.
- *Local oversight*: persons in other areas who know something would interfere with an allocation must make the others aware of the occurrence of such interference (mudslides, traffic jams, flooded roads, etc.).
- *Maintaining and servicing*: making sure that a resource is adequately maintained and re-supplied with associated items or people.

- *Situation analysis and awareness*: what is the overall consumption rate of this resource and what more is occurring in the way of threats that might increase demand?
- *Global resupply*: someone must be seeking other sources for increasing the availability of the resources.

For any large-scale disaster, at least these seven roles need to be explicitly known to everyone involved as the response takes place. In cases of explicit toxic and biological substances an added role function of the expert in the hazard type needs to be added. Since no one should work 24 hours a day, roles have to be backed up but at any moment there must be a person performing in each of these roles or we can easily go into situations of overload. The people involved have to be trained in multiple roles and have to trust one another enough to be willing to hand over their role to someone else when they are too exhausted to continue. They also need to know that when they come back to reassume their role that what has occurred and what they need to know at that moment will be waiting for them as a part of the system tracking the events associated with each role. Automated systems cannot work even for local oversight without very extensive sensor networks to input all possible local conditions while the disaster is in progress.

## 6.2 Planning and Analysis

The planning and analysis functions of emergency preparedness are core to any overall emergency management operation. They need to directly involve those who will actually execute the command and control functions as well as some of the on-site operations. They must focus on the processes and roles involved and should be tailorable with respect to the definitions of roles and events that are triggered by or reacted to the various roles. This means any local group should be able to tailor the content of the operational system they will be using. By assessing the risks and designing roles and event structures necessary to counter those risks, those who will use the system should be able to build templates that can be inserted into the command and control system to guide the actual response process. Since we cannot take all those who should be involved and afford to make them part of a single organization dedicated to this purpose of planning and analysis, the challenge is to turn this function into an HRO-style operation. It must be one we can have confidence in for large-scale disasters of any type, including those in corporations as well as those faced by government at all levels. A basic flaw of current emergence planning and response is the lack of a permanence in a core disaster response organization that can engage continuously in being an HRO organization, develop the plans, recommend the mitigation policies and actions, oversee the training, be the coordination, command, and control core, and integrate functions over all the organizations engaged in any large-scale response no matter what the societal relationships are among the responding parties. Any large-scale emergency is in effect a situation that demands complete control of the situation by one unified team for the duration of the situation. That core does not have to be large given today's technology and even in 1960s it never exceeded 400 for the federal government.

Instead of forming committees that meet only once in a while and hand down finished plans to others who must somehow execute them, we need in the future to set up virtual organizations (Mowshowich 1997, 2002) of those that would be involved in the command and control functions as well as the response functions. They should operate as virtual teams no matter where they are, using the same command and control system to create templates for roles and events based upon scenarios of offense threats and defense plans. This system would allow them to act out roles using the real system and in essence engage in training games that they and others have designed (Turoff et al. 2006). Over a week one would expect that they would spend four to eight hours individually, at a time of their choosing, doing this, much as one might play a multi-player recreational game.

In order to be an HRO, an organization has to exist and operate on a continuous basis. We cannot have emergency management teams for wide scale disasters that only exist when the disaster occurs or they will never be able to work as effectively as an HRO. Since we will always be faced with the limit that physical resources for most disasters do not come together until the disaster occurs, our only effective recourse is to set up a continuous ongoing virtual preparedness organization that uses the same command and control software as its ongoing virtual operational capability. This would appear to be the only feasible way to be able to bring together the people from different organizations (or different units of a single organization) and turn the emergency management function into a continuous operation for those that need to be involved. It has the added benefit of the resulting command and control function becoming a virtual command and control center. Given that we had lost the local command and control centers in both 9/11 and hurricane Katrina for the initial 48 hours or longer, this becomes an obvious direction to take. The need to allow people in different dispersed locations to get to know one another and work regularly together is another important element of developing the trust necessary for those collaborating in an emergency response environment (Hiltz et al. 2005).

## 6.3 Emergency Management

The endeavors of emergency management and business continuity need to become recognized professions in both industry and government. Today we face threats of great sophistication and wide-scale complexity that will demand a high quality of societal performance and commitment for our civilization to survive. As our society increasingly rests upon a foundation of information and communications systems, the so-called hacking threat of the past has given way to information warfare and international processes for identity theft and fraud. Where we once contended with nature as the source of major disasters we are increasingly faced with man-made disasters of both a short-term and long-term nature. The hundred-year disasters are becoming much more frequent and Mother Nature seems to be reacting to some of the abuses we have practiced upon her. In the US the age of critical infrastructure (roads, sewers, power grids, bridges, etc.) are now older than they have ever been in recent history (since the late 1940s) and growing older still with the lack of adequate replacement and maintenance budgets resulting from the short-term planning horizons and the pressures for budget cutbacks that are easier to politically make in the area of maintenance and replacement.

Instead of focusing on discovering our mistakes and correcting them, our current pressures in both the public and private sector focus on concerns for liability and political fallout, which tend to force the obfuscation of problems and mistakes in all sectors of the society. We still find infighting for political control of the emergency management function between different application areas (fire, police, medical) and the resulting segmentation of the problem rather than the recognized need for high-quality professionals in the field to be given control for integrated approaches for preparedness and response. Our responses to major disasters still seem to be short term spasms of response that are not integrated into long term plans of mitigation and recovery that would smooth out the difficulties in the recovery process years after the event. The fact that the FEMA maps for who should need flood insurance and who would not were thirty years out of date left large numbers of people with no funds to rebuild their homes and massive numbers of court cases now trying to determine if Katrina destroyed homes by wind or water! This is hardly a situation that gives confidence to the public in the ability of a government to protect them in future disasters.

In conclusion, we need a major commitment as a society to treat emergency management as a process that involves integrated planning by all the segments of the society so that mitigation and recovery, for example, are treated as two sides of the same coin. The tools for decision support need to be encompassing in that emergency management is a true multicriteria problem not easily reduced to smaller problems like models of the impact of weather on clouds of toxic substances. We have many such models in the literature, and not one that allows examination of the life cycle of a disaster impacting on a given location or organization that treats the balance between mitigation and recovery years before and years after the event, and integrates the requirements for resources to treat the event for the totality of the given location or the given organization.

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# CHAPTER 40
# Geographic Information and Analysis for Decision Support

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Many types of decision making have a geographic (spatial) component. Geographic information systems (GIS) facilitate the organization and display of spatial data and provide a variety of distinctive spatial operations with that data. These functions allow decision makers explore the spatial aspects of their decisions. Consequently, GIS can be seen as an increasingly important technology for decision makers.

**Keywords**: Geographic information systems; Spatial database; Spatial decision support system; Spatial decision making; Spatial information

## 1 Introduction

Many types of decision making have a geographic (spatial) component; the choice of ***where*** is an important part of deciding ***how***. Many important human activities require the consideration of spatial issues, for example travel and agriculture have required decision making from the earliest times. As people came to a better understanding of the world around them, a variety of representations of geographic data have been introduced. The best known of these is the map, which shows geographic objects and their spatial relationship. A sophisticated science of cartography has developed, and in the pre-computer age maps were one of the most developed forms of visualization used for decision making. This long tradition has meant that cartography was seen as providing useful guidelines to the development of other forms of visualization using information technology (IT) (DeSanctis 1984). Military and transport planners found that appropriate maps were needed for their operations and nautical charts were an important form of information for navigators. By 1800, map making had evolved to a sophisticated level, and maps were used to plan the routes of new canals and railways being built. In 1854 John Snow, an English doctor, used a map to attempt to understand the mode of dissemination of cholera, which was then widespread. He used a map of London to plot the locations of the homes of cholera fatalities. He also marked the location of water pumps on the map (Figure 1). Using this representation, it became clear that those with cholera were clustered around a particular pump and this supported Snow's theory that cholera was spread by polluted water. This is a striking example of how locations plotted on


**Figure 1.** Cholera patients in London, 1854. The original map drawn by Dr. John Snow (1813–1858), showing cases of cholera in London in 1854, clustered around the locations of water pumps

a map could provide information that was not obvious from an analysis of the non-spatial characteristics of the patients, e. g., their ages, diet, etc.

Because of the large amount of data required to represent geographic applications adequately, these were not among the very first applications of computer technology. The development of spatial applications has awaited the availability of more-powerful computers and has typically lagged a decade or more behind business computing. Consequently, geographical applications have a significantly different history from other types of information system (Coppock and Rhind 1991). Early developments in GIS exploited the computational ability of technology (Nagy and Wagle 1979). Computers began to be used in the late 1950s in North America for the automation of geographic calculations. The calculations required in quantitative geography, such as the calculation of the area of a region with irregular boundaries, were much more complex than in other forms of data processing. The Canadian Land Inventory (CLI) project in the mid 1960s was the first large-scale geographic computing project; this became known as the Canadian Geographic Information System (CGIS), which introduced the term GIS. This project was a multilayer land-use/planning map that sought to perform a detailed analysis to determine the areas in use or available for such activities as forestry, agriculture, or recreation. The large size of Canada meant that an area of about one million square miles (2.6 million $km^2$) was involved. In such a large project, the computational ability of the computer made an important contribution to productivity, in a similar way to the use of data processing in other fields.

There were various projects later in the 1960s, notably in Britain, to use computer technology for automated mapping. Initially the attraction of automated mapping lay in the productivity improvements that IT made possible. Computers assisted in the storage and editing of maps, just as word processing allows the easier manipulation of text. When these basic functions had been computerized, further gains became evident from the greater flexibility provided by IT. As technology improved, new types of complex maps could be represented on the computer screen as well as through output devices such as plotters.

This period prior to 1970 saw the introduction of many of the basic concepts in GIS, although their widespread implementation awaited further developments in computer technology. The development of sophisticated GIS applications required the introduction of computer systems that had the necessary speed and storage capacity to process queries on the larger quantities of data involved. In the early years of GIS application, the power required could only be provided by expensive mainframe computers, which could not be easily used in a flexible way by end users. While personal computers became useful for many applications in the 1980s, GIS only became feasible on this platform a decade later. Currently, a wide range of relatively inexpensive GIS software that provides distinctive database and interface components exists. Although of considerable potential value to decision makers, this remains largely unexploited outside of the traditional areas of GIS application.

## 2 GIS Software

Several categories of GIS software exist. Traditionally, at the top end of the GIS software market, large powerful packages capable of dealing with large amounts of data are used. The market leader for such software is the Environmental Systems Research Institution (ESRI) ArcGIS software (ESRI 2007). This powerful software is typically employed for building large datasets. This type of GIS traditionally required specialized workstations and was not always easy to use for decision-making purposes. Modern versions of this type of software are more flexible and can be more easily integrated with other applications. Below this level there are a number of user-friendly desktop software applications, for instance ESRI ArcView (ESRI 2007) or MapInfo (Mapinfo 2007), which are more often associated with decision-making applications. As desktop machines increased in performance, they acquired the capacity to deal with larger amounts of data. Consequently, each new version of desktop GIS software introduced additional features and improved interface design, making these applications accessible to a larger set of users. Mapping software, for example Microsoft MapPoint (http://www.mappoint.com), is less sophisticated than desktop GIS software. However, this software provides increasing functionality and may develop further to a level that makes it useful for decision-making applications.

Another technical development of interest is the extension of GIS techniques to the Internet. Internet standards have some limitations for use in spatial applications, but new software applications and plug-ins continue to be developed. A variety of current applications offer map displays, but frequently fall short of providing comprehensive GIS functionality. Nevertheless, services such as MapQuest (http://www.mapquest.com) and Google Maps (http://maps.google.com) illustrate how mapping can be delivered in a usable way over the Internet. Google Maps offers an interface that allows developers to embed Google Maps in their own web pages. Google Earth (http://earth.google.com) offers an Internet client that allows convenient access to satellite imagery. There is growing interest in the concept of online GIServices, which allow users to access data sets from remote geodata repositories (Tao 2001). As decision-making applications typically involve the use of large data sets to produce a much smaller set of output, the GIService model may be appropriate. Consequently, there is increasing interest in the use of the Internet for spatial decision making (Rinner 2003). Jarupathirun and Zahedi (2005) suggest that spatial decision support applications are moving towards a distributed Internet-based model.

# 3 Spatial Databases

The distinct capability of these spatial software applications is the provision of a spatial database, which provides the capability to reference data using a geographically referenced coordinate system. At a global scale we use the latitude and longitude system, which takes into account the curvature of the Earth. In practice, a local coordinate system is used for most maps; these simplify or ignore issues arising from the curvature of the earth. A simple coordinate system will provide a reasonably accurate relationship with reality over a limited area and commercial software can translate between coordinate systems. General database systems have been extended to cater for spatial data, for instance the Oracle Spatial database or the spatial data-blades from Informix. These enhanced systems incorporate spatial indexes and special spatial database operations that utilize these.

There are two distinct approaches to the representation of data in GIS. The raster approach uses a bitmap representation, storing a representation of the map where the entire area of the map is represented by pixels (dots) on a grid. This can be regarded as a form of digital photograph of the map whose quality is dependent on the size of the pixels. Consequently, this representation can be very storage intensive. A vector representation of a map builds a complex geometric representation from basic shapes, in a similar way to a computer-aided design (CAD) drawing. This approach has the advantage of providing a map representation that is not tied to one scale and is especially suited to the representation of relatively sparse data and the representation of line features such as boundaries. While vector representation is more demanding on computer processing power, the increased capabilities of IT mean that it is widely used.

Spatial databases generally store three basic vector objects: points, lines, and areas (also known as polygons) (Guting 1994). Points are represented by a single coordinate associated with attributes such as color or the type of symbol used to represent the object at that location. Points are typically used to identify the existence of objects whose actual dimensions are not of interest in the map in question, although a more-detailed map might show the object as an area. A single point on a map of a country may represent a town; while on a detailed map a point might be used to represent a postbox or traffic light. Lines are sequences of coordinate locations used on vector maps to represent linear objects such as roads or rivers. Each line is a pseudo-curve composed of a number of straight line segments defined in terms of the coordinate system of the map. In a vector map, a sequence of boundary lines forms an enclosed shape representing an area or polygon. Many natural features are represented in this way, including resources of economic interest such as gas fields. Areas are also an important form of representation for administrative regions and other political structures. Collections of spatial objects can share a common boundary. For instance, the ocean and the land are distinct entities, but the coastline provides a common border. This type of boundary can pose problems where data on each side is collected separately, for instance the borders of two countries will often not quite line up when represented in GIS. A network is a mathematical graph structure with points forming its nodes and lines describing the arcs. This structure is important for representing transportation (Thill 2000) and utility networks (Fritz and Skerfving 2005). Early GIS applications were usually more concerned with generating maps, rather than providing a data structure for mathematical processing. However, modern GIS software increasingly provides specialized data structures for networks and tools such as shortest-path techniques that use those networks.

While many GIS applications are two dimensional in nature, there is also increasing interest in three-dimensional (3D) applications (Zlatanova et al. 2002). Elevation data is routinely included in GIS, allowing the calculation of slopes and the representation of variations in the landscape. Many potential decision-making applications use this data. For instance, telecommunications mast location requires masts located at high points (Scheibe et al. 2006), while many applications are concerned with lower-lying areas liable to flooding (Hossain and Davies 2004), and 3D GIS can be used to model emergency situations arising from the collapse of buildings, such as the destruction of the World Trade Center in New York in 2001 (Kwan and Lee 2005).

# 4 Visualization

Computers have long been seen as particularly appropriate the displaying mapping data (Ives 1982), and modern multicolor computer displays are a powerful tool for representing maps and spatial data. More-recent developments in decision support such as business intelligence also exploit visualization, including the use of maps (Negash and Gray 2003). The rich display of spatial information is one of the major contributions of GIS. However the GIS interface must meet many needs and must achieve three main objectives. Like any software, GIS must provide an interface for computer-related tasks such as opening files and printing, and GIS should behave according to industry standards in this regard. GIS must not only provide graphical output for spatial operations, but users should be offered the possibility of specifying those operations visually using an interactive interface (Egenhofer 1994). For example, if the user wants to zoom to an area of interest, this operation is more conveniently specified using the mouse than by entering commands. GIS contains a visual interface for the display of this data in the form of maps, and this interface can be used to initiate spatial database operations. Ideally any system used by decision makers should support visualization of the decision and the software should accommodate decision makers working within this problem representation. GIS provides the ability to specify operations graphically and to see the results of those operations set against a background showing contextual geographic information (Blaser et al. 2000).

Consequently, the GIS interface serves as both a report generator and as a conduit for specifying user information requirements, both those relating to spatial operations and operations such as saving files and printing, which relate to the operating system of the computer. This dual role complicates the design of GIS interfaces and makes these systems relatively complex to use. Consequently, GIS applications can especially benefit from better-designed human-computer interfaces that meet their specific needs (Hearnshaw and Medyckyj-Scott 1993). Spatial visualization is appealing to non-traditional users as it allows them to appreciate spatial relationships (Hernandez 2005). However, spatial techniques are necessarily complex and, despite improvements in GIS interface design, this complexity is an obstacle to the wider use of GIS by decision makers in domains where users do not receive training in the use of spatial techniques.

If we list the attributes of geographic entities in a table we cannot easily see patterns in the relationships. However, when we plot this information on a map these relationships become apparent, in a similar way to Snow's original paper map (Figure 1). A choropleth map (thematic map) displays attribute data associated with relevant spatial units, and this is a commonly used and readily acceptable form of spatial visualization. If we plot data on gross domestic product per capita for Europe on a choropleth map (Figure 2), we can easily see that western Europe is generally more prosperous than eastern Europe, reflecting different historical circumstances.


**Figure 2.** Choropleth map of gross domestic product per capita (at purchasing power parities) of European countries

## 5 GIS Contribution to Decision Making

IT has a number of attributes that can contribute to decision making. Computers were initially used, as their name suggests, to perform faster calculations and GIS can assist in many complex spatial calculations that aid decision making. Goodchild (2000) suggests that computing power in GIS can assist by allowing measurement of geographic features, by identifying geographic features near to each other (adjacency), by allowing the enlargement or reduction in the size of geographic features (buffering), by allowing the overlay of features from different maps, and by providing a convenient editing function for spatial data. These functions are more complex than those used in the business data-processing applications that have been the reference point for information system (IS) innovations. Decision support systems (DSSs) developed when IT had evolved to provide a database and a user-friendly interface to complement its capacity for rapid calculation (Gorry and Scott-Morton 1971). DSSs remain an important area of IT application, taking advantage of new technologies and research in the three decades since the concept was first introduced (Shim et al. 2002)

GIS provides sophisticated spatial computations in addition to a distinctive spatial database capability which greatly facilitates spatial decision making. Modern GIS includes a sophisticated interface with both a cartographic representation of the spatial problem and features that allow the decision maker to interact with the calculation and database features of the software. When DSSs evolved in the 1970s, the volume of data involved with typical DSS applications was relatively small compared to applications found in the geographic domain. As computer systems became more powerful, some DSS-type applications evolved that used basic map display or incorporated some spatial information. A good example is the geodata analysis and display system (GADS) (Grace 1977), which was used for routing applications. Nevertheless, the technology it used had very limited graphics capability and inadequate processing power to exploit the full potential of spatial applications. While these developments in DSSs were taking place in the IS community in the 1970s, a largely separate trend of development took place in GIS. Spatial applications had placed heavy demands on the technology, and this slowed the progression from data processing to decision support applications. Nevertheless, improving performance from inexpensive computers has influenced spatial systems in a similar way to the development of other forms of computer processing. This included interest in spatial what-if analysis and modeling applications. The idea of a spatial decision support system (SDSS) evolved in the mid 1980s (Armstrong et al. 1986), and by the end of the decade SDSSs were included in an authoritative review of the GIS field (Densham 1991). This trend was evident in the launch of a research initiative on SDSS in 1990 by the U.S. National Center for Geographic Information and Analysis (Goodchild and Densham 1993).

Consequently, by the early 1990s, SDSSs had achieved a recognized place in the GIS community and were identified by Muller (1993) as a growth area in the application of GIS technology. The delay in the recognition of the importance of SDSSs compared to other DSS domains is a reflection of the greater demands of spatial processing on IT. Initial references to SDSSs in the mainstream DSS field began to appear in the mid 1990s (Wilson 1994). One of the first GIS-related papers in an IS-related publication illustrated the effectiveness of SDSS technology (Crossland et al. 1995). While there have been occasional papers in the IS literature dealing with spatial systems, these have been relatively uncommon. Nevertheless, a recent book provides a comprehensive review of the GIS field from an IS and business perspective (Pick 2005). One chapter in this book reviews the literature on GIS as a tool for business and gives an overview of the literature on the use of GIS for decision making (Huerta 2005). Another chapter in the same book reviews the main results of empirical studies on decision making using GIS (Jarupathirun and Zahedi 2005). These studies suggest that the use of maps can improve spatial decision making and that GIS allows decision makers to perform better than paper maps, especially if they are experienced GIS users.

# 6 GIS Analysis

GIS provides a variety of analysis tools (Table 1). Measurement is a fundamental operation in GIS, and an accurate measurement of spatial features is an important starting point for many types of decision. Measurement is made difficult by the complex shapes of many geographic features and because real-world objects vary in three dimensions, with varying height as well as irregular boundaries. GIS provides the capability to measure the area, length, volume, shape, and slope of geographic objects defined by the user.

A buffer in GIS is a band around the boundaries of a geographic object (Figure 3). GIS provides tools to identify a region within a certain distance from an object on the map; this can be a point, line, or area. Buffers have many practical applications and are widely used in spatial modeling and decision making. For instance, buffers could be used to identify the regions close to a main road that might be affected by noise; a similar technique could also be used to associate delivery locations with routes passing along the roads.

Information processing can be seen at its most powerful when it allows different sources of data to be synthesized. A major contribution of database management systems, such as relational database software applications, is their ability to combine information from different data sets. GIS incorporates spatial database functionality and the ability to query external databases, allowing the combination of different spatial data sets. This requires that different types of data be available for the same geographic area and that they are stored in the GIS in a compatible projection. This allows different types of geographic data to be treated as layers of the same map.

**Table 1.** GIS operations

| GIS operation | Data used | Example |
|---|---|---|
| Measurement | Point to point | Distance between two towns |
| | Length of line | Road distance |
| | Area of polygon | Size of lake |
| | Slope | Gradient of hill |
| Adjacency | Point/line | Nearest hospital to a railway line |
| | Polygon/polygon | Neighboring regions |
| Buffering | Point | Region near a shop |
| | Line | Area within 500 m of a road |
| Overlay | Point/polygon | Town in region |
| | Line/polygon | River in region |
| | Polygon/polygon | Overlap of two different types of region |

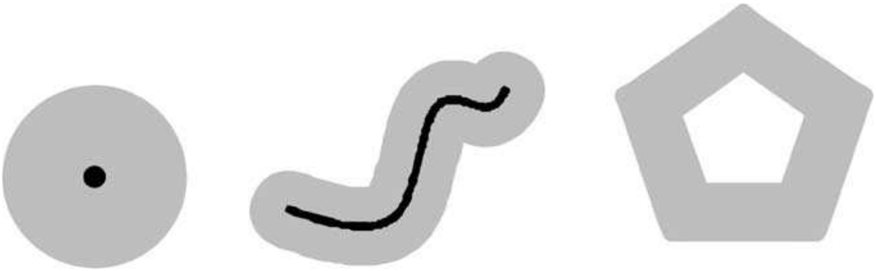

**Figure 3.** Buffers

Many forms of spatial decision making require information on the degree of overlap between geographic features stored in different layers. For example, one layer might show physical features such as forests, another layer might show political divisions such as administrative districts, counties, etc. We might be interested in knowing which administrative regions contained forests. Just as traditional

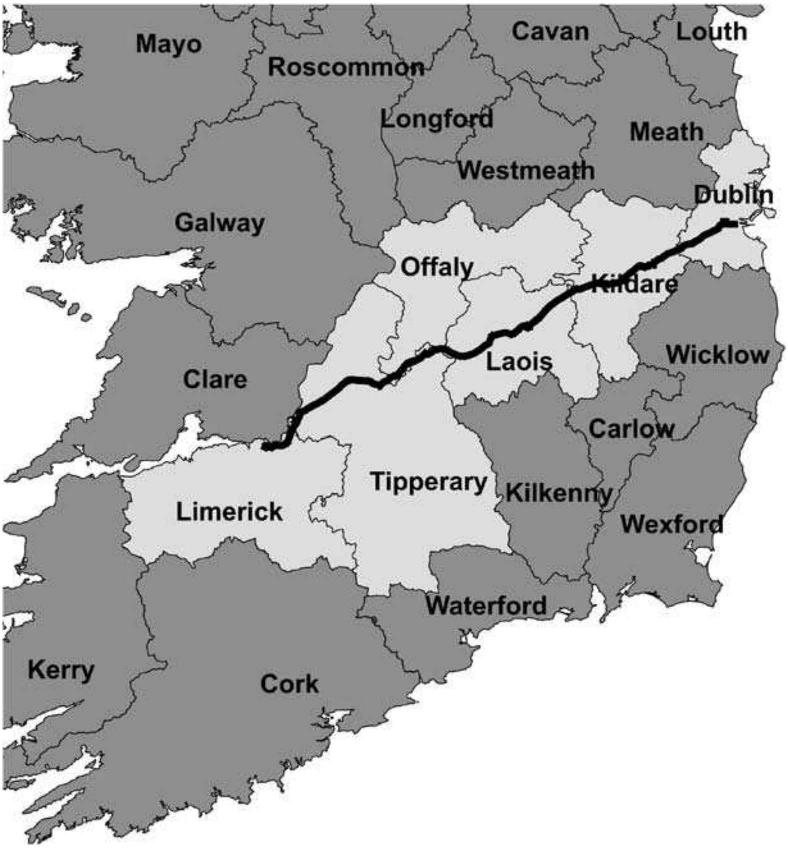


**Figure 4.** Using overlay to identify Irish counties traversed by the N7 road

databases allow the combination of different datasets, spatial databases provide spatial join operations that allow the combination of different spatial layers. The GIS operation known as overlay is one form of spatial join. Using overlay operations, GIS software can identify whether spatial features overlap with other spatial objects. In addition to area overlay, we can identify where lines or points overlay areas. For instance, we could identify the administrative regions along the path of a river or road (Figure 4).

## 7 Applying GIS

GIS offers powerful spatial database features and a visual interface for querying and reporting on that data, and this directly meets the needs of many decision makers, especially in sectors that traditionally use geographic information. However, a much wider range of potential users make use of spatial information as a component in their decision making. This wider group are typically users, rather than creators, of spatial data. As spatial applications have developed, a wide range of spatial datasets have become available, facilitating a much wider range of application for spatial techniques. The suitability of this data for decision making depends not only on its cost, but also on the ease of access to that data. Accessibility is facilitated by the availability of well-integrated spatial databases and the indexation of all relevant spatial data in a transparent and accessible way. In many countries, accessibility is enhanced by national spatial data infrastructure (SDI) initiatives to provide a set of policies, standards, and procedures to allow organizations and technologies to use spatial data efficiently (Masser 2005). The wider use of spatial techniques requires an effective market to transfer data between those who collect it and those who would like to use it for decision making (Keenan 2006). An effective market for spatial data requires agreement on the technical standards used and the economic arrangements governing the transaction. While there has been progress on data standardization, the market for spatial data needs further development in relation to issues such a licensing and payment mechanisms.

This wider range of decision makers requires that GIS systems can be integrated with other decision tools. Consequently, GIS vendors have recognized the importance of making their software flexible and customizable to the needs of this larger set of potential customers. From the late 1980s vendors added customization facilities to their products; initially these used proprietary standards, in the absence of well-established standards at that time. As systems evolved, vendors began to emphasize the modularity of their products. A modular approach meant that different parts of the system could be used as required by the different groups of potential users. This has now led to the situation where many of the off-the-shelf products are simply one of many possible configurations of the underlying tools with which the software is built. To facilitate integration with other software, GIS vendors provide access to the system functionality by creating and documenting a set of application programming interfaces (APIs). Where products are modular in nature, the API can allow the system builder interact with the various parts of the system.

GIS vendors are moving their products towards commonly recognized standards. For example ESRI, the largest GIS vendor, has discontinued its proprietary scripting language, Avenue, and has moved its products to a Visual Basic for Applications (VBA)-based scripting language. All vendors provide products that support popular software interchange standards such as object linking and embedding (OLE). Vendor software typically provides an API for integration with Java, C++, and Microsoft .Net. Adherence to these industry standards has facilitated third-party developers in producing a range of specialist add-ons for GIS products. For instance, add-ons for ESRI products include tools for mapping crime, for managing electricity grids, for planning new road developments, and for dispatching fire engines. There is continued interest in GIS software that is not subject to restrictive conditions on its use, and projects such as FreeGIS (http://www.freegis.org) and Open Source GIS (http://opensourcegis.org) aim to extend the role of free and open-source software in the GIS community. These systems have been used as a basis for SDSS, including the open-source GRASS GIS (Ducheyne et al. 2006) and the inexpensive IDRISI GIS (Rinner 2003).

## 8 Conclusion

GIS provides sophisticated database and interface features that allow the representation of many types of spatial problem. The database operations and visual problem representations that GIS provides are of considerable potential benefit to the decision maker. The usefulness of GIS can be greatly extended by integration with other forms of IT and models drawn from other disciplines, and GIS software increasingly makes this integration possible. However, the complex operations provided by GIS, which make the technology so powerful, also make it difficult for decision makers without training in spatial techniques to use. The development of GIS as a decision-making tool has also been hindered by the limited availability of some types of spatial data and by the expense and restrictive licensing required to use this data. Nevertheless spatial techniques are becoming more accessible every year and this will extend the use of GIS for decision making into many sectors that have not previously used spatial approaches.

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# CHAPTER 41
# Support for Real-Time Decision Making in Mobile Financial Applications

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Mobile users making real-time decisions based on current information need confidence that their context has been taken into consideration in producing the system's recommendations. This chapter reviews current use of mobile technologies for context-aware real-time decision support. Specifically, it describes a framework for assessing the impact of mobility in decision making. The framework uses dynamic context model of data quality to represent uncertainties in the mobile decision-making environment. This framework can be used for developing visual interactive displays for communicating to the user relevant changes in data quality when working in mobile environments. As an illustration, this chapter proposes a real-time decision support procedure for on-the-spot assistance to the mobile consumer when choosing the best payment option to efficiently manage their budget. The proposed procedure is based on multi-attribute decision analysis, scenario reasoning, and a quality of data framework. The feasibility of the approach is demonstrated with a mobile decision-support system prototype implementation.

**Keywords:** Mobile decision support; Real time decision making; Quality of data; Financial decision making

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## 1 Introduction

The use of mobile devices enriches today's world of widespread e-services and extends opportunities for decision support. Users can make real-time decisions based on the most up-to-date data accessed via wireless devices, such as portable computers, mobile phones, and personal digital assistants (PDAs). Business transactions, such as online shopping and banking, can be completed in a secure mobile computing environment. Travelers can optimize their trips and organize short-time holidays if customized sightseeing and entertainment recommendations are available from their mobile device (Carlsson et al. 2006, Nielsen 2004). A movie-goer can select from his/her PDA a movie that is currently showing in the nearest cinema at her preferred time (Jayaputera et al. 2003). A stock trader can monitor his/her stock investment from a PDA that provides alerts about interestingly behaving stocks (Kargupta et al. 2002). A TV fan can watch his/her favorite soap opera via the mobile phone (Carlsson and Walden 2007).

Mobile technology is increasingly evolving in conjunction with wireless networking capabilities. Advances in wireless and mobile technology brought into existence terms such as ***mobile era***, ***mobile commerce***, and ***mobile workers*** (Mennecke and Strader 2002). Its successful use and implementation in several fields has highlighted the need for growth in this area and its importance for decision support. It created opportunities for meeting users' information needs for real-time and on-the-spot decision making. In addition, the availability of up-to-date information, coupled with the potential for such tools to save time and increase productivity, are seen to highly motivate individuals to use such devices (Carlsson et al. 2005).

While decision support systems have typically been associated with desktop systems and involve considerable processing, the development of new compact and mobile technologies provides new opportunities (Aronson et al. 2005). Work environments that are mobile in nature and that cannot benefit from desktop-based decision support can now be accommodated through the use of mobile technologies. Such technology can also be adapted to current workplaces to address limitations of current systems (Sharaf and Chrysanthis 2002). Since accessing real-time information is essential for good decision making, the usefulness of mobile devises for decision support, in our opinion, is hard to overestimate.

In today's consumer-oriented society, "we are bombarded with advertising showing us that we can have it all now" (Tarica 2001). Merchants are now targeting mobile consumers' needs through intelligent advertising, in which the consumer receives location-based advertisements via the short message service (SMS) or multimedia messaging service (MMS) on his/her mobile phone, that are tailored to his/her personal preferences (Panis et al. 2002). Financial institutions offer online services that can be accessed by the mobile user via web enabled devices such as the personal computer (PC), Palm Pilot, Web Phone and WebTV (Reis et al. 2003). For the individual consumer, these online transactions include account balance enquiries, funds transfers, account applications, automated teller machine (ATM) locators, and electronic bill payment. For companies, online banking services include monitoring cash balances across a company's accounts, checking account balances, paying salaries, and checking transaction details (Rogers 2003). Electronic payments with credit cards are also very common and part of the consumer's daily life (Hartman and Bretzke 1999). With the introduction of location-based services, online banking and electronic payments, the consumer is left to make hard decisions responding to targeted marketing and advertising, requiring them to try and efficiently manage his/her budget with the real risk of acquiring high levels of debts which are often difficult to control.

In this chapter we review opportunities and challenges of mobile decision support. Mobility introduces additional uncertainties into the decision environment. Firstly, information held in a mobile device is likely to be incomplete or outdated, and may not reliably support the user's needs in critical situations such as healthcare management, national defence, or weather forecasting. In another context, the availability of e-services to support business transactions varies depending on the number of mobile users requesting services, changing locations of users, or type and size of mobile devices. We proposed a framework for assessing the impact of mobility in decision making based on a multi-attribute indicator for measuring quality of data (QoD) (San Pedro et al. 2003, Burstein et al. 2004). QoD can provide the basis for a decision support system (DSS) for generating alerts about changes in problem and user context. In this chapter we describe the way such indicator can be calculated and used in a decision process in a mobile environment.

As an illustration, we explore the factors that affect users' ability to make financial decisions in a mobile environment. We look at how to enhance the level of decision support that the mobile user can receive from his/her mobile device when making financial decisions. The aim is a real-time decision support procedure that provides on-the-spot assistance to a mobile consumer who wishes to purchase a product or pay for a service today, while still efficiently managing his/her budget for the month.

In the following section, we consider the concept of mobile, real-time decision support via a mobile device, including various technical architectures for such implementation. Section 3 illustrates how this concept can be applied to assist in financial decision making. Section 4 describes a mobile account management problem, followed by a proposed multi-attribute model and prototype implementation for a DSS which dynamically monitors account information.

## 2 Mobile Decision Support

Mobile technology provides a number of advantages over stationary computing. Two of the most notable are real-time information availability (Zhang et al. 2006) and higher flexibility for user interface (Van der Heijden and Junglas 2006). In conjunction with this are the electronic services that can be provided by mobile devices. Mobile devices and instruments can interact with each other using internet, wireless networks and protocols. In this sense the use of mobile technology can increase the productivity and efficiency of mobile users.

Mobile technology has benefited various industries, both public and private. Its wide range of applications and services include medical information services, and tracking and monitoring emergency services (San Pedro et al. 2005, Bukheres et al. 2003, Burstein et al. 2005). By providing cost-effective, pervasive access to information, wireless networks and mobile devices are reducing errors and improving access to information that was once central (Chatterjee 2003). By changing the way people work in today's dynamic work environment, we have seen the deployment of mobile technology in disciplines ranging from archaeology (Blunn et al. 2007), airport management (Pestana et al. 2005), education (Cabrera et al.

2005), healthcare (Michalowski et al. 2003, Cowie and Godley 2006, Padmanabhan et al. 2006), and many more.

Carlsson et al. (2006) suggest that the value of mobile devices cannot be applied generically, but rather it is specific to the context it may be useful in. The value of mobile devices can also be determined by applying the Braudel Rule (Braudel 1992). The rule suggests that the value of innovative services is determined by whether they change the structure of everyday routines. So for example, the widespread use of a mobile device implies it satisfied Brauden's rule. Churchill and Munro (2001) found that changes in technologies led to subsequent changes in the nature of work practices, as a result, "…many work practices that have been traditionally seen as static in fact involve considerable amounts of local mobility" (p. 3).

A high degree of mobility is desirable for most mobile decision-making environments, where provision of current information is essential and access to desktop computers is not available. Mobile technology is rapidly developing and encompasses a considerable number of devices, from small PDAs, to laptops and tablet PCs (Derballa and Pousttchi 2004). Mobile devices can be broadly divided into the laptop computer, handheld devices (e. g., Palm), telephone, hybrid (e. g., smart phone PDA/telephone), wearable (e. g., jewellery, watches), vehicle-mounted (in automobiles) and specialty, with enabling technologies such as global positioning system (GPS) and Bluetooth (Mennecke and Strader 2002). While all such devices can provide decision support benefits and, in a general sense, be considered mobile, PDAs and smart phones are of most relevance, and are becoming increasingly popular with general users (Burstein et al. 2004, Carlsson et al. 2005). In this chapter, we illustrate the potential for mobile decision support using a PDA style interface, as this is the device with which the authors have most familiarity. However, the style of interface is felt to be applicable across all devices.

## 2.1 Technical and Computational Architecture for Mobile Decision Support

Mobile decision support can be implemented in a number of ways, depending on user requirements, available technological resources, frequency of data access, urgency of data retrieval, etc. As research into such technology is relatively new, optimal architectures for various decision contexts, design configurations, and potential future applications have yet to be investigated. In this section we consider how fundamental component of DSSs, i. e., database (DB), user interface (UI), and analytical model (AM) (Aronson et al. 2005, Sprague and Carlson 1982) can be arranged in mobile decision support architectures. Figure 1 illustrates five possible types of mobile DSS implementation architectures.

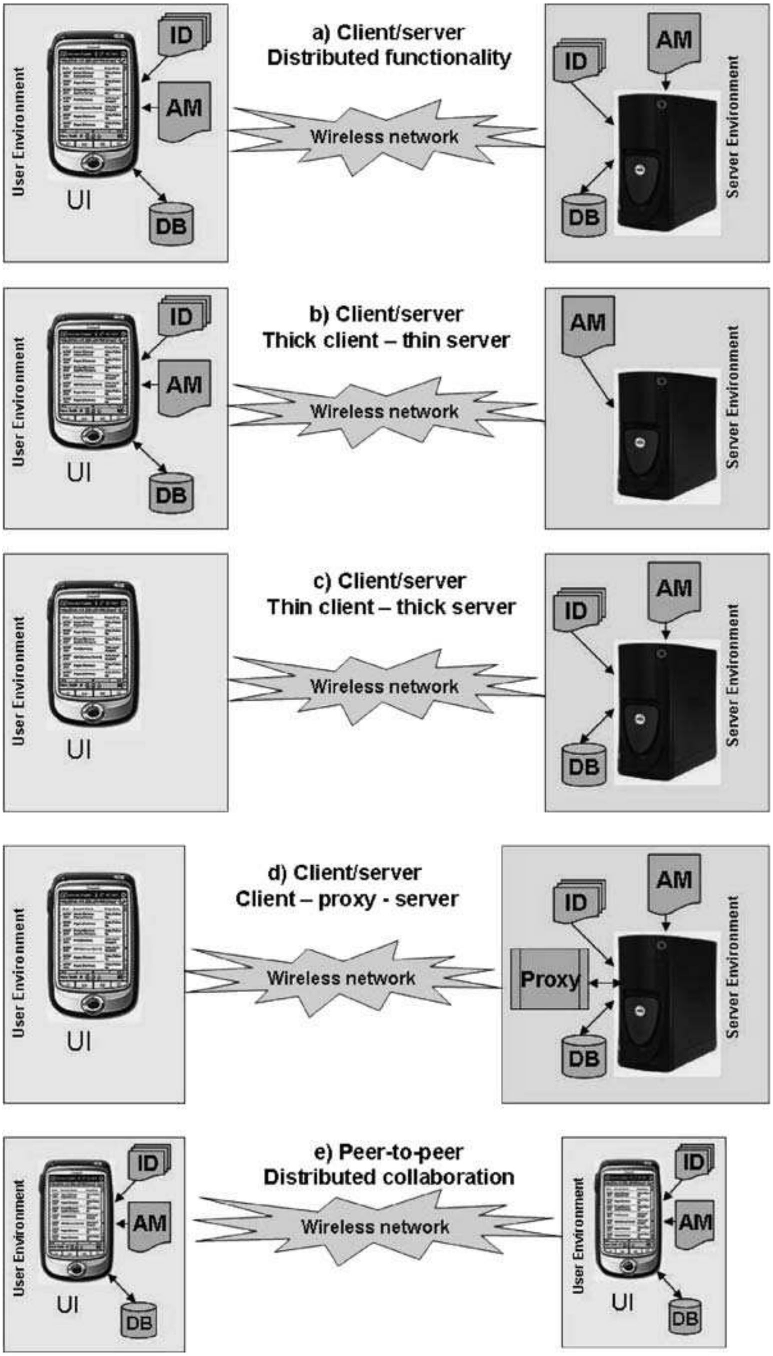



**Figure 1.** Mobile decision support architectures. Legend: UI – user interface; ID – input data; AM – analytical model; DB – database

Portable devices can act as computational platforms for task-specific applications, collecting, storing, processing, and providing data. The use of device-specific resources or server resources creates a distinction between possible types of mobile DSSs that can be provided (Navarro et al. 2006). Mobile decision support can be client-based, server-oriented, proxy-based or distributed across an ad hoc network of similar peer devices (Bukhres et al. 2003). The type of architecture depends on where information is stored and where computations are performed. These varying implementations have their advantages and disadvantages. The usefulness of each depends significantly on the application requirements and underlying technical infrastructure. Systems focused on access to significant amounts of information are more likely to use a server architecture given the limited processing and information storage capabilities of small portable devices. Alternatively, decision support that may suffice with preliminary processing of information could benefit from coarse-granularity processing on a resource-constrained portable device. Independent decision support provides increased system fault tolerance and reduced support requirements. Currently, the most popular is implementation (a), as depicted in Figure 1, where functionality is distributed across the client-server environment with the user interface (UI) located on the user's portable device, data distributed across both client and server, with user-sensitive data residing on the user device, while massive amounts of data, including historical, are located on a server. In this configuration, the analytical model (AM) is also distributed across client server with the user device performing elementary computations and delegating more-complex and resource-intensive computations to the server.

Thick client-thin server and vice versa represent more-extreme cases and therefore more-rare configurations (see Figure 1b). Given a high likelihood of disconnections in wireless environments, some systems may use the concept of a proxy architecture where a proxy process is located on a server side representing a client and, if connectivity is good, data and computations are simply channelled between a server and a client (Figure 1d). However, if a client becomes disconnected (e.g., driving through a tunnel), then the proxy assumes full functionality of the client and caches data and results until the client reconnects. With the proliferation of peer-to-peer computing, it is now becoming possible to form ad hoc networks of similar devices, discovered at a time of need, in order to consolidate resources and apply the AM in a distributed computing environment in a resource-efficient manner (see Figure 1e). These possible architectural implementations enable enough flexibility and scalability for any possible DSS application or scenario.

## 2.2 Quality of Data Model

Users need support when facing critical situations and would welcome alerts about the reliability of data in such situations, but may be dissatisfied with requests for attention when they are relaxing at home. In recent papers (San Pedro et al. 2003, Hodgkin et al. 2004), we proposed a framework for assessing quality of data (QoD) indicator as a measure of the impact of mobility in decision making (San

Pedro et al. 2003, Burstein et al. 2004, Hodgkin et al. 2004, Cowie and Burstein 2006). We identified some factors that may be considered in establishing a framework for addressing the issue of data accuracy in mobile decision support. QoD is based on multiple parameters, which measure user-specific, current technology-related factors, and some factors which can be learned based on past experiences with similar problem situations. By providing a QoD alerting service from the mobile device, the mobile user is warned against making decisions when the QoD falls below a predetermined threshold or when the QoD becomes critically low. The assumption we make is that a decision maker should feel more confident with the decision when the QoD is high, or be alerted when the QoD becomes lower than acceptable.

The QoD model aims at assisting the mobile users in selection of the best option, taking into consideration the reliability of the data such an option was based on. Figure 2 represents a model of QoD comprising attributes that contribute to data quality when supporting personal mobile decision making (Burstein et al. 2004).

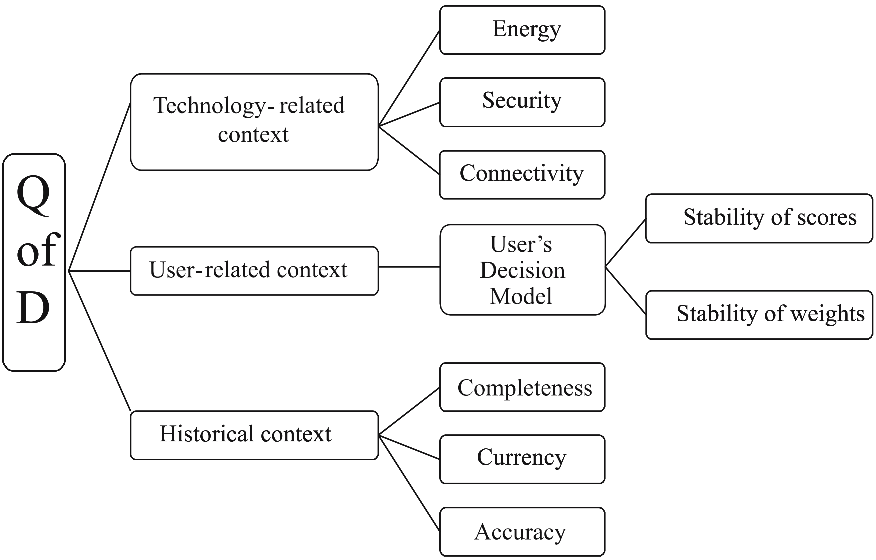



**Figure 2.** A sample multi-context representation of QoD, adapted from Burstein et al. (2004)

These QoD attributes include technology-related, user-related, and historical contexts. These attributes are further broken down into some QoD metrics relating to energy, security, and connectivity for technology-related contexts, stability of scores, and weights for the user's decision model relating to user-related contexts, and completeness, currency, and accuracy for historical contexts. Some of these metrics can be calculated by comparing current data with standard data.

The integrated QoD indicator can then be calculated as the weighted sum of technology-related, user context related and history-related attributes assessment either derived automatically or provided by experts (Hodgkin et al. 2003, Cowie and Burstein 2006). In mobile DSSs, QoD can be calculated incrementally at every stages of decision making process as the mechanism for alerting the user when more data and/or resources are needed before the best option can be selected. For example, following Simon's classical decision making principal phases (Simon 1960), when describing decision situations, QoD can be used to judge how accurate the set of data collected at the intelligence phase was; when designing alternative actions, QoD can assist in making sure the user is satisfied with the range of possibilities she is presented with for a choice; when a model is applied for selecting the best alternative, the final output includes a full and explicit representation of the QoD, which was derived as an aggregate of the ones used in the previous stages (see Figure 3).

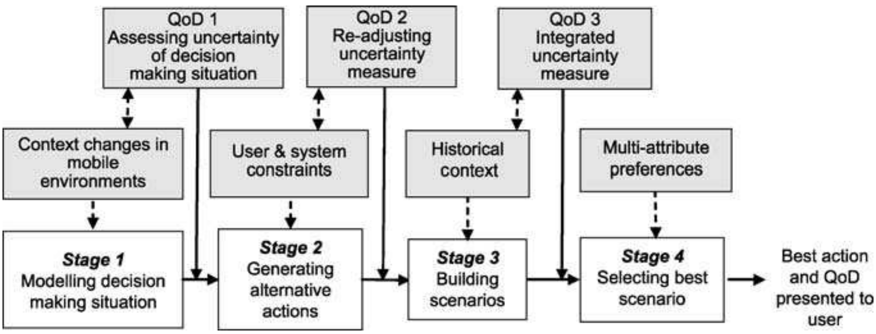



**Figure 3.** Decision process in mobile environments

In the next section, we illustrate how real-time decision support can be applied in financial decision context.

## 3 Real-Time Financial Decision Support

The way financial decisions are made is influenced by many factors. Today, there are many options available to consumers when most of financial transactions are made electronically. The "new breed of online consumer who will expect faster delivery, easier transactions, and more factual information" (Martin 1999) poses a difficult challenge to accounts management. When purchasing an item, there are a number of issues that must be addressed in deciding upon the best payment method.

This situation presents a good example of when real-time decision support could be beneficial (Hartmann and Bretzke 1999). For example, if someone wants to purchase an expensive holiday or pay for car service today using cash from his/her current account, will there still be sufficient funds to cover the direct debits due out of the account next week? If not, are there sufficient funds in the savings account to transfer cash into the current account to cover the direct debits? Would such a transfer of cash incur charges? What if the consumer opts to pay for the holiday on a credit card? Is the credit-card repayment date sufficiently far in the future that by such a date there will be enough funds to pay it off? Would it be a better option to pay off just the minimum amount due? How will this holiday purchase or car-service payment influence the regular monthly repayments? More importantly, could buying the holiday be done in a way that there is no need to cut down an overall spending?

These are some issues that the mobile consumer might be considering when deciding which payment option is best to minimise transaction fees, minimise credit card debts, and maximise monthly savings. Currently, many such decisions are based on intuition or past experience, and there are no analytical tools developed to assist mobile decision-makers in these situations. There are a few products on the market that provide different personal finance management solutions. Some of these products are Microsoft Money, SmartMoney, My Money, Quicken, and Mind Your Own Business (MYOB). These products support and manage operational transactions and permit some analysis of historical data. MYOB, for example is aimed specifically at Australian small-business users. MYOB replaces "the cash register with a point-of-sale system that streamlines store operations and manage sales, stock, goods and services tax (GST), staff and customers" (Tsang 2003). Microsoft Money allows a consumer to view vital financial statistics at a glance, set up regular bill payments as reminders, or have them taken from an account automatically, plan and maintain budgets, and see projected cash flow so the user knows how much to spend. However, most of these are not yet customised for access from a mobile device. The only mobile application that comes close to the decision problem described above is Microsoft Money for Pocket PC (http://www.microsoft.com). This mobile version of Microsoft Money, however, provides little decision support as it only allows the user to view the account balances (upon synchronisation with desktop Microsoft Money) and record any new transactions.

The financial decision support process in a mobile environment is a dynamic process that evolves with different context changes, is characterised by fluctuating uncertainty, and depends on multi-attribute preferences of the individual mobile decision maker. It should link past, current and future states of the mobile environment and needs to be adaptable to user and system constraints (Bukhres et al. 2003). In addition, mobile decision support requires the underlying distributed computing infrastructure with wireless and mobile networks as the main components (Ahlund and Zaslavsky 2002), which determine a suitable architecture for mobile decision support as described above.

Following the staged process, Figure 3 depicts this staged process schematically. Initially, the user must recognize the need for making a decision. In addition to addressing the problem at hand, the user must take into account context-specific criteria in assessing whether it is appropriate to use the support system. The next step in the process involves the generation of alternative actions. These are calculated from the available information about transaction history and financial institutions' charges. Again, consideration is paid to context-specific characteristics of the environment as well as the user. The support system utilises historical data, user profiles, and expert knowledge to produce scenarios of possible actions. Depending on how much access the system has to the up-to-date transactions history and the mobile DSS architecture set up, the QoD for decision support will vary and used as a mechanism to ensure enough data is available and the level of its reliability is appropriate to make a acceptable decision. Finally, a multi-attribute description of the problem situation is generated and user preferences evaluated in order to decide upon the best course of action.

In the following sections, we describe the mobile accounts management problem as an illustration of the dynamic multi-attribute decision making model. We then proceed with a proposed solution procedure using scenario reasoning to assist the consumer with a mobile decision support to foresee and analyse the consequences of a choice. Suitable measures of completeness, currency, and accuracy of data are also presented as QoD parameters that are related to historical context. Finally, we describe a prototype tool, called iAccountsMgr, which demonstrates the feasibility of the proposed procedure to support the mobile consumer in managing financial accounts (Burstein et al. 2004).

## 4 Mobile Accounts Management

A mobile accounts management problem refers to a mobile user's problem of selecting the best possible immediate payment option in relation to the associated future gains or losses. Payment options in an e-commerce context include payment by electronic funds transfer at point of sale (EFTPOS), electronic wallets (Anderson 1994, Tygar and Yee 1995), electronic coupons or electronic cash, and of course, more-traditional options (for example, paying by cash, lay-by, credit card, or cheque). With so many options to choose from, the mobile user can enjoy the convenience of paying for products or services electronically, and charging each to one of multiple bank accounts (savings, credit, cheque accounts). Some online financial services (such as online banking) allow the consumer to view the account balances online, or to record transactions electronically to keep track of his/her transactions and balances. A tool that helps the consumer save money and/or manage their accounts efficiently is regarded as highly attractive to the mobile user (Carlsson et al. 2005).

Our approach of supporting the mobile user with QoD indicator is also relevant to the mobile accounts management problem. This indicator can be useful to the mobile consumer when making real-time decisions about efficient accounts management since, in particular, together with the recommendation on the best option to realise future gains, they are informed of the QoD that was used to calculate the choice, or be alerted when QoD level was not good enough to justify the suggestion.

## 4.1 Pay by Cash, Credit or EFTPOS? A Dynamic Multi-Attribute Decision-Making Problem

In this section, we represent the concept of mobile accounts management, as described above, as a dynamic multi-attribute decision making model. A sample user's model is depicted in Figure 4. In the example, the alternative actions are to pay by: (a1) cash, (a2) credit card, (a3) EFTPOS, and (a4) EFTPOS and withdraw cash. The available alternatives are determined from user's profile. Thus, for a mobile user, paying by cheque can be one of the payment options but perhaps not the most attractive one. Internet-based transfer using a mobile device will do the job faster and might be a more-appropriate option. We assume that for this particular mobile accounts management problem, the mobile user's goal is to minimize transaction fees and credit and maximize savings by the end of the month.

The alternatives will be evaluated against multiple attributes. In our example, the multiple attributes are: (c1) cash at hand, (c2) savings1 balance, (c3) savings2 balance, (c4) credit balance, and (c5) overall transaction fees.

Note that there is some inherent uncertainty in the future state of the multiple accounts if a purchase is made today. Context changes due to user mobility also add some degree of uncertainty into the problem, because they can influence the future evolution of events. Thus, to support the mobile user in handling such uncertainty, we will derive scenarios based on one of: the user's strategy, a learned strategy, or an expert strategy.

A scenario is a sequence of sub-actions and events that may evolve in the future once an action is initiated. We can support the mobile consumer in his/her choice making, by allowing him/her to look ahead or to reason in terms of scenarios. For the non-aided mobile decision maker, the scenario reasoning process can be very complex and confusing due to all the possible consequences of a choice and associated probabilities that need to be considered (Pomerol 1997). Due to many constraints in mobile decision making (e.g., limited energy, unstable network connection, limited user interface capability, user mobility), we propose to build only scenarios that are based on the user's predefined instructions, rules derived from recorded transactions, or some expert's strategy.

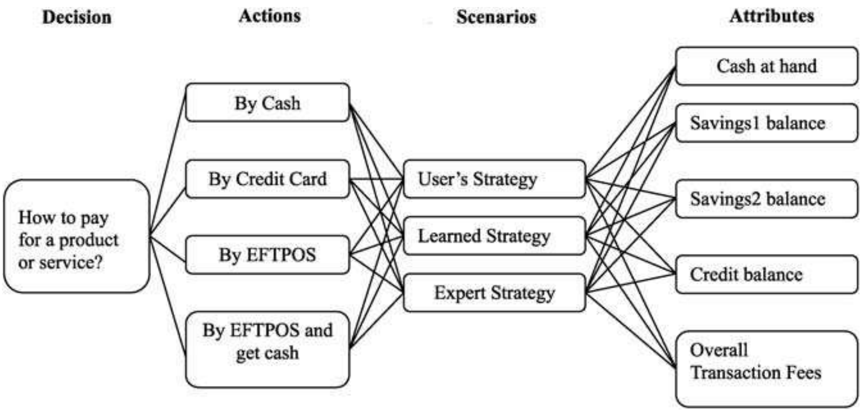



**Figure 4.** A sample user's model of accounts management problem

### 4.1.1 User's Strategy

Initially, the mobile decision-maker may have a predefined set of rules that he/she wants to impose when selecting the best payment options. The example rules can be:

- If there will be insufficient funds for tomorrow's direct debit payment, then transfer the required amount from savings2 to savings1 before midnight.
- Do not use credit card a week before credit payment is due.
- Do not use EFTPOS after the second EFTPOS or ATM transaction.

Rules such as these can be stored in a relational database or rule-based system, specific to the mobile user. Other user preferences, such as relative importance of criteria, available payment options, types of transactions, must-buy items, must-avoid items, target savings balance, etc., can be incorporated in the user profile by user registration of preferences. Initially, the user will have to manually input some minimal preferences through registration forms.

A sample set of scenarios for actions a1–a3 is shown in Table 1. The problem here is to determine the best payment option to pay for a car service worth $450, if paid by cash, or $500 if paid by credit card or EFTPOS. In this example, based on the user's profile, our particular mobile user has given the instruction to withdraw a minimum of $500 in alternative a4 when building scenarios. Thus, in Table 1, a4 is not a feasible option as there is only $800 available at hand. It is assumed that decisions are set to be made between some critical dates, when balances need to be updated, for example when credit card payment is due, regular credits are made to the accounts, or loan interests and other regular payments are due.

Consider **scenario 1**. Based on the user's predefined strategy for cash payment, $450 is deducted from cash at hand on day 17 (see column 4), and all other scheduled payments (including fixed and estimated amounts) until day 24 will be processed. This sequence of events is initiated by the support system. On the 25th day, the system will initiate a transfer of funds from savings2 to savings1 to pay the credit balance of savings1, pay succeeding estimated expenses and maintain a balance of $500 by the end of the month. Such transfer of funds will incur a transaction fee of $2.50 on the 25th day. In line with the user's predefined strategy, the expected balances at the end of the month will now be 0, 500, 5406, 220, 11.6 for cash, savings1, savings2, credit, and transaction fees, respectively.

**Scenario 2** on the other hand, will incur an additional credit of $500, and consequently, the user will reach the credit limit of $3000 before the credit payment due date on day 25. In order to avoid paying interest on the credit, or a fee for exceeding the credit limit in future payments, the user's strategy is to transfer funds from savings2 to the credit account. This transaction incurs a fee of $2.50. All other transactions are processed based on estimated expected payments following the user's predefined strategy. Scenario 2 will yield the balances 186, 920, 4750, 220, 9.1 on cash, savings1, savings2, credit, and transaction fees, respectively.

Based on the user's strategy for EFTPOS payment, scenario 3 will yield (186, 500, 5170, 220, 11.6). If the user has equal weights for the attributes, then taking the weighted sum of the balances will give an optimum of 1135 corresponding to alternative action a1 (see second to the last row, column 2). If the user, on the other hand, has the following criteria weights (0, 0.6, 0.2, 0, 0.2) then the best payment option will be by credit card with a weighted sum of 1500 (last row, column 3).

### 4.1.2 Learned Strategy

When the user chooses to overrule predefined strategy, scenarios can be identified by implementing soft computing methodologies and intelligent technologies to derive rules from the transaction history. User registration is sometimes not appealing to the user, especially when lots of details need to be manually incorporated into the system. Soft computing and intelligent technologies such as rough sets (Pawlak and Slowinski 1994), case-based reasoning and Bayesian networks (Schiaffino and Amandi 2000), fuzzy logic (Nasraoui and Petenes 2003), neural networks (Chen and Chen 1993, Jennings and Higuchi 1992) and clustering techniques (Kim and Chan 2003) may be used to learn about the user's payment strategy in the past. We refer to such strategy as *learned strategy* in Figure 4.

Consider for example the transaction history from the past year. Scheduled direct debit/credit payments with fixed amounts (health insurance, car loan, salary, other income), or variable amounts (e. g., grocery, petrol, gas and electricity bills, phone bill) can be detected from the transaction history (see column 3 of Table 1). Note that some rules may be deduced by simple sorting of transaction dates or by type of transaction. Variable amounts can be estimated using simple statistical forecasting techniques. Other implicit rules such as the user's decision to not use the credit card a week before credit payment is due; or the user's weight preferences (e. g., maximizing savings2 is more important than minimizing transaction fees); or the user's rule-of-thumb when there are insufficient funds to pay an unscheduled, emergency purchase, can be derived using more-complex intelligent technologies.

What is interesting in learning about the user's payment strategy based on transaction history is that the system can reproduce how the user made decisions in previous occurrences. Thus, the system can recommend solutions based on the user's context, memory and experience, and potentially can target the user's needs.

### 4.1.3 Expert Strategy

The expert strategy will correspond to a strategy based on expert's advice without considering the user's context, but taking into consideration external factors such as credit card interest rates, bank fees, foreign exchange rates, home loan rates, market prices, government policies, end-of-season discount rates and special offers, that directly or indirectly affect the future evolution of events. Such a strategy can be provided by financial advisers and analysts, risk managers, and other experts in the mobile commerce, e-commerce, and financial services or acquired dynamically from other external "expert" sources.

By embedding expert advice, the user can also learn if his/her payment strategy is non-optimal or unsatisfactory and can be advised of better ways to achieve his/her goals. By embedding an expert strategy in the system, we can raise the level of decision support offered by mobile services by providing the user with expert advice based on external factors, or generally based on context changes that are beyond the user's control. For more-complex online or mobile financial services, such as portfolio selection (Parkes and Huberman 2001), building scenarios based on expert strategy can be very useful in supporting the mobile user.

An expert strategy that might be suitable for the proposed mobile accounts management problem is that of comparing a scenario that considers future gains if a purchase is made today against scenarios where the purchase is made tomorrow, or at the end of the season, or even at the end of financial year. Thus, if credit interest rates are expected to increase by tomorrow, or if car service fees will be lower next winter, or fees are at their lowest at the end of financial year, then the mobile user potentially will be better informed of what might happen in the future, and which scenario is likely to best address his/her needs.

## 4.2 Quality of Data Model for Mobile Account Manager

Due to the inherent uncertainty in using scenarios to select the best option today to realise future gains, mobile decision support can be made more reliable if the user is made aware of the QoD that supports the decision. The QoD indicator, as described in section 2.2, is based on the assumption that the user will be aware that the recommended solution is based on transaction history for a given period (e. g., one year, six or three months) and he/she will be aware of how complete, accurate and current the data is being used to support his/her choice.

The attributes for QoD metrics relating to energy, security, and connectivity for technology-related contexts, stability of scores and weights for user's decision model, and those derived based on user contexts, as well as completeness, currency, and accuracy of historical contexts, are well applicable in mobile financial decision making. In the same way these metrics can be calculated by comparing current data with standard or historical data. For example, completeness of historical data can be considered as a fraction of complete account data available at some particular date when making particular decision. Currency can be calculated based on current time and frequency of transaction updates. In this section we focus on how using historical context attributes can assist mobile decision maker in QoD assessment for better, more-accurate decision support.

### 4.2.1 Historical Context

Using this sample mobile accounts problem, we can come up with suitable measures for completeness, accuracy, and currency of data from transaction history.

- *Completeness* – part or fraction of the complete data. In our sample of accounts management problem, completeness is a fraction of a complete transaction statement for a given time frame. If a purchase is to be made today, and it is the $17^{th}$ of the month, we can say that the transaction history we have available is 52% complete (because we had a transaction history for 16 out of 31 days of the month). When purchase is to be made on day 28, four days before the next transaction statement is issued (i. e., 28/31 is approximately 0.90 in a 31-day month), then we can say that the transaction history is about 90% complete. Thus for all the scenarios from Table 1, the transaction history used to support the choice is 52%.
- *Currency* – determines how current today's purchase is relative to the nearest critical date. By critical date, in this case, as was defined above, we mean a date when balances need to be updated, such as credit card payment due date (as in scenario 1, Table 1), the date when a credit limit will be reached (as in scenario 2), or a date when transfer of funds is expected to incur a transaction fee (scenario 3). The data will be more current if the purchase date is close to the nearest critical date. Thus from Table 1, we can say that scenario 3 is most current, as payment by EFTPOS today will immediately incur a transaction fee. The currency scores for three scenarios are calculated based on the following formulae:

$$\text{currency of data \_Scenario1} = \left(1 - \frac{\text{9 days to nearest critical date}}{\text{15 days to end of month}}\right) = 0.40$$

$$\text{currency of data \_Scenario2} = \left(1 - \frac{\text{2 days to nearest critical date}}{\text{15 days to end of month}}\right) = 0.87$$

$$\text{currency of data \_Scenario3} = \left(1 - \frac{\text{1 day to nearest critical date}}{\text{15 days to end of month}}\right) = 0.93$$

- *Accuracy* – number of correct transaction values/total number of transactions until the next update. For our example, in scenario 1 in Table 1, we have four fixed payments out of nine expected transactions until the nearest critical date (the remaining five transactions (in bold font) are predicted values). Thus, if payment is by cash, then the data from transaction history is 100 * (4/9)%, approximately 44% accurate. For scenarios 2 and 3, the data is 100% accurate.

Based on historical context, the QoD can be represented as a weighted sum of completeness, currency, and accuracy. If we assume equal weights, then history-related QoD measure is 0.45 (45%) for scenario 1, 0.80 (80%) for scenario 2 and 0.82 (82%) for scenario 3. Based on the proposed QoD framework, if equal criteria weights are used and alternative a1 is recommended as the best option (see Section 3.2) and QoD is only 45%, it is up to the mobile user to accept or reject the recommended solution. A 45% QoD can indicate that the critical date is too far in the future to accurately predict the likely balances at the end of the month.

These measures are used as illustrations only and could be adjusted in other contexts if necessary. In the same way the formulae for calculating the completeness, currency, and accuracy of data can vary depending on the user's preferred definition. It is important that the user understands how such QoD indicator is calculated to ensure its meaningful consideration in their decision making. Thus by recommending to the user that the best option is to pay by credit card and that the associated QoD is about 80%, he/she can interpret this as a high quality recommended solution, relative to the transaction date.

### 4.2.2 User-Related and Technology-Related Contexts

If the mobile user can be supported online, the user can download a transaction history that is complete, current, and accurate. In this case, prediction is likely to be more accurate than when using outdated and incomplete data. However, there is also a need to inform the user of technology-related QoD parameters or attributes such as network security, connectivity, and mobile device energy to guarantee a secure and stable environment to perform online transaction. To date, networked-wide infrastructures for supporting wireless connectivity (Zaslavsky 2002) and network security (Reis et al. 2003, Ghosh 1998) have been developed and proposed to handle uncertainties due to unreliable communications and possible disconnections from the network. The approach considered in this chapter is focussed more on modelling these uncertainties by providing technology-related QoD parameters.

If the mobile user is offline, the completeness, accuracy and currency of the data will be calculated by considering the last time transaction history was downloaded from or synchronised with the user's online banking server. In both cases, when the user is relatively consistent with his/her purchases and payment strategies, or when external factors indirectly influence the user's choice, the scores of alternatives against criteria can be fairly *static* (Hodgkin et al. 2003) for the rest of the month. If the user is inconsistent with his/her purchases, or if the system has not learned enough from user's profile and transaction history, the evaluation scores can be fairly *dynamic*. Equivalently, if external factors can directly impact on future evolution of events, the evaluation scores can also be dynamic. Thus aside from completeness, accuracy, and recency of data, we can also consider stability of data as a user-related QoD parameter. We can classify the first three parameters as QoD attributes related to historical context; stability of data as a user-related parameter; and security, connectivity and energy as technology-related QoD parameters. The overall QoD measure can then be derived as the weighted sum of user-related, history-related, and technology-related parameters (Hodgkin et al. 2003, Cowie and Burstein 2006).

# 5 Mobile Accounts Manager

In this section we describe how the proposed approach to mobile accounts management can be implemented using mobile devices. We call our prototype mobile decision support tool, iAccountsMgr. Sample user interface designs for PDA implementation are shown in Figure 5.

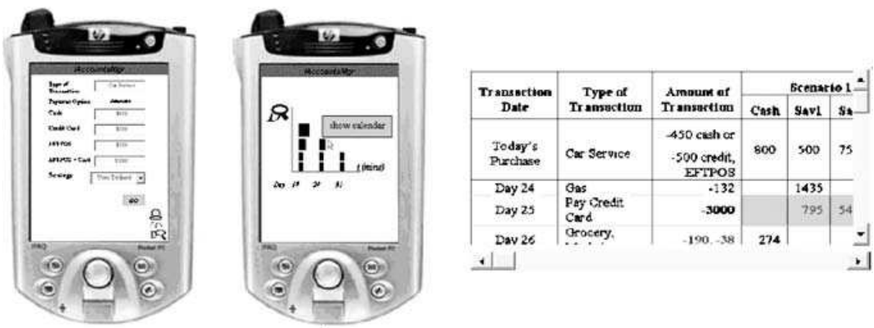
In Figure 5a, the required user inputs are the type of transaction and purchase amounts corresponding to alternative payment options. The user must also identify the strategy (user, learned, or expert) to be used by the system for scenario building. A tap on the GO button will instruct the system to retrieve the multiple accounts of the user based on user's profile, present them as criteria, and prompt the user to specify weights using a slide bar. A tap on the GO button in Figure 5b will instruct the system to select the best payment option based on the user's specified weights and chosen strategy. Figure 5c presents the recommended payment option and the expected balances at the end of the month.

The icon on the lower right of each of Figures 5a–c represents the overall QoD. It indicates the quality of data that is available for the decision support procedure in producing a recommendation to pay for the product/service today, using transaction history that is locally available in the system. The measure of QoD is visually represented here as a bar graph. One bar indicates a very low QoD while four bars indicate a very high QoD.


a b c

**Figure 5.** Sample user interface for iAccountsMgr

When QoD is critically low, the QoD bar is replaced by a QoD bell with sound alert as shown in Figure 6a. The predicted QoD for selected days (e. g., day 24 or 31 in Figure 6c) can also be visually represented as shown in Figure 6b.




a b c

**Figure 6.** QoD indicators and calendar in iAccountsMgr

This QoD graph gives an overall view of possible changes in QoD over time. Selecting one of QoD bars will display a calendar indicating expected transactions, expenses, and fees from the selected day until the end of the month. The user may then bypass some predefined settings or rules as desired and new predictions can be calculated.

# 6 Conclusions

Decision support tools for real-time decision making are in high demand especially when users need to make informed decisions in time-critical situations (O'Leary, 2007). In this chapter we reviewed the technologies available for providing mobile decision support in such situations. Due to the demands and opportunities of mobile computing, most context-aware computing applications are relying on mobile information access which results in high uncertainty level. Real-time access to information does not always sufficiently support decision-making activities. In this perspective, we exploit the possibility of extending context-aware computing to context-aware mobile decision support.

In this chapter we review the current approaches available for providing mobile decision support. The challenges and limitations faced by developers of such systems are highlighted. In attempting to address today's dynamic requirements to mobile systems, we propose a framework by which information provided by a mobile DSS can be evaluated and assessed in terms of its usefulness and relevance for the decision being made.

The application area of mobile accounts management is described as a means for illustrating how such a framework could be utilised. A prototype system, iAccountsMgr is designed to provide mobile decision support for this area. The proposed procedure aims at providing a mobile user with on-the-spot assistance for decision making concerning the payment method for products and services aiming at efficient management of the periodic (monthly) budget. Equipped with the proposed system, the user will be able to assess the future consequences of a choice, and alerted about the implications when buying an item on the move, or before charging emergency purchases against her bank accounts. The main innovation of the mobile DSS is that together with calculating possible scenarios the system provides a measure of reliability – the QoD – to each scenario according to the data used in calculating these scenarios. We feel that combining strategic information related to the decision at hand with a measure of the quality of the information (the QoD indicator) provides the decision maker with the ability to make a better informed choice based on the most up-to-date, relevant information available.

The realities of the changing way in which we make decisions and the advances in mobile technology create multiple challengers for decision makers and computer system developers alike. Making decisions on the move under uncertainty requires decision support systems that can adequately provide up-to-date, context-specific, complete information in a way that is understandable and useful to the decision maker. We believe that by embracing the technologies that facilitate mobile decision support and capitalizing on well-founded methodologies for representing decision-maker's context, whilst accommodating a measure of the quality of the data and information decisions on the move can be supported just as effectively as those made behind the desk.

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**Table 1.** Scenarios associated with payment options

| Trans-action date | Type of transaction | Amount of transaction | Scenario 1: Pay by cash | | | | | Scenario 2: Pay by credit card | | | | | Scenario 3: Pay by EFTPOS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Cash** | **Sav1** | **Sav2** | **CCard** | **TFees** | **Cash** | **Sav1** | **Sav2** | **CCard** | **TFees** | **Cash** | **Sav1** | **Sav2** | **CCard** | **TFees** |
| Today's purchase | Car service | −450 cash or −500 credit, EFTPOS | 800 | 500 | 7500 | −2500 | 0 | 800 | 500 | 7500 | −2500 | 0 | 800 | 500 | 7500 | −2500 | 0 |
| Day 17 | Car loan | −245 | 350 | 255 | | | | | 255 | | −3000 | | | 188 | 7067 | | −2.5 |
| Day 18 | Health insurance | −60 | | 195 | | | | | 195 | 4500 | 0 | −2.5 | | 128 | | | |
| Day 19 | Grocery | **−190** | | | | −2690 | | | | | −190 | | | | | −2690 | |
| Day 20 | Phone | **−128** | | 67 | | | | | 67 | | | | | 0 | | | |
| Day 21 | Petrol | **−30** | | | | −2720 | | | | | −220 | | | | | −2720 | |
| Day 22 | Market | **−38** | 312 | | | | | 762 | | | | | 762 | | | | |
| Day 23 | Pay salary | 1500 | | 1567 | | | | | 1567 | | | | | 1500 | | | |
| Day 24 | Gas | −132 | | 1435 | | | | | 1435 | | | | | 1368 | | | |
| Day 25 | Pay credit card | **−3000** | | 795 | 5420 | 0 | −2.5 | | 1215 | | 0 | | | 795 | 4920 | 0 | −2.5 |
| Day 26 | Grocery, market | **−190, −38** | 274 | | | −190 | | 724 | | | −190 | | 724 | | | −190 | |
| Day 27 | Other income | 250 | | | 5670 | | | | | 4750 | | | | | 5170 | | |
| Day 28 | Petrol | **−30** | | | | −220 | | | | | −220 | | | | | −190 | |

**Table 1.** Continued

| Transaction date | Type of transaction | Amount of transaction | Scenario 1: Pay by cash | | | | | Scenario 2: Pay by credit card | | | | | Scenario 3: Pay by EFTPOS | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | **Cash** | **Sav1** | **Sav2** | **CCard** | **TFees** | **Cash** | **Sav1** | **Sav2** | **CCard** | **TFees** | **Cash** | **Sav1** | **Sav2** | **CCard** | **TFees** |
| Day 29 | Mobile, market | **–50, –38** | 236 | 745 | | | | 686 | 1165 | | | | 686 | 745 | | | |
| Day 30 | School | **–500** | 0 | 481 | | | | 186 | | | | | 186 | | | | |
| Day 31 | Car loan | –245 | | 236 | 5406 | | –2.5 | | 920 | | | | | 500 | | | |
| End-of-month balance | | | 0 | 500 | 5406 | –220 | –11.6 | 186 | 920 | 4750 | –220 | –9.1 | 186 | 500 | 5170 | –220 | –11.6 |
| Weighted sum (.2, .2, .2, .2, .2) | | | | | | | 1135 | | | | | 1123 | | | | | 1123 |
| Weighted sum (0, .6, .2, 0, .2) | | | | | | | 1379 | | | | | 1500 | | | | | 1332 |

# CHAPTER 42
# Context-Sensitive Decision Support Systems in Road Safety

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Enterprises often embed decision-making processes in procedures in order to address issues in all cases. However, procedures often lead to sub-optimal solutions for any specific decision. As a consequence, each actor develops the practice of addressing decision making in a specific context. Actors contextualize decision making when enterprises are obliged to decontextualize decision making to limit the number of procedures and cover whole classes of decision-making processes by generalization. Practice modeling is not easy because there are as many practices as contexts of occurrence. This chapter proposes a way to deal effectively with practices. Based on a conceptual framework for dealing with context, we present a context-based representation formalism for modeling decision making and its realization by actors. This formalism is called contextual graphs and is discussed using the example of modeling car drivers' behaviors.

**Keywords**: Context; Decision making; Contextual graphs; Knowledge management

## 1 Introduction

Decision makers face a very large number of heterogeneous contextual cues. Some of these pieces of information are always relevant (time period, unpredicted event, etc.) while others are only used in some cases (number of lines on the road, position on the line, etc.). Thus, actors must deal with a set of heterogeneous and incomplete information on the driving situation state to make their decisions. As a consequence, a variety of strategies are observed for driving situation solving; these differ from one actor to another, but also at different instants with the same actor. Thus, it is not obvious how to obtain a comprehensive view of the mental representations at work in the subject's brain in many human tasks.

This situation is not new. In artificial intelligence, the lack of explicit representation of context is one of the reasons for the failures of many knowledge-based systems (Brézillon and Pomerol 1997). In most real-world applications, a decision maker faces ill-defined situations where the form of the argumentation rather than the explicit decision proposal is crucial (Forslund 1995). As a consequence, it is better to store advantages and disadvantages rather than complete decisions.

Procedures are diagnosis/action plans elaborated according to technical constraints, security, and service rules. Each procedure explains how to treat a particular state of driving behavior. As the goal of the highway code is to cover a large class of driving situations, procedures are poorly contextualized deliberately. For example, the announcement of a crossroad is given by a unique road sign whatever the real topology of the crossroad (a cross, an X, a T, a Y, or a more-complex intersection). However, procedures are dependent on the operational environment, the type of people who operate them, the culture of the society they live in, and the nature of the driving situation. Procedures are not inherent to, or predicable by, any single entity. As a consequence, actors adapt procedures in order to deal with the complexity of the situation. The actor establishes a strategy that is based on procedures and a set of contextual cues depending on the actor's experience and the situation characteristics. Such a practice is a kind of compilation (or contextualization) of a procedure in which knowledge pieces and contextual cues are structured into comprehensive knowledge about actions [a chunk of knowledge, as discussed by Schank (1982)]. In contrast to procedures, practices are highly contextualized, and may introduce new sub-strategies not foreseen in the corresponding procedure.

Actors in an enterprise plan their action in real time rather than relying on procedures for two main reasons. Firstly, the procedure is never perfectly adapted to the situation at hand and can lead to improper actions or sub-optimal solving strategies. Secondly, the actor may miss some important facts and notice them too late to solve the problem adequately. Nevertheless, actors consider procedures useful guidelines to be tailored for each particular focus. Thus, each actor transforms the procedure into a practice to address a focus in a specific context, and one observes almost as many practices as actors for a given procedure. This is a general way to reach the efficiency that decision makers intended when designing the task (Pomerol 2001). Such know-how is generally built up case by case and is complemented by makeshift repairs (or unwritten rules, magic books, etc.) that allow actors to achieved the required efficiency. This is a way of getting the result irrespective of the path followed.

As a consequence, the process of decision making relies on practical reasoning that depends on a number of pieces of contextual knowledge and information. Practical reasoning is not logical and theoretical reasoning, for which the action leads to a conclusion. Practical reasoning is more similar to inductive probabilistic reasoning: the conclusion cannot be detached from the premises. Modeling actors' reasoning is a difficult task because a number of contextual elements are used. These pieces of knowledge, which are not necessarily expressed, result in more or less proceduralized actions that are compiled in comprehensive knowledge about actions.

Context plays an important role in domains where reasoning intervenes, such as decision making, understanding, interpretation, diagnosis, etc. These activities rely heavily on a background or experience that is generally not made explicit, but gives an enriched contextual dimension to the reasoning and the knowledge used in the reasoning. Context is always relative to a focus: the context of the reasoning, the context of an action, the context of an object, etc.

In this chapter, we present contextual graphs, a context-based formalism for representing reasoning. Contextual graphs are used in a large spectrum of domains such as medicine, ergonomics, psychology, defense, information retrieval, computer security, road safety, etc. A common factor is that enterprises establish procedures to guide such reasoning. Procedures are collections of secure action sequences developed to address a given focus in any case. These procedures are decontextualized in order to cover a large class of similar focuses (generally differing by their contexts of occurrence), e. g., the procedure to follow when a driver arrives at a crossroad, whatever the details of that crossroad are.

Hereafter, this chapter is organized in the following way. The next section introduces the idea of context in the decision-making area. We firstly describe a conceptual framework for modeling context, secondly we present the contextual-graphs formalism implemented in this framework, thirdly an example in road safety is described, and fourthly we present the building of the proceduralized context that is key for decision-making processes in this approach. In the following section, we discuss the consequences of the proceduralized context building for learning. First, we show that contextual graphs lead to the creation of bases of experiences for intelligent systems. Another important aspect concerns the possibility to represent good as well as bad practices in a contextual graph. We finally present the perspectives opened by a context-based approach to decision making.

# 2 Context in Decision Making

## 2.1 A Conceptual Framework for Modeling Context

We cannot speak of context out of its context. Context surrounds a focus (e. g., the decision-making process or the task at hand) and gives meaning to items related to that focus. Thus, on the one hand, context guides the focus of attention, i. e., the subset of common ground that is pertinent to the current task. Indeed, context acts more on the relationships between the items in the focus than on the items themselves, modifying their extension and surface. On the other hand, the focus allows the identification of the relevant elements to consider in the context. It specifies what must be contextual knowledge and external knowledge in the context at a given step. For example, a focus on the driving task mobilizes contextual knowledge such as knowing the meaning of the traffic signs, knowing how to drive, etc., i. e., knowledge that could eventually be used when the focus evolves. Knowledge from a driver's personal context could also be considered, such as previous experience with the driving task. For example, this corresponds to the choice of a specific method at a given step of a task. To solve a driving situation, a driver has several solutions, e. g., several behaviors for crossing an intersection. Indeed, some contextual elements are considered explicitly, say for the selection of the behavior, and thus can be considered part of the way in which the problem is solved at the considered step.

The focus evolves along with the execution of a series of actions, resulting in the decision-making process that is adopted. As a consequence, the context of the focus also presents a dynamic system as external events may also modify the context of the focus. Focus and context are therefore interlocked.

Contextual elements selected for the focus are more or less significant for the focus at a current step. Thus, context has a granularity that depends on the distance of contextual elements from the focus. Such a view allows an actor to address local questions such as, “Must I brake now or not?” but also more-global questions such as “How far is the next service station?” Several paths are explored (fisheye views, focus plus context, etc.). Brezillon et al. (2000) used the metaphor of an onion with central eyes (the focus) and skins (layers of contextual elements). Information surrounding the focus follows the rule that, the greater the distance of the information from the focus, the less interesting it must be for it to be shown. Thus, it is possible to view local details and global context simultaneously. Moreover, contextual elements generally intervene in several types of decision making and thus provide a network between different types of decision making. Such a domain ontology would be associated with the reasoning representation.

In reference to a focus, Brézillon and Pomerol (1999) consider context as the sum of two types of knowledge. First, there is the part of the context that is relevant at this step of decision making, and the part that is not relevant. The latter is called ***external knowledge***. External knowledge appears in different sources, such as the knowledge known by the decision maker, but is implicit with respect to the current focus, the knowledge unknown to the decision maker (out of his competence), contextual knowledge of other actors in a team, etc. The former part is called ***contextual knowledge***, and obviously depends on the decision maker and the decision at hand. Here, the focus acts as a discriminating factor between the external and contextual knowledge. However, the frontier between external and contextual knowledge is porous and moves with the progress of the focus.

A sub-set of the contextual knowledge is proceduralized for addressing the current focus specifically. We call this the ***proceduralized context***. The proceduralized context is a sub-set of the contextual knowledge that is invoked, assembled, organized, structured and situated according to the given focus and is common to the various people involved in decision making. A proceduralized context is quite similar in spirit to the chunk of knowledge discussed in SOAR (Schank 1982, Laird et al. 1987), and, in its construction, to Clancey’s view (1992) on diagnosis as the building of a situation-specific model. A proceduralized context is like a local model that accounts for a precise goal in a specific situation (at a given step). In an approach reminiscent of cognitive ergonomics (Leplat and Hoc 1983), we could say that contextual knowledge is useful to identify the activity whereas the proceduralized context is relevant to characterize the task at hand (i. e., it is concerned with the activity).

Because a contextual element can itself become a temporary focus (thus, with its context), we meet McCarthy’s observations (1993) on context: (1) A context is always relative to another context, (2) contexts have an infinite dimension; (3)

contexts cannot be described completely; and (4) when several contexts occur in a discussion, there is a common context above all of them into which all terms and predicates can be lifted. The main conclusion to retain for a decision support system is that one must consider only the contextual knowledge in the system, the external knowledge staying out of the system, and the system must have a mechanism for the incremental acquisition of the missing knowledge from the decision maker when the system fails (i. e., when the system does not possess the needed knowledge). We will come back to these points later in the chapter.

Another important issue is the passage of elements from contextual knowledge to a proceduralized context. This proceduralization process, which depends on the focus on a task, is task oriented just like the know-how, and is often triggered by an event or primed by the recognition of a pattern. This proceduralization process provides a consistent explanatory framework to anticipate the results of a decision or an action. This consistency is obtained by reasoning about causes and consequences, and particularly their relationships in a given situation. Thus, we can separate the reasoning between diagnosing the real context and anticipating the follow up (Pomerol 1997). The second step requires conscious reasoning about causes and consequences.

A second type of proceduralization is the instantiation of contextual elements (see also Grimshaw et al. (1997) for a similar observation). This means that the contextual knowledge or background knowledge needs further specifications to fit the decision making at hand perfectly. The precision and specification applied to the contextual knowledge is also part of the proceduralization process that leads from the contextual knowledge to the proceduralized context. For each instantiation of a contextual element, a particular action will be executed. There are as many actions as different instantiations. However, once the corresponding action is executed, the instantiation does not matter anymore, and the contextual element leaves the proceduralized context and goes back to the contextual knowledge. For example, arriving at a crossroad, a driver looks at the traffic light. If it is a green signal then the driver will decide to cross. The instantiation of the contextual element "traffic light" (green signal) has guided the decision-making process and then the decision was made. The color of the traffic light does not matter after the decision is made.

## 2.2 A Context-Based Representation of Decision Making by Contextual Graphs

In previous work for incident management in a subway area (Pomerol et al. 2002, Brézillon et al. 2003), we showed that context-based reasoning has two parts: diagnosis and action. The diagnosis part analyzes the situation at hand and its context to extract the essential facts for the actions. The actions are undertaken in a foreseen order to realize the desired task. Sometimes, actions are undertaken even if the situation is not totally or even partially analyzed, for example, when a driver puts their vehicle into gear before any action or situation analysis. Other actions are carried out before the proceduralization of part of the contextual knowledge. Thus, diagnosis and actions constitute a continuous interlocked process, not two distinct and successive phases in context-based reasoning. Moreover, actions introduce changes in the situation or in the knowledge about the situation, and imply a revision of the diagnosis, and thus of the decision-making process itself. Note that our view of context-based reasoning is at a finer granularity than Gonzales and Ahlers's view (1998), as shown in a comparison of the two context-based formalism made elsewhere (Brézillon and Gonzales 2006).

Contextual graphs propose a representation of this combination of diagnosis and action (a contextual graph represents a problem-solving situation). Diagnosis is represented by contextual nodes. When a contextual node is encountered, an element of the situation is analyzed (and the value of the contextual element, its instantiation, is taken into account). Thus, contextual graphs allow a wide category of diagnosis/action representations for a given problem-solving situation.

Contextual graphs are acyclic due to their time-directed representation and guarantee algorithm termination. Each contextual graph (and any sub-graphs in it) has exactly one root and one end node because the decision-making process starts in a state of affairs and ends in another state of affairs (not necessarily with a unique solution for all the paths), and the branches express only different context-dependent ways to achieve this goal. This gives a general structure of a spindle to contextual graphs. A path represents a practice developed by an actor, and there are as many paths as practices known by the system.

The elements of a contextual graph are: actions, contextual elements, sub-graphs, activities, and parallel action groupings (Brézillon 2005). An action is the building block of contextual graphs. A contextual element is a pair of nodes: a contextual node and a recombination node. A contextual node has one input and *N* outputs (branches) corresponding to the *N* instantiations of the contextual element. The recombination node is [*N*, 1] and represents the moment at which the instantiation of the contextual element does not matter anymore and the paths of all the branches starting at the contextual node are identical. Sub-graphs are themselves contextual graphs. They are mainly used for obtaining different displays of the contextual graph by aggregation and expansion, like in Sowa's conceptual graphs (2000).

An activity is a particular sub-graph that is identified by actors because it appeared in the same way in a different problem-solving situation. An activity is defined in terms of an actor, situation, task, and a set of actions. More precisely, an activity is a sequence of actions executed, in a given situation, to achieve a particular task that is to be accomplished by a given actor. In the decision-making area, an activity is identified by actors as a recurring structure in problem-solving situations. This recurring sub-structure is a complex action in the spirit of the notion of scheme given in cognitive ergonomics (Vergnaud 1985), where schemes are intended for the completion of sub-goals. Each scheme organizes an activity around an object and can call on other schemes to complete specific sub-goals. A scheme can be specified by a name, a goal, and a contextual graph, representing a decision that allows the achievement of its goal in a context-sensitive way. Both contextual graphs and schemes allow the representation of actors' activity and all their variants (procedures and practices), the integration of automatic learning and adaptation in a system, a clear representation of the context in actors' reasoning, and the organization of the actors' activity itself.

A parallel-action grouping expresses the fact (and reduces the complexity of the representation) that several sub-graphs must be crossed before continuing, but the order in which sub-graphs are crossed is not important; they may even be crossed in parallel. The parallel-action grouping could be considered as a kind of complex context. We will discuss this point later in the chapter.

## 2.3 Example of the Behaviors of a Car Driver in Contextual Graphs

Brézillon et al. (2006) give the example of the situation at a crossroad to show the expressiveness of contextual graphs (see Figure 1). The situation concerns two cars; a black car going straight ahead and a white car at a give-way sign that plans to turn right. The study is lead according to the viewpoint of the black car's driver (and not from the external viewpoint of an observer), and the paper discusses five scenarios from this situation in a situation space and in a contextual graph. We only consider here the second representation of the driver's behavior in contextual graphs, as given in Figure 2 and Table 1 (square boxes, *Ai*, represent actions, and circles represent contextual elements with a contextual node, *Ci*, and a recombination node, *Ri*).

Each path represents a behavior of the driver of the black car in a given scenario (digits are in circles). Note that a given behavior can appear in different scenarios and several behaviors can appear in a given scenario.

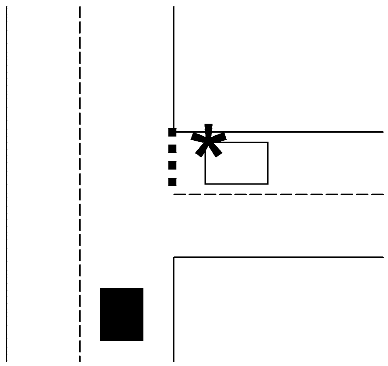

**Figure 1.** A crossroad situation

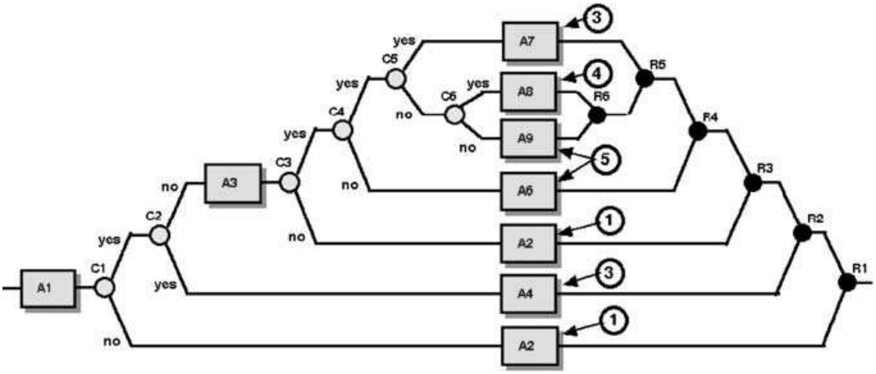


**Figure 2.** A contextual graph of the crossroad situation solving

**Table 1.** Contextual elements and actions while dealing with a crossroad in Figure 2

| Contextual element | |
|---|---|
| C1 | Car coming from the right? |
| C2 | Does the other car have priority? |
| C3 | Is the other car coming down my road? |
| C4 | Can I avoid the other car? |
| C5 | Is it sufficient to brake? |
| C6 | Can I overtake the other car on the left? |

| Action | Definition |
|---|---|
| A1 | Detect a crossroad |
| A2 | Keep the same behavior |
| A3 | Keep the same behavior and be careful |
| A4 | Let the other car go ahead |
| A6 | Announce my coming to the other car |
| A7 | Brake to reduce speed |
| A8 | Overtake the other car |
| A9 | Brake strongly |

## 2.4 The Interaction Between the Decision and its Context: Proceduralized Context Building

When a contextual element moves in the proceduralized context, this element is considered through one instantiation. The proceduralized context (PC) is contextual knowledge that is explicitly used at the current focus. For example, action *A7* in Figure 2 is executed because the contextual element *C5* is instantiated with the value “Yes”, and thus explicitly intervened in the focus (i. e., the selection of action *A7*).

In Figure 2, the fact that the white car coming from the right of the black car has a give-way sign is a contextual element of the graph (the instances of the contextual elements *C1* and *C2* are “Yes” and “No”, respectively). Thus, the driver of the black car has priority over the white car. With the identification of the contextual elements concerned and their specific instantiations, the black car’s driver solves the crossroad situation, say, for the upper path of Figure 2 by:

*A1* – *C1*(Yes) – *C2* (No) – *A3* – *C3*(Yes) – *C4*(Yes) – *C5*(Yes) – *A7*

with the situation solved through the sequence of actions *A1* – *A3* – *A7*, and the proceduralized context leading to action *A7* through the sequence of instantiated contextual elements: *C1*(Yes) – *C2* (No) – *C3*(Yes) – *C4*(Yes) – *C5*(Yes).

In a contextual graph, a proceduralized context is an ordered set of contextual elements that fit into each other like a nest of dolls (Russian dolls). As a consequence, the practice development first leaves the last contextual element entered. For example, once the action *A7* has been executed, the instantiation of the contextual element *C5* does not matter anymore. Then, the instantiation of *C4* does matter, etc. Thus, what is important is not so much the collection of contextual elements, but the way in which they are related and ordered in practice to allow their execution. Note that this ordering of the contextual elements depends on the practice development by an actor, and cannot be obtained from the domain ontology. Thus, representations in contextual graphs are experience based.

Once used, a proceduralized context is not lost, but it goes into the body of contextual knowledge from which its elements come. This is not simply a chunk of contextual knowledge that is stored, but is all the ways in which this proceduralized context has been built, the reasons behind the choices (the contextual elements considered and their instantiations), the alternatives abandoned (the instantiations not retained in a practice and the corresponding abandoned actions), etc. The proceduralized context is totally integrated into the body of contextual knowledge. This is a kind of learning that results in an accommodation process. The proceduralized context could be recalled later either as a whole (as a part of a new proceduralized context) or explained in terms of the way in which it has been built and can be reused in the new proceduralized context. This is a type of learning through the structuring of the contextual knowledge; the more experienced a person is, the more they possess the available structured knowledge (i. e., chunks of contextual knowledge).

# 3 Learning and Context-Based Decision Making

## 3.1 Experience Bases for Intelligent Systems

By the uniform representation of elements of reasoning and of contexts, contextual graphs offer a mechanism through which to learn the way in which all these elements (reasoning and contexts) are assembled in practice. By using a context-based representation, an intelligent assistant system (IAS) will address the building of experience more directly than simple knowledge building. This is why we call such systems context-based intelligent assistant systems (CIASs), and this is now our concern in the design process in road safety. Our objective is to develop a CIAS for the support of continuous training of car drivers, essentially like apprentices but also later, as their experience develops, by contextualization of the highway code learned at car school. For such CIASs, contextual graphs allow the development of experience-oriented knowledge bases.

The knowledge base of the CIAS is developed in two steps: (1) by a short elicitation of knowledge from operators and a use of reports, books, and related matter, and (2) an incremental enrichment of contextual graphs by interaction with actors. This approach has the advantage of rapidly providing a mockup that can be improved progressively. This is a kind of incremental acquisition of new knowledge pieces where knowledge is acquired as needed and in its context of use, as well as learning new strategies when an actor's reasoning relies on a new practice (i. e., a new path in the contextual graph). Such systems present a smart solution to one of the main weaknesses of prior systems, namely the lack of the ability to evolve.

Anticipatory capability is enhanced in a representation by contextual graphs because a CIAS is able to develop a reasoning that is more directly related to the real situation, not in a mechanical way like with a procedure. Thus, the support of an actor concerns elements of reasoning and contexts and how all these elements are assembled in practice. An anticipatory system uses knowledge about future states to decide what action to take at the moment. It should be able to predict what will probably happen, and alert the driver to the occurrence of a crucial or time-critical event and its consequences. An anticipatory capability supposes a simulation component in the system. Simulation is also a way for a system to provide explanation by contextualizing its reasoning.

An efficient system supports actors by dealing with practices and not only procedures. This supposes that such systems can use a context-based representation of the knowledge and of the reasoning for problem solving. As a side-effect, CIASs are able to rationalize the solutions that they propose to the actors. They can explain at different levels of detail the rationale behind the solution, as operators are generally interested in the contextual cues behind a fiven solution. Because contextual graphs organize knowledge at a high level, the intelligent assistant system expresses its knowledge and reasoning in a form that is directly understandable by the actors.

## 3.2 Learning

Contextual graphs offer a solution to Henninger's claim (1992) that "you won't know what is really needed until you're in the design process," because contextual graphs include a natural process for incrementally acquiring missing knowledge and jointly learning new practices. Incremental knowledge acquisition and practice learning intervene in contexts in which the system fails, i. e., where the contextual graph does not include the correct practice. Incremental knowledge acquisition plays an important role in two situations:

- When the knowledge is missing in the current context, and the user adds new knowledge through explanations that enable the contextual knowledge to be proceduralized.
- A chunk of knowledge may be used incorrectly by the system because a link to the current context is missing. Here, incremental knowledge acquisition must focus on the refinement of the proceduralized context, and explanation can support that refinement.

Gathering and using knowledge in the context of use greatly simplifies knowledge acquisition because the knowledge provided by experts is always in a specific context and is essentially a justification of the expert's judgment in that context.

Several approaches have been proposed to acquire knowledge in context. We give here two examples. Firstly, Compton and Jansen (1988) proposed to capture the context by entering the expert's new rule only when it is necessary to refine a rule. More precisely, when a rule fails to identify a piece of expertise, the expert is requested to give some additional knowledge or a new rule. The new rule is directly related to the rule that failed and the expert is reminded of that failed rule because it gives the context for writing the new one. Secondly, Gruber (1991) considers justification-based knowledge acquisition. The machine provides the computational medium, including the knowledge representation and the context of use, such that everything acquired from the user can be assimilated into the computational model. The dialogue is directed by the machine, which can thus provide a frame to fill up, allowing some kind of syntactic checking and ensure that all required parameters are given.

The main idea of these approaches is that experts provide their knowledge in a specific context, and that knowledge can only be recorded with its context, that is, the system acquires the new knowledge and the context in which this new knowledge is required. Thus, knowledge is not generalized when it is acquired. It is fundamental to record the context in which the knowledge is acquired and can be used. In other terms, the expert provides a triplet {problem, context, solution}, when for early expert systems the knowledge engineer generalized by a pair {problem, solution} in a more-general context that could be different from those in an expert's mind.

Sometimes, the building of a proceduralized context fails for a given focus and new (external) knowledge is needed. This leads to: (1) an incremental acquisition of new contextual elements and actions to execute in this instantiated context, and (2) the learning of a new practice. Acquisition and learning occur in a specific context that is acquired and learned jointly with the new knowledge. Indeed, learned practice and acquired knowledge can be considered two aspects of a learning process that is an assimilation process, because this corresponds generally to a process of refinement of contexts. Moreover, if the addition of a piece of external knowledge in the proceduralized context correspond to knowledge acquisition, it is nevertheless a learning process because the piece of external knowledge is not simply added to the proceduralized context, but assembled and connected to the construction that already exists. Thus, it is later possible to explain and justify each practice or item in the contextual graph.

This triple aspect — context growth by integration of external knowledge in the proceduralized context building, by integration of a new chunk of knowledge in the contextual knowledge, and context change by the movement between the body of contextual knowledge and proceduralized contexts — are dynamic aspects of context (Brézillon 1994). This dynamic component is generally not considered in the literature and explains why making context explicit in an application is a difficult task, except if we restrict context to what can be obtained by sensors, as in context-aware applications.

## 3.3 Learning Good and Bad Practices in Car Driving

Storing experience-based situations in contextual graphs leads to the development of a set of corporate memories, with each corresponding to the collection of all practices developed for the solving of a situation. The next step is the design and development of an intelligent assistant system that would be able to use such a structured knowledge base to provide the actor with experience-based support, in contrast to early expert systems that used flat knowledge bases built from explicit knowledge or heuristics.

By their mechanism of incremental knowledge acquisition and practice learning, contextual graphs allow the collection of all the ways of solving a problem. This is the policy followed in various real-world applications, such as applications for solving incidents on a subway system (Pomerol et al. 2002, Brézillon et al. 2003) or for the retrieval of information (Brézillon 2005). In our current application for the training of car drivers, we explore a new use of contextual graphs by considering the correct practices provided by the highway code (the behaviors of good drivers), but also the bad practices executed by novices, bad drivers, or drivers under the influence of drugs (Brézillon et al. 2006). Our interest in storing bad practices in contextual graphs is to allow a CIAS to identify online the current behavior of a driver and anticipate the consequences of the scenario chosen by the driver. Rich data are available concerning road accidents in a number of situations (for the modeling of bad practices). We are currently identifying the behaviors of drivers based on previous work (GADGET 1999), data provided by INRETS (Bellet 2005, van Eslandre 2001), and a questionnaire. The next step will be to couple the contextual graph of the behaviors of drivers (i. e., their decision-making process) with the corresponding situation space to identify scenarios of good and bad behaviors. For training, the system will propose a scenario with a critical driving situation learnt from bad drivers, and interact with the driver-player to help him make the right decision in the pre-critical situation where the driver still has the option to achieve a normal resolution. In more-general terms, this leads to a game in which the system knows the different ways that lead to a good decision as well as those leading to a known bad decision. In the latter case, the CIAS will have the means to anticipate critical situations and explain the mistakes of the apprentice, which are generally misinterpretations of contextual cues.

Other variants will be considered later. We study the representation of a given situation solved by all the drivers in a unique contextual graph to focus on all the practices developed by drivers, independent of their experience. Another approach is to represent each driver's view (and all the practices imagined by the driver in the solving of a situation), according to his experience, familiarity with driving, etc. Then, a contextual graph corresponds to the solving of a problem by an actor. All these contextual graphs can then be classified according to the experience of the driver, from the complete novice to the very experienced driver (we are currently testing this approach on the simple decision to buy a subway ticket, which is solved by different people who are more or less knowledgeable about the Paris subway system). The two approaches could lead to two views on a driver's behavior: a personal view on his personal evolution in his contextualization of the theoretical knowledge, and a collaborative view of the driver interacting with other drivers.

## 4 Conclusion

We propose contextual graphs for the uniform representation of elements of reasoning and contextual elements at the same level. This is different from the views of, for example, Campbell and Goodman (1988) and Hendrix (1975) for semantic networks, that consider context as a way to partition a graph. Moreover, context in our formalism intervenes more at the level of the links between elements of reasoning than the elements themselves. As contextual elements are organized in contextual graphs in the spirit of a nest of dolls, there is no hierarchy of context, because a given contextual element is itself contextualized and can appear encompassed in other contextual elements. Rather, a contextual element is a factor of knowledge activation.

A contextual graph is a kind of micro-corporate memory that provides a knowledge base that is more experience than goal oriented. Contextual graphs are the experience-based representation of the knowledge and reasoning needed by intelligent systems. Relying on contextual knowledge and the possibility to acquire automatically most of the contextual information, an intelligent system is able to: (a) identify a user's intention, (b) simulate (in accelerated time) the execution of the user's decision to anticipate consequences, (c) compare theoretical and user behaviors, and (d) alert the user either of a wrong decision (by lack of the right context) or of a discrepancy in planned and effective outcomes of the decision.

There are several problems still open from both a theoretical and practical point of view.

First, we note that the contextual elements considered in a contextual graph constitute a heterogeneous population that is difficult to represent in a hierarchy or ontology. A contextual element can concern the actor (e. g., I prefer a secure solution to a risky one) but does not belong directly to the domain of application. The representation of a set of such (heterogeneous) contextual elements is a challenge.

Second, a contextual element may itself be a chunk of contextual knowledge, where underlying, more-basic contextual elements intervene. For example, a contextual element such as “Must I respect the traffic light yellow?” may cover (sub-)contextual elements such as “I am in a hurry,” “I have room and time to cross,” etc. The challenge here concerns modeling of a contextual element at a finer granularity and perhaps by extension modeling of parallel action groups.

Third, the introduction of parallel action groupings (PAGs) simplifies the representation of contextual graphs. A parallel action grouping generally represents (as a simplification) a complex entanglement of contextual elements corresponding to a low level of description of the problem solving modeled in the contextual graph. In the popular example of coffee preparation given in UML manuals, it is said that we must use the coffee and the filter in one order or the other (or in parallel). However, depending on the type of coffee machine (e. g., one which requires that we take it apart to fill the reservoir with water), the piece of the coffee machine where the filter must be placed can be independent of the coffee machine, mobile within the coffee machine, or fixed directly into the machine. Each situation would be considered independently, but all situations will conclude with the unique action of putting the coffee in the filter. Thus, instead of making a complicated contextual graph to represent this (natural) complexity, which is at a lower level of detail, we use parallel action groupings.

Fourth, an activity is a sub-graph identified by actors as a recurring structure appearing in several contextual graphs. The introduction of activities relieves the representation by contextual graphs by introducing a sub-contextual graph and leading to a network of contextual graphs, i. e., of problem solving. However, the most interesting observation here is the fact that the notion of activity allows simplified interaction among actors, one actor giving the name of the activity and the other actor developing the activity. For example, turning right is an activity that a car driver translates into turning the indicator on right, looking behind to insure that the following car is not too close, braking to reduce speed, looking at pedestrians crossing the other road, etc.

Fifth, a proceduralized context is perceived as a chunk of contextual knowledge leading to the choice of an action to execute. However, the contextual elements intervening in this proceduralized context, their instantiations, and their relationships will remain available. This leads to the possibility of generating rich explanations, and even of new types of explanations like the way in which a contextual graph grows from the initial procedure to the last practice introduced.

Context plays a role in many types of reasoning, and notably in decision making. Making context explicit in the representation of a decision-making process allows the integration of incremental knowledge acquisition and practice learning as part of the process of decision making. Moreover, contextual graphs offer the possibility of representing good as well as bad practices, are a tool for learning all the ways of solving a situation (both good and bad practices), a tool for identifying behavior, and a tool for proposing a rational way to improve our behavior. This seems to us to be a first step towards an attempt to rationalize the decision-making process.

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# PART VII

# Scopes of Decision Support

# CHAPTER 43
# Personal Decision Support Systems

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Personal decision support systems (PDSS) are small-scale information systems that are normally developed for one manager, or a small number of managers, for an important decision task. They were the original form of using information technology (IT) to support management decision making. They remain the largest component of decision support systems (DSS) research and are used by most managers in corporations today. This chapter places PDSS in the history of decision support and identifies the unique nature of PDSS. It then describes the evolutionary approach to developing PDSS and illustrates PDSS concepts with two contemporary case studies. The chapter ends with comments on the current environment of PDSS.

**Keywords**: Personal decision support systems; Evolutionary development; Case study

## 1 Introduction

Decision support systems (DSS) are computer-based information systems (ISs) that are designed with the purpose of improving the process and outcome of decision making. There are many approaches to using information technology (IT) to support managers and executives. In practice the current emphasis is on the large-scale systems of business intelligence (BI) and data warehouses (DWs). The original approach to DSS was much smaller and therefore less complex. This approach can be termed personal decision support systems (PDSS). PDSS are relatively small-scale systems that are normally developed for one manager, or a small number of managers, for an important decision task. Despite the dominance of BI and DWs in the management support component of IT budgets in organizations, it may be the case that PDSS remains the most used form of decision support, particularly in the form of spreadsheet-based models.

This chapter addresses the nature of PDSS today. The chapter begins with a reflection of the place of PDSS in the history of IT-based management support. This is followed by a discussion on the general nature of PDSS with a focus on the differences between PDSS and operational information systems. One of these major differences, the use of evolutionary development, is then discussed in more detail. Next, two case studies are presented to illustrate the nature of contemporary PDSS. Finally, some concluding comments about the current environment of PDSS are offered.

## 2 The Place of Personal DSS in Decision Support History

This section is taken from the discussion of the history of all types of DSS in Arnott and Pervan (2005). There are a number of fundamentally different approaches to DSS and each has had a period of popularity in both research and practice. Each of these DSS types represents a different philosophy in terms of support, system scale, level of investment, and potential organizational impact. They may use quite different technologies and support different managerial constituencies. Figure 1, based on Arnott and Pervan (2005, Figure 1), traces the evolution of the field from its radical beginnings to a complex disciplinary structure of partially connected sub-fields. In the figure, the emphasis is on the theoretical foundations of each DSS type. The decades indicated on the left-hand side of the diagram refer only to the DSS types and not to the reference disciplines. Another dimension to the evolution of DSS not shown in the figure is

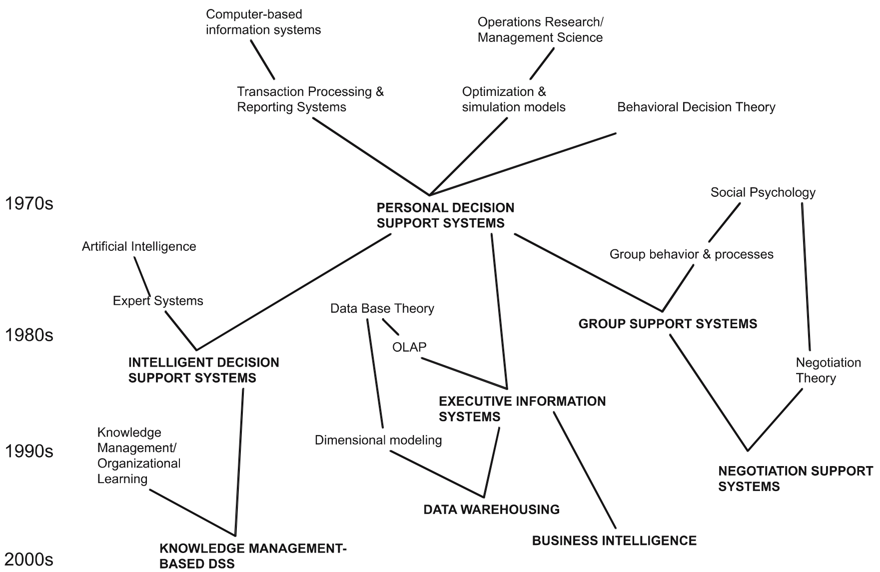


**Figure 1.** The evolution of the decision support systems field (source: Arnott and Pervan 2005, Figure 1)

improvement in technology, as the emergence of each of the DSS types has usually been associated with the deployment of new information technologies.

PDSS are the oldest form of decision support system and for around a decade they were the only form of DSS in practice. They effectively replaced management information systems (MISs) as the management support approach of choice in the 1970s and 1980s. The world of MISs was that of the Cold War and the rise of the multinational corporation. The focus of management in this environment was total integration, efficiency, and central control, and the large, inflexible MISs mirrored this organizational environment. The emergence of PDSS also mirrored its social and organizational environment. The 1960s and 1970s saw a radicalization of western society, especially in response to the Vietnam War. The emphasis was on empowering individuals and a democratization of decision making. PDSS followed this philosophy by supporting individual managers rather than attempting to support the more-nebulous concept of the organization. An important difference between MISs and PDSS was that PDSS were successful systems (Alter 1980). The technology that enabled the development of PDSS was the minicomputer (for example, Digital Equipment Corporation's PDP series) and relatively user-friendly software applications, especially financial modeling and database software. In the mid 1980s the personal computer and spreadsheet software further drove down the cost of technology and dispersed PDSS through all levels of management.

Table 1 is reproduced from Arnott and Pervan (2005, Table 7). It shows all types of DSS publishing from 1990 to 2003 in 14 major journals[1]. Details of the method, protocol, and selection of journals and articles can be found in Arnott and Pervan (2005). The table shows that PDSS research at 35.3% constitutes the largest part of DSS research. Although its share is declining over time as new decision movements emerge, in the most recent analysis period (2000–2003) it remains the largest area of DSS research, with 30.1% of articles.

In conclusion, PDSS remain an important aspect of IT-based management support in both academic research and contemporary organizations. Modern PDSS can source data from data warehouses and deploy powerful modeling approaches from management science/operations research. The current industry term for the latter class of PDSS is ***analytics*** (Morris et al. 2003).

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[1] The journals in the sample are: *Decision Sciences*, *Decision Support Systems*, *European Journal of Information Systems*, *Group Decision & Negotiation*, *Information & Management*, *Information & Organization*, *Information Systems Journal*, *Information Systems Research*, *Journal of Information Technology*, *Journal of Management Information Systems*, *Journal of Organizational Computing & Electronic Commerce*, *Journal of Strategic Information Systems*, *Management Science, MIS Quarterly*.

**Table 1.** DSS publishing 1990–2003

| DSS type | 1990–1994 | | 1995–1999 | | 2000–2003 | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Number of articles | % of period | Number of articles | % of Period | Number of articles | % of Period | Number of articles | % of Sample |
| Personal DSS | 144 | 38.1 | 150 | 35.5 | 66 | 30.1 | 360 | 35.3 |
| Group support systems | 108 | 28.6 | 126 | 29.8 | 64 | 29.2 | 298 | 29.2 |
| Executive information systems (EIS, includes BI) | 27 | 7.1 | 32 | 7.6 | 15 | 6.8 | 74 | 7.3 |
| Data warehouse | 0 | 0.0 | 2 | 0.5 | 11 | 5.0 | 13 | 1.3 |
| Intelligent DSS | 63 | 16.7 | 61 | 14.4 | 23 | 10.5 | 147 | 14.4 |
| Knowledge management-based DSS | 3 | 0.8 | 6 | 1.4 | 12 | 5.5 | 21 | 2.1 |
| Negotiation support systems | 6 | 1.6 | 18 | 4.3 | 17 | 7.8 | 41 | 4.0 |
| Many | 27 | 7.1 | 28 | 6.6 | 11 | 5.0 | 66 | 6.5 |
| Total | 378 | 100.0 | 423 | 100.0 | 219 | 100.0 | 1,020 | 100.0 |

# 3 The Nature of Personal DSS

In a sense PDSS are the purest form of IT-based management support. The classical view of PDSS is that in a project a systems analyst supports one manager for a particular decision task. A more-contemporary view is to focus on a DSS engagement, a project that involves a contract or relationship between manager/users and developers to deliver decision support capabilities. A particular engagement may focus on a major decision task but this could manifest in a number of smaller, discrete but interrelated tasks. Each of these smaller tasks can be supported by one or more IT applications. As a result, a modern PDSS engagement can have multiple clients and multiple developers.

What then is different about PDSS compared to operational ISs? Early in the history of DSS, Keen (1980) defined the environment of PDSS development. His characterization remains relevant today. Keen argued that for PDSS projects:

- Users do not know what they want and analysts do not understand what users need,
- The analyst and user cannot provide functional specifications,
- Users' concept of the task will be shaped by the DSS, and
- Users have the autonomy to tackle the tasks in a variety of ways.

This is a radically different environment to that of operational ISs. It requires different development approaches and different skills in the DSS analyst. The preferred PDSS development approach is described in more detail in the next section. However, what drives Keen's DSS environment is the nature of the client and user of a PDSS. PDSS users are normally senior or middle-level managers. They may also be business analysts that support these managers. Managerial users are discretionary and demanding clients. Unlike the users of operational systems, and even modern BI/DW systems, they can choose to use, or not to use, the PDSS. These users are organizationally powerful and can mobilize resources to support their needs from alternative sources, both internal and external to their organization. Typically, they see their decision support needs as urgent and are intolerant of delays in the delivery of PDSS capabilities. They are typically bright and talented knowledge workers who learn quickly. Operational ISs do not operate in such a dynamic environment. Finally, PDSS are difficult engagements for systems analysts because of the fragmented and varied nature of managers' working days (Mintzberg 1973). An analyst may only have 15 minutes access to a senior manager client at a time and these sessions may be fragmented over a working week.

## 4 The Evolutionary Development of Personal DSS

This section is based on part of Arnott (2004). The major contribution of PDSS to IS theory is evolutionary systems development. The notion that a DSS evolves through an iterative process of systems design and use has been central to the theory of decision support systems since the inception of the field. Evolutionary development in decision support was first hinted at by Meador and Ness (1974) and Ness (1975) as part of their description of middle-out design. This was a response to the top-down versus bottom-up methodology debate of the time concerning the development of transaction processing systems. Courbon et al. (1978) provided the first general statement of DSS evolutionary development. In what they termed an *evolutive approach*, development processes are not implemented in a linear or even in a parallel fashion, but in continuous action cycles that involve significant user participation. As each evolutive cycle is completed

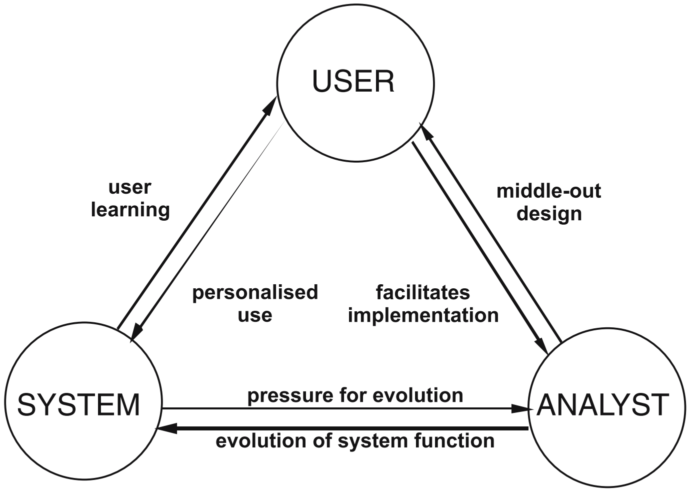


**Figure 2.** Keen's adaptive design framework

the system gets closer to its final or stabilized state. Keen (1980), building on Courbon's work, developed a framework or model for understanding the dynamics of decision support systems evolution. The approach proposed by Keen, shown in Figure 2, was termed adaptive design, although adaptive development is a more-accurate term, as the approach comprises development processes other than design. The importance of this work was to give the concept a larger audience; Keen (1980) remains the most cited and thereby the most influential description of the evolutionary approach to DSS development.

Sprague and Carlson (1982, Chapter 5), in an analysis of system adaptation and evolution, identified four levels of DSS flexibility: the flexibility to solve a problem in a personal way; the flexibility to modify a specific DSS to handle different problems; the flexibility to adapt to major changes that require a new specific DSS; and the flexibility to evolve with changes in technology. They believed that these levels exist in a hierarchy with technology-based evolution at the top. They argued that "DSS must evolve or grow to reach a 'final' design because no one can predict or anticipate in advance what is required. The system can never be final; it must change frequently to track changes in the problem, user, and environment because these factors are inherently volatile" (p. 132). Sprague and Carlson's ROMC (representations, operations, memory aids, and control mechanisms) design method was designed to provide this flexibility in DSS development. A number of cases have reported the use of the ROMC approach for PDSS evolutionary development (for example, Igbaria et al. 1996, Antes et al. 1998). In addition to the seminal works on DSS evolution by Courbon, Keen, and Sprague and Carlson, there have been numerous other contributions to the understanding of the evolution of DSS in general, some of which are highlighted in Table 2.

**Table 2.** Selected contributions to general DSS evolution theory

| Article | Contribution |
|---|---|
| Keen and Gambino (1983) | DSS adaptation occurs at the sub-task rather than the task level. This is a driver of system evolution. |
| Stabell (1983) | DSS evolution should take place in a tension between the descriptive and prescriptive views of the target decision. |
| Alavi (1984) | DSS prototyping yields higher utilization of systems as well as better designer and user attitudes towards the design process. |
| Young (1989) | Developed a three-stage DSS methodology whose final stage is iterative use, refinement, and assessment. |
| Arinze (1991) | DSS methodologies are a tool for reducing the unstructuredness of managerial decision making |
| Sage (1991) | Developed a seven-stage iterative DSS design methodology. Information requirements determination exists in all stages of the DSS development process and is likely to be the driver of system evolution. |
| Shakun (1991) | Used evolutionary development in group decision support systems. |
| Silver (1991) | Extended evolutionary theory by considering how DSS restrict or limit decision-making processes and how DSS can guide or direct a user's approach to the operation of the system. |
| Suvachittanont et al. (1994) | Extended Keen's adaptive design model to executive information systems. |
| O'Donnell et al. (2002) | Identified evolutionary development in commercial data warehousing methodologies. |
| Arnott (2004) | Developed a framework for understanding DSS evolution based on its etiology, lineage, and tempo. |

# 5 Two Case Studies of Personal DSS

In order to understand the nature of PDSS, and in particular the nature of evolutionary development of PDSS, this section presents two cases of PDSS that played significant roles in supporting major decisions by senior executives. The cases shared a common method, namely participant observation. The first case, relating to strategic decision making about an organization's new office building, is taken from Arnott (2004). The second case concerns supporting a strategic decision about the structure of a consulting company; it is taken from Arnott (2006).

## 5.1 Research Method

Both case studies used a single case design (Yin 1994, Chapter 2). The unit of analysis was the system development process. The selection of both cases was opportunistic. The data collection technique in both cases was participant observation (Cole 1991, Atkinson and Hammersley 1994). The main benefit of participant observation for these projects was gaining access to organizational processes (especially meetings and discussions) and people that would not have been possible in non-participant observation (Cole 1991). Most of the interaction between the projects' clients and the DSS developers was observed. Observations were recorded in running diaries and some sessions were audio recorded. Where possible, versions of the various IT-based systems were archived for later analysis. A condition of approval of the projects by the researcher's university ethics committee was anonymity for the organizations and subjects.

## 5.2 Case 1: Deciding on a New Office Building

Gamma, a large semi-government authority, was faced with a problem of housing its administrative staff. The current office accommodation was severely overcrowded and further staff were required to cope with a planned expansion of the Gamma's activities. Gamma had been housed in government-owned buildings and was charged very little in rent. However, as part of a new business-oriented budgetary strategy, the government had announced that it would be forced to sell some of Gamma's buildings to help reduce state debt, and further it would be forced to increase Gamma's rent to commercial levels. Gamma would also need to rent further commercial space at market rates for the planned staff expansion. Gamma's board and senior management felt that it should relocate all administrative staff to one large building, rather than have them scattered across a number of buildings. Gamma had two main options: rent an existing building or construct a building on suburban land already owned by Gamma. After much discussion the board (a very conservative body that liked Gamma to be in total control of its assets) decided upon the construction option. Historically all capital funds had been provided by the government, but in this case Gamma had been advised that, subject to ministerial approval, it would have to raise external finance for the new building.

A deputy director was given the task of submitting a proposal on the possible financing of the building to a board meeting scheduled for two months time. The deputy director, like other senior managers in Gamma, had been internally promoted and had little experience in the competitive financing of large capital projects. A common practice for a manager in such a situation would be to hire a financial consulting firm to analyze the situation and provide a recommendation of the preferred strategy. The deputy director related that he was unhappy with such an approach even though it may have been the easiest course in terms of his current workload. He felt that some expertise in such matters should be developed by Gamma, as he was sure that commercial decisions relating to large projects would be increasingly required in the new corporate-like public sector environment.

The deputy director contracted a DSS consultant to assist him in preparing the proposal for the board. On the DSS consultant's advice, two further authority staff were assigned to the project: Gamma's financial controller, who at 55 had been in the public service all his working life, and a systems analyst from Gamma's information systems department. The systems analyst was a recent graduate with degrees in information systems and accounting. The DSS consultant came to the building project with ten years of experience in developing information systems for management. He saw his role as training authority staff in DSS development and facilitating input from a number of experts.

The DSS consultant and the deputy director jointly decided that the first step was to make a construction cost estimate for the new building. A computer model was developed (after three major revisions) that would calculate the cost of construction of an office building, given a variable number of floors, usage patterns, car parking, and other factors. The data for this model turned out to be easily available from both internal (square meters per staff member, number of staff) and external sources (publications with various building costs, service area ratios). Although the deputy director fully understood the model and co-developed it, he was not completely confident of the validity of the cost estimates. The DSS consultant suggested a test strategy whereby the specifications of a number of alternative buildings would be valued by the DSS. The same specifications were provided to a real-estate valuer experienced in estimating large building costs. The estimates of the valuer and the DSS closely agreed. The Deputy Director then went from a state of skepticism about the accuracy of the decision support system to a state of considerable overconfidence.

The validation of the building cost model marked the end of the first stage of the project. The team's attention then focused on determining the size of the building that was required by Gamma. The systems analyst conducted questionnaire-based surveys of Gamma's departments to determine their accommodation requirements. This data was stored in a personal computer database application. Care was taken to point out to departments that their responses were the first stage in a longer planning process and that the main reason for collecting the data was to determine the feasibility of a new building and not to allocate the space that departments would actually move into. The deputy director reviewed the responses and changed them according to his view of Gamma's future, increasing some, decreasing others.

To assist in deciding upon the general nature of the new building, a computer assisted drafting system was used. This part of the project was carried out at the architecture department of a local university. With the help of an architect, the deputy director was able to construct rough models of the required building. The areas of different components of the building were automatically calculated by the software. These figures were then input to the validated building cost model. The building cost model outputs, which included data required to evaluate running costs and possible rental revenues from potential non-authority tenants, formed the base data for the next stage of the project.

The third stage of the project involved developing a series of financing models around a number of alternative strategies. As the deputy director and the financial controller considered new financing concepts, the models were revised by the DSS consultant and systems analyst. This in turn stimulated more changes to the models, including the building cost model. While the financial controller was a charted accountant and was the team member with most financial experience, it was felt that an external financing expert's input was important. A finance consultant was engaged on an ad hoc basis and was present at a number of model-building and analysis sessions. The deputy director was pleased with the format of this expert input, as he and the financial controller had clarified the financing problem before the consultant was brought in and consequently felt in control of the process. The deputy director commented that he was getting maximum return for the finance consultant's time and was therefore reducing the cost of such service.

After six weeks, the board prematurely requested a briefing paper on the new building. Fortunately the deputy director had already developed some clear strategies. Together with the managing director of Gamma, the deputy director was able to present these strategies to the board using information generated by the DSS. The deputy director's ability to expertly brief the board at short notice was a major visible payoff of the DSS approach. Had he adopted the approach of delegating the task entirely to an external consultancy it is unlikely the he would have been able to provide the briefing. In fact, he could have presented something to the board after three weeks because of the evolutionary nature of the development. Following the briefing the board approved a financing strategy for the new building. The recommended building was a large high-rise building with retail space on the lower floors and office space on the upper floors. Some office floors would be rented to external organizations in the medium term but would be used in the future to house Gamma's long-term expansion.

The DSS project was considered to be successful by all stakeholders. The deputy director was not only satisfied with the outcome of the building project; he was convinced that the decision support approach was appropriate to other strategic decision tasks. The board and Gamma's managing director also praised the project in the board meeting's minutes.

## 5.3 Case 2: Restructuring a Consulting Firm

This case used a systems development method that conceives DSS development as the interaction of three cycles: initiation, analysis, and delivery. During initiation cycles the general problem area or decision is defined, resources allocated, and stakeholders engaged. Analysis cycles involve understanding the decision task and diagnosing aspects of the task that can be supported by IT. The delivery cycles involve iterations of designing, constructing and using the IT-based DSS.

Delta Consulting is a business services firm whose services include strategic consulting, project management, training, and IT development. These areas reflect the interests of the founders, who mostly came from an academic environment, except one, who came from a large multi-national consulting firm. Delta has five office staff and 26 principal consultants. When required, external contractors are employed for specific projects. The service and product portfolio of Delta was under formal review by the board of directors. All areas of the company were profitable, although the training area was barely breaking even. The board had commissioned an external consultant (who was not considered a competitor) to review Delta's performance and prospects. His report recommended that Delta maintain its core activities of strategic consulting and project management at the current level. He recommended that the training area be closed and that a strategic alliance with a specialist training provider be investigated. He argued that the time and energy that Delta would save from this alliance could be devoted to the IT development area, which he believed had a huge potential for revenue growth. Delta's training services involved 19 courses that ranged from half-day to three-day programs. Most of Delta's consultants were involved in training but the only full-time employee in the area was the training manager. The board considered the external consultant's report and other briefing information and after fifteen minutes of discussion there was a general feeling that the closure of training services was a desirable strategy, although no final decision was taken. The possible closure of the training area was flagged as an item for detailed discussion and decision at a board meeting in two months time. After the meeting the managing director began to have reservations about the external consultant's recommendation and the prospect of Delta not having a training function. At this time the board meeting to consider the training area closure was five weeks away.

### 5.3.1 First Initiation Cycle

Although the managing director had to formally recommend a course of action to the board, he had the strong impression that the decision was largely his and that the Board would probably adopt his recommendation, as it had on numerous other occasions. However, with only five weeks available, he was unsure of the correct strategy. To help his decision process he engaged a consultant systems analyst to develop a DSS, triggering the first initiation cycle of the project. He had no firm idea about what support he needed, just that he needed more information and more options. There was no need for the analyst to explicitly address unfreezing the decision-making process as the manager had effectively unfrozen himself when he identified the need for specialist support. The decision problem can be classified as a possible application error (Kahneman and Tversky 1982) in that the managing director was a competent decision maker but was faced with a decision situation that he had not encountered before. The analyst and the managing director discussed a development strategy that would challenge the managing director's. approach to decision making. This strategy has been termed active decision support (Keen 1987). The analyst began the first analysis cycle with a number of unstructured conservations with the managing director. He studied the financial documentation that was presented to the board, as well as the external consultant's report.

### 5.3.2 First Analysis Cycle

The project then moved from working on planning and resourcing the DSS to the diagnosis of problems with the decision task. The training closure decision was modeled using functional decomposition (Avison and Fitzgerald 1995, p. 62) and influence diagrams (Bodily 1988). During this analysis, it became clear that the confirmation bias was likely to have a major negative impact on the decision, as the information available to the board seemed to strongly support a closure strategy. The confirmation bias acts against a fundamental principle of the scientific method, which holds that information that refutes a hypothesis is more valuable than information that supports it. However, under the confirmation bias, people tend to search for information that confirms their hypotheses and gloss over, or even actively ignore, disconfirming information (Evans 1989, Russo et al. 1996). Following this, the analyst undertook a series of semi-structured interviews with the managing director to elucidate the hypotheses or propositions that were addressed by the managing director and the board when the prima facie case to close the training area was made. The information sources known to be used by the managing director and the board were then attributed to the various propositions and the information was classified as being confirming, disconfirming, or neutral. As can be seen in Table 3, virtually all of the information was found to be confirming in nature.

**Table 3.** Information used by the board for the prima facie closure decision

| Information | Type | Source | Decision impact |
|---|---|---|---|
| Profit and loss statements (year-to-date and last two years) | Quantitative | Office manager | Confirming |
| Report on the future of Delta Consulting | Qualitative | Consultant's report | Confirming |
| Revenue and expenditure forecasts (Total company, next three years) | Quantitative | Consultant's report | Confirming |
| Revenue and expenditure forecasts (By divisions, next three years) | Quantitative | Consultant's report | Confirming |
| Course attendance history (last three years) | Quantitative | Training manager | Neutral |

During this diagnostic activity the analyst began to develop a vague idea of what sort of DSS could help the managing director; it would probably have a data focus, rather than a model focus, but it would probably not be a standard database application. This vague speculation about the information system marked the start of design activities in the engagement. The next event in the project was deeply symbolic. Rather than refer to the project as the training closure decision, through a number of conversations, the analyst convinced the managing director to rename the project the training area evaluation. This neutral reframing of the decision task was noticed and commented on by a number of company staff. It was the first time that they knew the training area closure was not a done deal, and that the managing director was considering other strategies. The analyst described the nature of the confirmation bias to the managing director and briefed him on the results of the information stream analysis. They mutually decided to develop a system that would attempt to reduce the effect of over-confirmation in the target decision. A search for possible disconfirming information was undertaken, led by the managing director and assisted by Delta's office manager. Much of this information was of a qualitative nature and was included in documents such as office memos and consultant performance reviews.

### 5.3.3 First Delivery Cycle

The first delivery cycle produced a DSS, which became known as the intelligence system. The system was named by the managing director. It was constructed using hyperlinked documents on a dedicated personal computer; in essence it was an unpublished web site. The document navigation tree was based on the decision influence diagram and a hierarchy chart of identified hypotheses. In this way, the theory of confirmation bias was used to provide the physical structure of the information system. Financial statements and other board reports were pasted into the relevant documents, as was relevant disconfirming information. The system was then used by the managing director to explore the training area decision. All other board members were given access to the system. While the document structure implied which information sources could be used to arrive at the decision, the system did not force a set retrieval pattern on the user. The developer inserted as many hyperlinks as possible into each document to allow users to follow hunches that were triggered by system use. While using the system, the managing director repeatedly asked for additional information to be added, as did another director who briefly used the system. These minor delivery cycles significantly increased the amount of information contained in the intelligence system but did not significantly change the logic or structure of the system.

### 5.3.4 Second Initiation Cycle

While using the intelligence system, the managing director developed new ideas about the role of the training area. He began to wonder if training was generating business for the other areas of Delta or if it was important in retaining clients. The possible presence of a cross-subsidy was difficult to assess as the additional business generated by the training activities could follow the initial work by a significant period of time, or be from a seemingly unrelated client because a person previously related to Delta through training could have changed employer. These ideas triggered the second initiation cycle of the project. The managing director called this second stage the subsidy system, because it emerged from his training cross-subsidy hypothesis.

### 5.3.5 Second Analysis and Delivery Cycles

The subsidy system was not a discrete decision support application or set of applications in the sense of the intelligence system. Rather, it is best described as a series of ephemera – ephemera in the sense that they existed sometimes for hours, sometimes for days, and were then discarded. This phase of the overall project was characterised by chaotic analysis and design cycles. Design cycles were much more numerous and used more human resources than the analysis cycles, although it was hard at times to tell when one cycle ended and another began. The people involved with the intelligence system were also involved with the subsidy system. The managing director was personally involved in virtually every DSS application and devoted significant time to the system. He indicated that the project was one of his highest priorities and asked to be interrupted if new reports became available. The analyst and system developers worked full-time on the project and at times their effort was augmented by a company IT consultant.

**Table 4.** Example applications from the subsidy system

| Question | IT-based decision support | Data sources | Non-IT based decision support |
|---|---|---|---|
| How many of our clients for strategic consulting were initially clients of the training area? | Databases | Client files, training mailing list | Managing director contacts selected clients |
| Is there a relationship between consultant participation in training and their consulting performance? | Databases, Spreadsheets | Sales data, consultant staff files, training evaluations, survey | Managing director has conversations with selected project leaders and consultants, formal survey of all consultants |
| What are the infrastructure and human resource costs of expanding IT development? | Spreadsheets | Generic building cost data, human resources budget | Office manager consults with office landlord |

The office manager was more involved in this stage of the project than for the intelligence system. Her main role was as data provider for models and databases developed by the development team. The applications that made up the subsidy system were organised around questions articulated by the managing director. Once a question was defined, the analyst and programmers built an information system as quickly as possible and populated it with data. Applications were developed using relational database and spreadsheet packages. Answering some of the questions involved non-IT support or data gathering, for example, asking a long-standing client about an issue at a business lunch to inform system development. Table 4 illustrates how the managing director's questions guided the development of the subsidy system applications. All of these applications were ephemeral in nature.

### 5.3.6 Recommendation to the Board

As a result of using the various applications that made up the subsidy system phase of the project, the managing director decided to retain the training area of Delta. He believed that consultants benefited significantly from the formalisation of knowledge and experience that was required to conduct a training course. He believed that this benefit manifested in increased consultant performance and in increased sales. That is, he believed that a significant cross-subsidy existed between training and the core consulting areas. He also discovered that the consultants enjoyed the training work and that this contributed to their decision to remain with Delta. This was an important finding because maintaining a high-quality staff establishment in the highly mobile consulting industry is very difficult. Using material from the decision support applications, the managing director prepared a paper for the board that recommended retaining the training function. As predicted, the board accepted the managing director's recommendation and resolved to investigate potential efficiencies in other areas.

## 5.4 Observations from the Case Studies

Both cases illustrate the DSS environment described in section 3 and the evolutionary development approach discussed in section 4. In both cases the problem areas were characterized by high levels of task equivocality (Daft et al. 1987). Both clients reacted to high equivocality by pursuing an active DSS approach to the engagements (Keen 1987). Both cases crossed a number of decision domains and both required the input of professionals from a number of fields. The managerial clients and users were very senior; they were intimately involved in the development process and actively shaped the nature of the PDSS applications; they directly used the applications and equated system success with their ongoing use of the applications. Both the Delta and Gamma engagements involved the development of a number of discrete but interrelated applications. These applications were constructed using a number of different technologies. In both cases there was significant and rapid evolution of the logic and scope of applications. The trigger of major evolutionary events was executive users learning about their decision tasks through the development and use of the PDSS. In both cases the PDSS project resulted in major changes in the decision processes of the users. Both projects had significant effects on the organizations.

The two cases discussed in this section are representative of modern PDSS. The appendix adds to the understanding of PDSS by providing references to a large number of academic papers published between 1990 and 2004 that involve the development and use of PDSS. The list in the appendix is not exhaustive. However, it comprises research from high-quality general and specialist IS journals and provides an reasonable sample of PDSS scholarship.

# 6 Concluding Comments

Personal DSS were the foundation of the DSS discipline. From this origin the field has blossomed into a number of support approaches and technologies that are institutionalized in modern organizations. However, PDSS remain an important part of most managers' working life The major intellectual contribution of PDSS to the parent discipline of information systems has been evolutionary systems development. PDSS are arguably the last home of bespoke development in commercial ISs.

While PDSS have a 30-year history in practice, contemporary PDSS are in many ways different to their forebears. These differences have been driven by sustained improvements in IT, particularly in processing power, data storage, and the Internet. However, while improvement in IT is fundamental in improvements in PDSS, two other factors have changed the PDSS landscape. The first is that senior executives are now sophisticated users of IT. In the 1970s and 80s the relatively low computer literacy of managers was the major constraining factor in what was possible with DSS. Many managers refused to use computers, seeing keyboards as a secretarial technology. The second factor is the mathematical ability of managers. Over the history of PDSS, business schools have been emphasising quantitative skills and the early graduates of these schools are now ascending to executive ranks. The executives can integrate complex analytical models into their decision processes.

The increase in the sophistication of IT use and mathematical ability and improvements in IT means that PDSS developers face a demanding development environment. They require more-sophisticated IT and IS knowledge, and skills than the original DSS developers and also require more-detailed business domain knowledge. The speed of the evolution of applications within an engagement is also likely to be faster. While a demanding environment, the development of contemporary PDSS can be a rewarding experience for both managers and analysts.

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# CHAPTER 44
# Developing Practical Decision Support Tools Using Dashboards of Information

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Over 50 years of research on how to support managers' decision making, numerous solutions have been proposed under a variety of banners, as discussed in the contributions presented in this book. One of the recent terms to have been proposed is Business Inteligence (BI), which aims at leveraging new technologies for the gathering, presentation, and analysis of up-to-date data about the firm's operations to top management. BI is largely distinguished from previous concepts by its reliance on new platforms and technologies (for instance web technologies) to provide nimbler solutions, more responsive to managerial needs than earlier types of systems. As part of BI, the concept of dashboards of information or digital dashboards has been revisited, notably by software vendors. This chapter explains in detail what dashboards of information are and how to develop them. It considers where business data come from and how to use them to support decision making with a dashboard. Using the concept of cognitive levels, it differentiates between different types of aplications of the dashboard concept. Finally, the chapter aspects of its activities and concludes presents an illustrative case study of a firm seeking to develop a nimble tool for measuring and understanding the key that it is the *content* of the dashboard and the *context* in which it is used that are the key elements in the process of developing a dashboard.

**Keywords**: Dashboards of information; Digital dashboards; Decision support systems

## 1 Introduction

Over the last 40 years of the evolution of Information Systems (IS) in business, IS specialists and managers alike have been attracted by the much-hyped potential of computer-based systems to provide answers to difficult managerial questions, as evidenced by the seminal paper authored by Russel Ackoff in 1967 and its provocative title "Management MIS-Information Systems." During this period, many waves of systems have been implemented in organizations that specifically aimed at meeting the information needs of the highest levels of management. Whilst some clear successes have been achieved under the name of Executive

Information Systems (EIS) as reported in the yearly publication "the EIS Book" (1989, 1990, 1991)—for instance the EISs developed at British Airways or at Phillips 66—a great deal of skepticism has also been evident as many applications developed for top managers fell into disuse after a short period or ended up being used by lower level staff instead of top managers. Throughout that time, it has remained evident that basic tools such as spreadsheets have formed the bulk of computer-based decision support (Fahy and Murphy, 1996).

Lately, further advances in technology have brought renewed enthusiasm for a rejuvenated form of Business Intelligence (BI) tools: information cockpits or dashboards of information (Dover, 2004; Gitlow, 2005; Paine, 2004). Whilst not new (paper based dashboards have been in use in firms for decades, all the way back to Singer's chart room in the early part of the 20th century), the concept has been given a new lease of life by the availability of new tools and technologies, mostly web-based and reliant on relational databases or multi-dimensional modeling tools (Business Tools, 2005; BPM Tools, 2005). However, there are signs that the BI story is similar in many ways to previous installments of decision support technologies with 40% of respondents to a recent study by the electronic forum *The Register* saying that the language used by vendors can often be ambiguous or confused, and a further 44% referring to vendors as creating an unhelpful mire of marketing speak around BI (Vile, 2007).

Indeed, whilst the concept of BI is comparatively simple—*a business management term that refers to applications and technologies used to gather, provide access to, and analyze data and information about company operations* (Wikipedia, 2007a)—vendors have ensured that a substantial overhead of jargon has been built into the BI debate. SAP® and Oracle® are now pushing the concept of *embedded analytics* and Vile (2007) describes how other vendors have rearranged older concepts such as cockpit, dashboards, data marts, and scorecards as part of the marketing efforts to promote their new portal technologies. According to Lock (2007), the problem is heavily compounded by the fact that vendors are pounding potential users (i. e., business managers) with their marketing efforts and make disproportionately small efforts to keep IT professionals adequately informed about their products creating a tension in many firms, especially small firms which cannot easily sink much time into experimentation with new BI technologies.

After providing a rapid exploration of the concept and definition of a dashboard of information, this chapter emphasizes the most important problems raised by applications of the dashboard concept to the provision of information to support the decision making of managers. To clarify these explanations, a case study of dashboard development in an organization is provided.

## 2 Understanding the Concept of a Dashboard

The concept of a dashboard of information has been proposed by analogy with other types of dashboards (e. g., a dashboard in a motorcar, the control room in a plant) to promote the development of very practical types of information systems that have a direct impact on key managerial activities, for instance, decision making and monitoring as well as group activities, such as collaboration. The analogy with the dashboard in a car in particular, has been proposed to explain how a simple collection of indicators provided to managers in a timely fashion can allow them to "drive the business" by scrutinizing broad areas of activity of their firm at a glance. Wikipedia (2007b) has proposed the following definition for the concept: *A digital dashboard, also known as an enterprise dashboard or executive dashboard, is a business management tool used to visually ascertain the status (or "health") of a business enterprise via key business indicators. Digital dashboards use visual, at-a-glance displays of data pulled from disparate business systems to provide warnings, action notices, next steps, and summaries of business conditions.*

Paine (2004) contends that rediscovery of the dashboard approach is linked to a need to cut through the ever-increasing volumes of data available in the corporate information systems. Schmidt (2005) argues that the emergence of the approach is a logical development of the use of balanced scorecard (BSC) activities, in a bid to make them more flexible to novel ways of measuring performance and to automate the overly costly and time-consuming approach to data preparation inherent in BSC. Nevertheless, dashboards of information are aimed at the same objectives as BSC, namely to enable the use of a balanced set of performance metrics to avoid overly narrow focus on financial and accounting measures of organizational performance that has characterized past attempts at capturing the essence of what makes organizations go well (Kaplan and Norton, 2000, 2004). Dashboards of information, however, provide a much more flexible approach, better suited to organizations of various shapes and sizes than the immutable four pillars of BSC—shareholders, customers, internal processes, and innovation & learning.

By contrast, Gitlow (2005) sees dashboards as a prolongation of the quality management philosophy (e. g., Deming's theory of management) aimed at improving both organizational results and organizational processes. Finally, Dover (2004) has noted that dashboards are derived from EIS and, that, like EIS, they were initially developed for individual managers, before gradually being extended to lower levels of management as a way to communicate about performance and improve the response of the organization to everyday problems (EIS was later reinterpreted as *Everybody's Information System*).

In reality, the concept of dashboards also owes much to the development of their engineering equivalents—especially control rooms—that are used in plants (e. g., power plants) to control complex production processes without the need for thousands of highly specialized operators or in situations where human operators could not survive an inspection as in the case of a nuclear power plant. The control room is a key concept because it allows operators to fully control and actively manage a dynamic process that they cannot see, touch, or hear directly. This aspect of the dashboard concept makes it particularly interesting to managers of business processes that span multiple functional areas and multiple sites, as in the case of multinational corporations, because of its inherent promise to allow them to control and manage what they cannot see.

Notwithstanding the definition proposed above, there is not total consensus in the literature when it comes to having a definitive definition of the concept of a dashboard of information, and this can be expected in a domain that has been traveled extensively by both academic researchers and software vendors for quite a number of years. This is confirmed by Vile's (2007) observations that there is some confusion in firms regarding BI tools, within both business manager and IT manager communities. Nevertheless, "bringing real-time operational performance monitoring to executives' desktops (…) compare(ing) an organisation's actual performance (…) to well defined measurable targets and communicate(ing) the results to all levels of the enterprise" (Schmidt, 2005; p. 29), delivering "at-a-glance summaries presented in highly visual and intuitive format so managers can monitor progress towards goals" (Dover, 2005; p. 44), or providing "a tool used by management to clarify and assign accountability for the critical few objectives, key indicators and projects/tasks needed to steer an organisation toward its mission statement" (Gitlow, 2005; p. 345) encapsulate the well-identified characteristics or trademarks of the dashboard approach.

Gitlow (2005) proposes some key intended benefits of the approach, including a focus on the entire firm rather than a fragmented view (a system's approach in a certain way) and a type of management that promotes cooperation, not competition because the trade-offs and relationships between the components of organizational success are better understood by all actors. Dover (2005) adds that the dashboard approach also ensures that "all managers have access to the same version of the truth" (p. 44). He goes so far as to contend that the dashboard approach has the potential to change the culture of an organization by transforming it into "a performance-accountable company" (p. 43). Arguably, it is worth noting that some of these benefits cannot reasonably be exclusively associated with a computer system and require much more than just a dashboard. Rather, they require the implementation of substantial organizational change. A well-managed dashboard project can then support these initiatives by providing the tools managers need to manage performance and allocate resources optimally.

Software vendors, of course, have not been slow to realize the potential of this concept and have devised and marketed products that can serve as toolkits for the development of dashboards, including ready-made objects in the shape of gauges dials, icons, traffic lights, and so forth. In the 1980s, Comshare®'s famous product Execu-View provided a very easy-to-use environment to exploit the most complex of multi-dimensional models developed on the firm's One-Up product and, in pre-GUI days, popularized the concept of "point and click" manipulation of data sets amongst top managers. Nowadays, Cognos® and Hyperion®, among others, offer leading-edge products that also aim to simplify the architecture side of dashboards by bringing together data from multiple sources seamlessly (Business Intelligence, 2005; BPM tools, 2005). These products are often-web based and the latest Cognos offering is characterized by its ability to develop "portlets" or small portals that provide alerts, metrics, graphs and so on in a way that is tailor-made for individual managers. Referring to this approach as “self service,” Cognos claim that its product can substantially reduce IT department involvement (Business Intelligence, 2005). This is evidence of the dangers highlighted by Lock (2007) (see our introduction) regarding the gap that is created between the buoyant discourse addressed to managers by BI products vendors and the paucity of information provided to IT specialists. Self-service systems that go wrong or begin providing incorrect information are not only a manager’s nightmare, they also quickly become an IT specialist nightmare when they are called to come and fix them without having had substantial input into their initial development or extension. Vile (2007) has characterized this phenomenon as a case of too many users “going it alone” with BI.

Thus, it remains true, now as much as ever, that the key element in a dashboard is not only the design of the interface (as many tool kits are available from software vendors to develop advanced dashboards with minimal programming expertise), but the enlightened selection, and accurate capture in the organization’s current data sources, of the critical indicators most useful to the business. Evidently, this requires collaboration between managers/users and IT specialists. This is an age-old problem as far as information systems are concerned, which has been discussed in relation to decision support systems, executive information systems, and generally any other types of system that have been proposed for managerial support since the 1960s (Abualsamh et al., 1990; Ackoff, 1967; Ballantine and Brignall, 1994; Cats-Baril and Huber, 1987; Gulden and Ewers, 1989; Keen and Scott Morton, 1978; Kleinmutz, 1985; Mintzberg, many dates; Paller and Laska, 1990; Rockart and Delong, 1988; Scott Morton, 1986; Wallenius, 1975; Watson et al., 1993; Wetherbe, 1993).

Despite years of research on how the work of managers can be supported by IT, developing computer systems that are ultimately adopted by top management has remained a complex and uncertain task. New technologies and new types of applications have come and gone, but information systems for executives raise specific problems, which have primarily to do with the nature of managerial work itself (Mintzberg, 1973), as they are intended to tackle the needs of users whose most important role is “to create a vision of the future of the company and to lead the company towards it” (King, 1985; xi), and with our failure to properly specify what problems we are trying to solve. Lest these observations be dismissed as outdated, they are in fact as accurate today as they were when they were printed. Evidently, computer-based systems can help with decision making and information dissemination, but managers also spend considerable effort in their role of “go-between,” allocating work to subordinates and networking with internal and external peers (Mintzberg, 1973; Kotter, 1984). How computer systems can be used for these activities is largely unknown apart from the use of computer-mediated communication media—for instance email, which has a long history of successfully supporting managers (Crawford, 1982), sometimes with unintended consequences (Lee, 1994).

Whether in a push or a pull scenario, whether dashboard developers provide indicators they have identified, or managers request some specific information, failure to discover the indicators that truly capture the essence of business activities will result in a dashboard falling into disuse no matter how advanced and useable the interface. The issue for researchers is therefore to work on providing methodologies that managers and developers can use to organize and structure their discussions towards an immediately useful system that can also evolve over time toward increasingly broad coverage of relevant topics for managers. Interestingly, Paine (2005) warns practitioners that picking the tools only comes in step 5 of her methodology, once all the analysis work has been completed. She adds that no design is final, however, as "making continuous improvements" is an imperative for a successful dashboard approach. Because of this clear need to develop improved expertise and methods for properly analyzing the problems that the dashboard approach is intended to solve, this chapter does not review mainstream literature on dashboards or empirically examine issues in their design. Rather, reflecting our concerns with the difficult tasks involved in developing actual systems that are used by managers at various levels in a firm, we consider where data come from and what they are then used for, and present an illustrative case study constructed specifically to explore how the concept of dashboards may be applied to the solution of a variety of organizational problems.

## 3 Where Data Come from ... and What They Are Used for

Data warehouses have been proposed as one method to provide unlimited data from a multitude of sources to a dashboard of information. Figure 1 illustrates how data warehouses can be developed as corporate repositories of data covering all, or a number of (in the case of a data mart), required areas. This diagram is very useful to grasp the practical complexities involved in trying to provide managers with broadly based decision support systems.

The left-hand side of the diagram illustrates where the data come from and the need to integrate data from as many sources as applicable. One problem of note that is not captured by this diagram must however be pointed out: even though with the latest advances in technology, data warehouses are able to obtain data from most systems (often at the cost of some labor-intensive tasks of coding and cleaning), there can still be a problem of latency when it comes to providing timely feedback on operational measures. Carton and Adam (2007) found that even for seemingly trivial data such as shipments and completed sales orders, large systems such as ERP systems begin to grind to a halt at the close of accounting periods when quarter-end figures must be known in real time with great certainty because stock markets around the world or at least shareholders may be expecting a timely announcement of profit figures (failing this, share prices may plummet) and managers are trying to meet the target figures set for them. In one

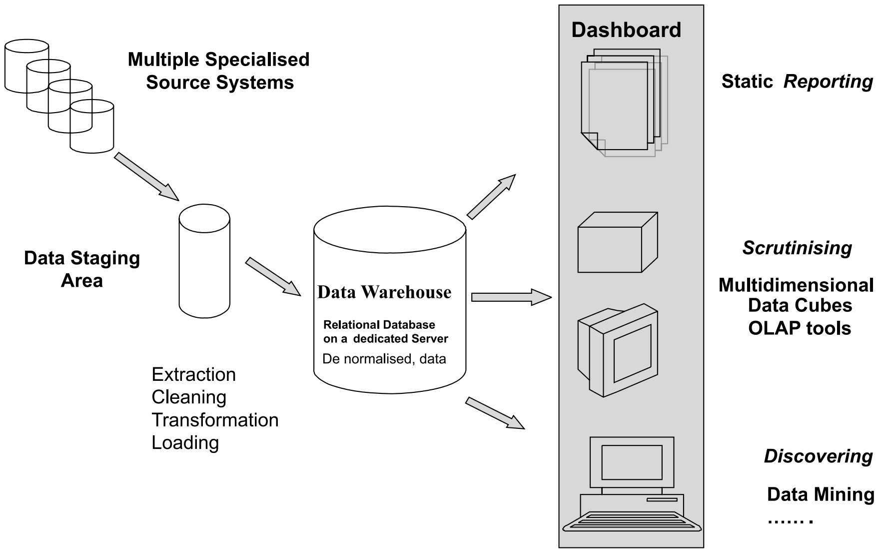



**Figure 1.** Data warehousing and decision support

firm, the headlong rush to meet targets was such that operators began working off the system on the last day of the period and a 32nd day had to be invented to allow them to catch up with the data entry corresponding to these transactions (without pushing them into the following accounting period, in which case they could no longer be counted as turnover in the period that had ended). As absurd as it may seem, it is the only way managers and IT specialists have found to solve the basic number-crunching problem they face which lengthened response times beyond what operators could cope with. In such situations, Transaction Processing Systems (TPS) cannot cope and fall behind; needless to say, data warehouses are even further behind as they are dependant on regular scheduled data uploads. So, although ERP and data warehouses are often put forward as the most robust basis for providing real-time data to managers, they raise further technical problems.

Thus, providing data access to managers is going to rely on data warehouses as described in Figure 1, but must also rely on more immediate access to data and even sometimes on paper-based documents and back-of-the-envelope calculations. Technical solutions exist to alleviate these problems—the mythical “on-line data warehouse” for instance, but they can be very costly over time and push organizations even further away from the nimble IS solutions they really need (Business Intelligence, 2005). These very “nuts and bolts” issues must be considered if managers are going to be given access to a “single version of the truth” (Dover, 2005, p. 44) that really is the truth!

The right-hand side of the diagram in Figure 1 shows what the data can be used for—that is, the three types of inquiry that can be conducted based on the data provided by a dashboard:

- *reporting*, when questions and answers are known and answers are monitored over time with the use of tightly restricted models that embody previous decisions and ways to resolve them,
- s*crutinizing*, where questions are known in broad terms, but are still difficult to ask precisely using incomplete models, and
- *discovering*, where questions are not even known at a specific level, in a complete absence of a model, or indeed even of a specific problem to solve.

The three decision support activities: *reporting*, *scrutinizing*, and *discovering*, presented in Figure 1 are practical from a developer's viewpoint because they correspond to levels of knowledge that an analyst can gain a priori about an informational need they are about to tackle. These three types of support must be matched against the level of understanding that managers have of the problems they face. Humphreys and Berkeley (1985) have usefully characterized this level of comprehension with their concept of *representation* levels. These five representation levels are a theoretical characterization of the evolution of managers' thinking as they make decisions. They are characterized by: (1) the degree of abstraction in the representation managers have about the problems to be tackled, and (2) the degree of formalization in the representations of proposed solutions and models to be built into the systems. The five representation levels are illustrated with Humphreys and Berkeley's (1985) description of the problem handling process:

1. At the highest level, representations are mainly cultural and psychological; managers are more or less aware of what a problem involves, but its expression is mostly beyond language. It is at this level that the problem is shaped; this is beyond the reach of any decision support system. Indeed, it is beyond any modeling endeavor.
2. At this level, the representations become explicit and the problem can be broken down into a number of sub-problems, some of which can be formalized. The structuration of the problems is still partial rather than detailed and managers refer to 'the marketing function' or 'the marketing process' without being able to formalize processes in greater detail. Data mining may be used at this level as a way to help formalize ideas to a greater extent and to test hypotheses. Some pre-models may be developed in broad terms by managers, but it is still difficult for them to discuss these with analysts.
3. At this level, decision makers are able to define the structure of the problems they must solve. They are able to put forward models that can be used for the investigation of the alternatives they will pursue and discuss these with analysts; these discussions can then be used to develop small applications leveraging OLAP tools or multidimensional tools.

4. At this level, the decision makers perform sensitivity analysis with the models they have defined in the previous stage so as to determine which input values are the most suitable; saved searches and saved views created using scrutinizing tools can become increasingly formalized over time and proceed from level 3 to level 4.
5. Finally, at the lowest level, managers decide on the most suitable values and the representation of the problem they must solve is stable and fully operational. At that stage, report templates can be created, based on which regular or ad hoc reports will be made available to managers with minimum effort or time required.

The process described by Humphreys (1989) is a top-down process whereby the structuration of the concepts investigated is refined from one level to the next over time. As noted by Lévine and Pomerol (1995), levels 1 and 2 are generally considered as strategic levels of reflection handled by top executives (problem defining), whereas the remaining three levels correspond to more operational and tactical levels (problem solving). Although, all levels of management span the five levels, it is clear that lower levels of management are more likely to be given problems already well formulated to work on such that their thinking is mostly geared towards levels 3 to 5.

Although it is beyond the scope of dashboard development, level 1 is particularly important in that, at this early stage, the decision maker has total freedom to decide on a direction to follow. The only factors limiting the horizon of the decision maker are either psychological (unconscious) or cultural (e. g., his or her educational background, experience, values). In the literature on human decision making, this initial step appears under the name "*setting the agenda*" (Simon 1997) or "*problem setting*" (Checkland 1981). This stage is also important because it conditions the outcome of the decision-making process as avenues not considered at this stage are less likely to ever be considered. Simon (1997) reports an experiment proving that accountants set as an accounting problem the same problem that sales supervisors would set as a sales problem, and so on ... In addition, the natural progression across the levels of the framework is one that goes from 1 to 5, and rarely back to a previous stage unless a strong stimulus forces a change of mind about the situation.

This representation of managers' information needs is a simplification in that it separates what is essentially a continuous process into separate ones. However, from the point of view of the designer of management decision support systems, this framework has the great merit of clarifying what design avenues can be pursued to support managers in situations that are more akin to stage 1, stage 2, or any other stage. Discussions between designers and managers can be aligned with the degree of understanding of managers, moving away from a situation where analysts complain that managers do not know enough and managers complain that analysts are trying to tie them to simplistic solutions.

Figure 2 illustrates how the cognitive level framework maps onto the model presented in Figure 1.

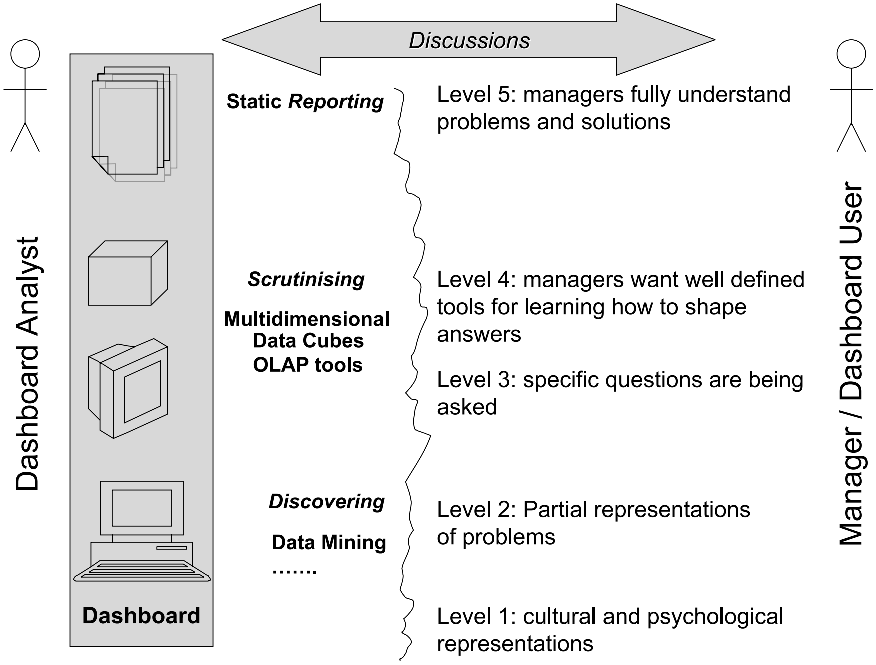



**Figure 2.** Matching dashboard content to managerial needs

Figure 2 shows that, if managers can name specific performance indicators and know how these must be represented, the situation corresponding to the fifth representation level in the Humphreys and Berkeley framework (especially if they are also able to calibrate performance level based on their own knowledge). This is essentially a reporting scenario where specific answers are given to specific questions. When, however, it is not exactly known how to measure or represent an indicator, this corresponds to levels 3 and 4 in the framework. This is more of a scrutinizing situation where managers know they are on to something, but they are not sure how to formally monitor it. Finally, when managers are not sure what indicator should be monitored to measure emergent changes in the activities of their organizations, or changes to market responses, this is more akin to a level 2 situation, or a level 1 situation if managers are still at the problem-finding stage (Pounds, 1969). The discussion between designers and managers is on-going, as different methods are experimented with to study how different indicators, calculated in different ways based on different data sources, respond. The development of the dashboard thus becomes an iterative process where problems and their representations improve over time and where discovery turns into scrutiny and scrutiny turns into reporting over time. This is illustrated in the cumulative case study constructed in the following section under the name Good Food Limited (not the firm's real name).

## 4 A Case in Point—Good Food Limited

In January 2001, the first indications were given that the Irish-based subsidiary of a large multinational food firm in Dublin, Ireland was going to be closed down. Few believed these unconfirmed reports, least of all those who were employed in the Dublin facility, which was believed to be a very profitable and inventive site of the corporation. Indeed, Dublin-based staff had participated in the development of the most innovative products of the firm using improved recipes that increased the shelf life and resistance of the products. By March of that year, however, it was confirmed that the 300 jobs involved in the manufacture and sales of products were to be moved to other locations abroad. The parent company, an excellent employer and good corporate citizen, gave every employee in the Dublin site the opportunity to transfer with their jobs. A significant number of employees chose not to transfer. In search for an interim solution, the parent company set up a core group of approximately 80 people to operate a production facility in Dublin for one year from 1st July 2001, up to and including 30th June 2002. The parent company did this for three reasons (i) to give employees and the community time to adjust to the fact that the firm was leaving the area, (ii) to give employees time to look for jobs elsewhere and (iii) to give all involved including the local community, and the national development authority (the IDA or Industrial Development Authority) the opportunity to secure a new owner and employer for the facility.

It was during this one-year period that local management, in particular the local managing director, who had decided to stay, approached existing and potential local customers and those in the local community with responsibility to encourage the creation of new jobs in indigenous industry start-ups. This led to local management incorporating a milk processing and food preparation company in July 2002 under the name Good Food limited. Crucially, the parent company allowed the new firm to keep producing under this new name all the products that had been produced in Ireland initially before the site was acquired (the Irish site had been a very small independent food producer over 20 years previously) and all the new variants that had been developed in the Irish site since the take over. This supportive decision made the whole adventure viable and meant that staff members were happy to stay.

One of the key elements in the creation of this new venture was making the transition between the management of a subsidiary of a large MNC and the management of the small firm, with typical associated problems such as cash flow. As part of this, a complete Key Performance Indicator (KPI) set was developed to allow the now small managerial group to keep a close eye on the critical factors in the business. This KPI set was then used as a basis for development of a computer-based dashboard delivering, in timely fashion to managers and workers, the key information they needed to steer the new firm towards profitability in the critical initial period and beyond. A small multidisciplinary team made up of management accountants, sales managers, production and quality control specialists and local IT personnel was assembled and put in charge of developing the architecture, content, and interface of this ambitious computerized dashboard. At the problem-setting stage, the team quickly identified that some areas of investigation were better charted than others. Some areas of sales and some areas of manufacturing were very well known and *reporting* facilities could be developed that very quickly would give a good coverage of managerial concerns. In other areas, by contrast, the data could be identified, but it was uncertain how to best display them, other than supporting managerial *scrutiny*. Finally, there were areas where no definitive avenues for creating a dashboard were identified leading to more abstract discussions on how to best allow the early *discovery* of problems. The development team worked its way through these different elements.

## 4.1 Reporting—Level 5 Understanding of the Problems

As the new firm had been a subsidiary of a large MNC for many years, staff had been used to working within the context of a reasonably rigid and all-encompassing budget which was put together on a yearly basis and was used systematically for the purpose of reporting and debriefing. Such was the expertise of key staff in predicting and budgeting that it was felt continuing with a similar system was desirable. The core of the KPI set was therefore developed around a system of variances calculated as the difference between budget and actuals. For instance, the sales plan was a 52-week rolling plan, forecasting the sales of each product in each territory, including forecasted discounts, and all other costs, direct and indirect so a weekly profit and loss account could theoretically be computed. In practice, however, there was no need to compute all actual figures on a weekly basis, though some needed a daily or hourly update cycle. Thus, the *actual* indicators were computed more or less frequently depending upon their usage. For instance, production information and raw materials usage were computed on an hourly basis, as was quality control information, whereas salaries and wages variances were only computed on a monthly basis.

Of particular interest were the areas of "sales" and the "cost of raw materials" which represented a substantial proportion of total costs, and "productivity" and "raw material usage." To properly evaluate the latter indicator, the firm could rely on very detailed and accurate costed budget recipes against which actual consumption and labor usage could be compared. This made the development considerably easier.

***Commentary:***

The managerial principles hereby presented evidence the high degree of understanding of the problems by management. This is a mature site with very specific ideas on how it should run itself. The budgetary system in place, with all its intricacies in terms of production costing, production and productivity standards, cost of raw materials (negotiated with suppliers for the 12 months ahead) are all the result of years of accumulated experience and provide inherent structure to the solution of the problems anticipated by management. The focus on specific areas, in particular, sales volumes and cost of raw material, shows the knowledge of the local management group in terms of CSFs for profitability.

In theoretical terms, the tight framework for measuring profitability and performance is the end product of the process of deciding how the firm should be managed. Discussions clearly take place at level 5 of the Humphreys' framework where managers can readily tell developers what they require, how often, how to compute it, and what benchmarks to use. However, one must realize that such a level of certainty brings with it a restriction of the outlook of managers and ultimately means that other questions and other ways to consider what happens in the life of the firm are *de facto* excluded. This is well illustrated in the choice of the three key indicators for the business in the following section.

To operationalize these management principles towards the creation of the dashboard, the measure of the firm's performance was built around three key indicators:

- Volumes of sales—the value of sales as they occur, where they occur.
- Respect of formula—the extent to which consumptions of raw material followed expected standards.
- Price of components and services—the cost of actually producing the products and the full cost of distribution, including discount, transportation, and so on.

These three were selected because they could be mathematically constructed into a complete measurement system which did not require the capture of new data where it is the most costly—in live activities such as sales or production. Also, this scheme allows managers to properly assess the origin of each variance—the volume variance measured the impact of the lower than expected level of sales on the bottom line, the price variance shows the impact of not having negotiated the price of inputs with suppliers at the expected level, and the formula variance shows the impact of having over or under-consumed inputs (including labor). This is a critical point in dashboard development because it is far less useful to measure the firm's internal performance in a way that is not tied to specific managerial responsibilities.

***Commentary:***

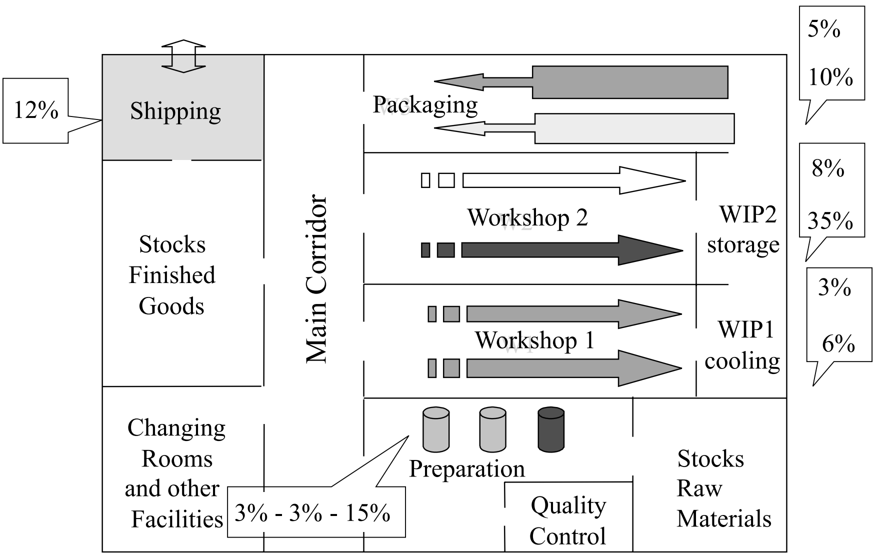
Although the calculation of these variances can always be performed at the overall level from accounting figures in the general ledger, it is more difficult to collect some of the actuals data (the budget is fully specified in advanced and stored in a database), especially when it comes to actual labor hours for each workstation, as staff may have been sent to work in a different place for a short period of time. Some approximation or indeed, some surrogate measures may be used to guesstimate a specific variance. Often, for managerial purposes, knowing the direction of the variance with a good degree of certainty is an excellent starting point as it can give an early warning signal. The accurate measurement of variances can come later. This is one of the signs that managerial understanding is still at level 4 and not at level 5 in the Humphreys' framework.

These three variances can conveniently be displayed on a weekly basis as a pie chart with the relative proportion of each variance in the total variance, although following the evolution of each variance and the total on a line graph is more informative as it allows for the monitoring of the impact of corrective actions that may have been taken. This could be of use for top management as a complete real time debriefing of the execution of the yearly plan. This may be of some interest for other levels of management, but it is mostly within each of the indicators that great decision-making value can be derived from the model, because it allows for drill-down into the components of the variances down to a level where specific action can be taken. Thus, the price variance can be broken down into the variance for each of the raw materials, although an ABC approach based on the proportion in the cost of production is probably more interesting. For instance, the top ten most costly components (labor, for instance) could be listed on a separate table so as to provide a measure of their relative importance. Typically, one or two components may be responsible for 80% of the variance and this may trigger immediate action—search for an alternative supplier or for an alternative raw material. The same principle can be applied to the formula variance and may lead to an investigation of why the consumption for a certain raw material is varying from the expected standard. The volume variance can be broken down per product and per region or per sales representative, which gives great flexibility in terms of analyzing the reasons why sales volumes deviate from budget. Regional explanations can be found such as entry of a new competitor, closure of a large customer, and so forth.

The case study illustrates the difference between reporting and scrutinizing on the one hand, and discovering on the other hand. Whilst the scheme hereby described can yield answers to questions that are not explicitly asked by managers and definitely adds up to a comprehensive set of KPIs, it still does not constitute *discovery*, insofar as it is fully determined by the rules that have been used to devise it. It delivers some degree of *scrutiny*, but will not present managers with problems that they did not anticipate or did not understand. Furthermore, it is quite biased in terms of the identification of the causes of bad performance. For instance, it is geared toward measuring products sales and analyzing variances against budget, but the scheme does not suggest collecting data about weather patterns to explain how temperature may induce changes in consumer behavior, neither does it analyze potential changes in consumer life style which may lead to more sophisticated understanding of the performance of products in the market.

## 4.2 Scrutinizing—Level 4 Understanding of the Problems

In addition to this scheme, managers put in place other ideas to cover specific areas where they knew they could expect potential trouble. For instance, because downtime had been a problem at times, due to the age of some of the machines, an analysis of the maintenance activity (which may be used to explain why production could not keep up and therefore why sales are down—downtime having affected certain machines) was added to the dashboard as illustrated by the sample screen in Figure 3. There was a cost to this investigation in that maintenance operators had to fill in additional forms to describe their interventions, but this seemed a reasonable price to pay. There was however, considerable resistance to this scheme for reasons that were hard to anticipate: in addition to providing feedback on the way the machines were performing, it also revealed, by accident, the efficiency of individual crew members in the maintenance team. Even though management never thought of using these data for such a purpose, as it was simply




Note: Arrows denote an assembly line, cylinders denote a preparation oven and WIP stands for work in progress.

**Figure 3.** Location (% of all accidents)

not part of the underlying model used to develop the indicator, maintenance staff complained they were being investigated because great differences in the intervention times of different members of the crew surfaced. Evidently, this was a consequence of the nature of the problems they were called in to address, so a rating for task difficulty was added to calm fears. The later introduction of mobile tracking devices reduced the cost of data collection and served to establish this part of the dashboard at the center of the administration of the plant, as it was made available to everyone and even became a feature of a large display panel in the factory which read: “number of hours of downtime this week: XX.”

***Commentary:***

The screen in Figure 3 shows a geographical representation of the location where production time is lost through machine downtime. Over time, this indicates which machines should be replaced and may lead to a preventive maintenance plan. Color coding is used to show the areas where the greatest time is lost. In a large plant, where information about problems may not always be known to the production director, such a dashboard can reveal many hidden problems, week after week. The interface allows for the identification of problem areas at a glance, whereas a complete list of maintenance interventions or accidents would only confuse managers (there may be a significant difference between the number of interventions in one area and the total time spent in restarting production).

Interestingly, the selected indicator gives rise to the possibility of measuring the performance of individuals. In the site where this was implemented, the co-signature of the forms by maintenance crews and foremen had to be implemented to discourage false reporting, as both sides had an inherent interest to minimize (maintenance crew) or maximize (foremen) the time of interventions. Co-signatures meant accurate reporting was guaranteed.

This indicator amounts to a *scrutiny* type activity, insofar as the cause and effect relationships analyzed are well understood, even if the occurrence of problems is hidden from view. A few iterations may be required until the exact nature of how the indicator can be used for maximum effect is known, but it is well understood why the indicator should be used in the first place. This is a hybrid situation where managers sense that problems can occur, but without a specific model to describe in specific terms what cause-and-effect relationship they want to investigate. Over time, as the indicator begins to vary and send warning signals, managers will come to define a stronger model to describe the cause-and-effect relationships, which means saving or losing money with downtime and maintenance. The introduction of an industry-wide benchmark for expected downtime may also lead to a more complete model for analyzing the maintenance activity.

This learning may lead to the ultimate step in maintenance within manufacturing environments: preventive maintenance, where production is halted at scheduled intervals to carry out scheduled maintenance in a bid to prevent any incident before it occurs. This is much cheaper (if it works) because scheduled interventions have a lesser impact on production. In certain industries, preventive maintenance is a requirement—e. g, air travel—because accidents cannot be left to happen.

## 4.3 Scrutinizing—Level 3 Understanding of the Problems

The area of product returns and product defects was one that caught managers' attention after a while. Now that the profit or loss of the firm was essentially a matter of survival, managers became far more sensitive to the volume of sales return (not actual returns, because in the food area, food products that are damaged are destroyed rather than returned—an added complexity for investigating the validity of claims). Whereas in the past, they would have been happy to consider gross sales, it became apparent that focusing on net sales, discounting returns was more meaningful. Sales returns could actually account for quite a substantial proportion of sales at times and for certain customers and this became a worry. Good Food did not sell to consumers directly and would typically ship large consignments to supermarket chain depot centers.

This issue was a thorny one because Good Food did not have the custody of its products once they left the factory as they used independent haulers to deliver to their customers. Thus, many problems could occur away from its scrutiny. Visible damage to products was easy to blame on haulers when packaging had been damaged, but it was more difficult to ascertain when temperature had been the problem and products did not make it to the end of their shelf life. The dashboard that was developed to solve this problem was not computerized! It consisted of keeping sample products for each batch in three confined areas: one at 4 degrees centigrade (the recommended temperature), one at 8 degrees (the theoretical tolerance threshold of the product), and one at 12 degrees (a temperature that is likely to damage the product within its shelf life). On the basis of the observation of the samples, one could then make comparisons with descriptions made by customers. This allowed a more informed decision to be made regarding the issuing of credit notes. It also allowed the rapid identification of contaminations that may compromise the product.

In time, it was felt that this approach could be computerized when the patterns of sales returns would be better understood. The plan was to create a reputation system that would mine previous data for each customer and the returns they made for each category of product and to rate their reliability against the benchmarks obtained in the experimentation in the fridges. Thus, over time, this problem would come to be better understood to the point where it could be automated and decisions on credit notes could be taken at the touch of a button.

***Commentary:***

The above problem is an illustration of the search for surrogate measures to solve a particular problem. Obviously, managers cannot follow products wherever they go, through the vagaries of delivery and shelving. The proposed measurement is therefore a surrogate, but it does provide an accurate picture of the only parameter that is really of importance to managers—how resistant their products really are. That is, is it their fault when products go bad on the shelves? On the basis of the observation of the evolution of samples in the confined areas, they must then use judgment to recall products in case of visible bacterial development within the shelf life and to judge the merit of customer complaints.

This example is interesting because it shows that a dashboard can be of a non-computer nature and that direct observation may be required in some cases, rather than reliance on an informational intermediary. However, the fact that this indicator is different from the previous examples does not mean that it takes us into the *discovery* domain because managers know very well what answers they seek in creating a "walk-in" dashboard.

The prospect of computerizing this area into a reputation system gives a view on the evolution of managers' understanding from level 3 up to levels 4 and 5.

## 4.4 Discovering—Level 2 Understanding of the Problems

After a year of relative success, and with the company in a sound condition financially, managers at Good Food had to face up to the fact that survival was no longer a sufficient business goal: a more ambitious long-term growth target was required. The current portfolio of products, because it had been stripped of some of the parent company's product a year earlier was not sufficient to support the growth of the company in the future. In particular, it was a worry for top management that too many of these products may be near the end of their life cycle. That a new range of products was needed was beyond doubt, but what these products should be was less certain. The possibility of whole new families of products had to be contemplated.

In the food sector, producers are at a disadvantage because they have little direct contact with consumers, especially when they are SMEs because of the costs involved in market research. Typically, managers in supermarket chains know more about consumer behavior than any of their suppliers do because they have access to direct information through their loyalty card systems. Discovering patterns and correlation in such a volume of raw data is commonplace, as illustrated by Kelly (1996) who describes how Walmart managed to identify the correlation between purchases of beer and nappies in their data. Managers at Good

Food were aware of this problem and sought to generate their own primary data for the purpose of discovering who their final customers were and what they would have liked. They enlisted the services of a marketing firm that recommended the creation of a panel of customers. The panel was a group of existing and would-be customers, selected after a careful investigation by the marketing firm, who met on a regular basis to sample existing products and share their thoughts and experiences with the product. To avoid going around in circles over time, new members were added and others were eliminated on a regular basis. Over time, they came to represent a group of expert consumers for such products (they were also made to sample competitor products) and all proposals for new products were submitted to them first. This provided direction for future developments in Good Food.

In parallel, web surveys were implemented because they were much cheaper to administer and the regular results from these were posted on to a dashboard in the shape of a forum of contributions. Even though managers liked browsing these contributions, they were not sure what to do with them or how to classify them to derive abstracted information about potential market opportunities.

***Commentary:***

This example shows the level of understanding that managers have at the second level of Humphreys' framework. They are aware of the problem and can make a general statement about it, but they are uncertain how to progress and will rely on external information with a very open mind. This is an example of the *discovery* mode of managerial thinking.

Data mining has been proposed as an obvious ground for discovery whereby computer programs dedicated to the search for unexpected correlations and patterns are let loose on vast volumes of raw data. However, this is only available in situations where a dense base of data is available—such as a retail business or insurance business. Other firms can only rely on judgment or inspiration when it comes to either tolerating high levels of uncertainty or collecting totally new data.

The above example is a clear illustration of what discovery can look like in a domain where no raw data is available. In this case, the dashboard takes the shape of an on-going focus group providing feedback from the market about the firm's products. Computer systems can offer support in terms of on-line surveys or as a dissemination tool for the data collected. They could be used to create a virtual (and therefore much cheaper) version of the panel of customers. However, the fact that consumers are brought together in a location to discuss their ideas is probably a must in this scenario.

# 5 Conclusion

In this chapter, we have explained how dashboards of information constitute another stage in the development of information systems for top managers initially and, by extension, for all other levels of the firm. We have illustrated, with the help of a case study, that the difficulty in developing such dashboards of information no longer resides in the application of complex technologies or toolkits, as many excellent platforms are now broadly available in a rich software market, but in sourcing and computing data, and designing models and interfaces that fit the level of understanding of the managers who need them. Instead of getting bogged down in discussions about the lack of specific data or the difficulty in specifying upfront requirements for problems to be tackled, the communication between a business manager and a developer of decision support systems can be structured to ensure that the needs of managers are served in terms of reporting, scrutinizing, or discovering depending on how much managers know and understand. Thus, a dashboard becomes, over time, more than just a collection of a few well-charted indicators: in the hands of the right managers and with the help of the right developers, it becomes a very flexible learning tool, which can also be used for training purposes.

The two important factors that must always be understood are the *content* of the dashboard (i. e., what it really shows) and the *context* in which it is used (i. e., why it is important to show such data and what will managers do with it). Designers and programmers of dashboards must first strive to generate good, reliable information—and this can be very costly. Managers must strive to understand what the indicators mean and how they evolve over time so they can learn what action to take in response to variations of the indicators. Thus, the cost of developing a dashboard only makes sense if the implementation of an indicator in a dashboard increases, facilitates, accelerates, or makes more reliable, the delivery and presentation of information to decision makers. This value-adding dimension of a dashboard is the justification for developing it, such that it can become a solid distribution medium for knowledge that can support decision making at the level of the individual, the functional area, and the firm.

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# CHAPTER 45
# Business Intelligence

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Business intelligence (BI) is a data-driven DSS that combines data gathering, data storage, and knowledge management with analysis to provide input to the decision process. The term originated in 1989; prior to that many of its characteristics were part of executive information systems. Business intelligence emphasizes analysis of large volumes of data about the firm and its operations. It includes competitive intelligence (monitoring competitors) as a subset.

In computer-based environments, business intelligence uses a large database, typically stored in a data warehouse or data mart, as its source of information and as the basis for sophisticated analysis. Analyses ranges from simple reporting to slice-and-dice, drill down, answering ad hoc queries, real-time analysis, and forecasting. A large number of vendors provide analysis tools. Perhaps the most useful of these is the dashboard.

Recent developments in BI include business performance measurement (BPM), business activity monitoring (BAM), and the expansion of BI from being a staff tool to being used by people throughout the organization (BI for the masses). In the long-term, BI techniques and findings will be imbedded into business processes.

**Keywords:** Business intelligence; Data warehouses; Data mart; Analytics; BI software; Recent BI developments; BI people issues; BI improvements; Real-time BI; BAM; BAP; Dashboards; BI cases

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## 1 Introduction

This chapter examines business intelligence. Some argue that the combination of business and intelligence is an oxymoron. In this chapter we explain why the term is not an oxymoron and describe the state of the art.

## 1.1 Definition

We define business intelligence (BI) as systems that combine:

- Data gathering
- Data storage
- Knowledge management

with analysis to evaluate complex corporate and competitive information for presentation to planners and decision maker, with the objective of improving the timeliness and the quality of the input to the decision process.

This definition looks much like the way decision support systems (DSSs) are defined. Indeed, a good way to think of business intelligence systems is that they are, in Dan Power's framework (Power 2002), data-driven DSSs. That is, they emphasize analysis of large volumes of structured (and to some extent semi-structured) data.

Implicit to this definition is that business intelligence systems provide actionable information and knowledge at the right time, in the right location, and in the right form.

## 1.2 History

The term business intelligence was first used in 1989 by Howard Dressner, then a research fellow at Gartner Group, as an umbrella term to describe concepts and methods to improve business decision making by using fact-based support. The term resonated with decision support professionals, with vendors, and with general managers. It was widely adopted and replaced terms like executive information systems. Nonetheless, it is an evolutionary term that can be expected to be replaced by other nomenclature as fashions change.

## 1.3 Business Intelligence and Competitive Intelligence

The term competitive intelligence (CI) refers to monitoring the competitive environment. As defined by the Society for Competitive Intelligence, it is a systematic and ethical program for gathering, analyzing, and managing external information. CI is a subset of BI and is discussed seperately in the next chapter.

## 1.4 What Is New?

Business intelligence is the result of a series of innovations over the years. Its antecedents are the early decision support systems described, for example, in Alter (1980), fourth-generation financial planning languages such as IFPS (Gray 1983),

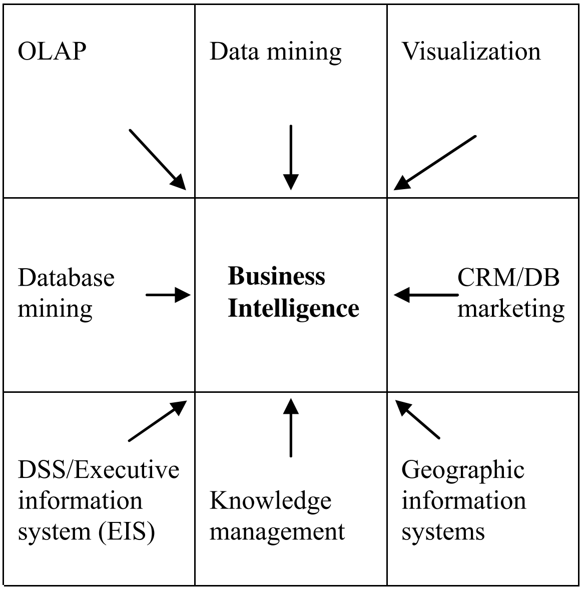


**Figure 1.** The components of business intelligence

executive information systems (Watson et al. 1992), the data warehouse (Inmon 1992), online analytical processing (OLAP, Codd 1993), and data mining (Fayyad et al. 1996). Each iteration was more sophisticated than the one before it.

Today, software brings all of these components together in a single system (Figure 1).

## 2 The Role of the Data Warehouse

Business intelligence relies on business data that can be analyzed for decision making. As shown in Figure 2, data is usually made available in a data warehouse for use in analysis. In this section, we describe the data warehousing environment. The analysis environment is discussed in Section 4. Note that, although data from any source can be used for BI, most firms use a data warehouse as the primary source for business intelligence information. Wayne Eckerson (2003) of the Data Warehousing Institute argues that the data warehouse is a data refinery. Just as an oil refinery creates multiple products from raw material, the data warehouse converts data into information. In terms of the conventional knowledge hierarchy, the data warehouse converts data into information, which in turn is converted into knowledge by analytic tools (Section 3). The knowledge is used in rules and models for planning and eventually combined with experience to create action. Wisdom comes from continual review, measurement, and further refinement.

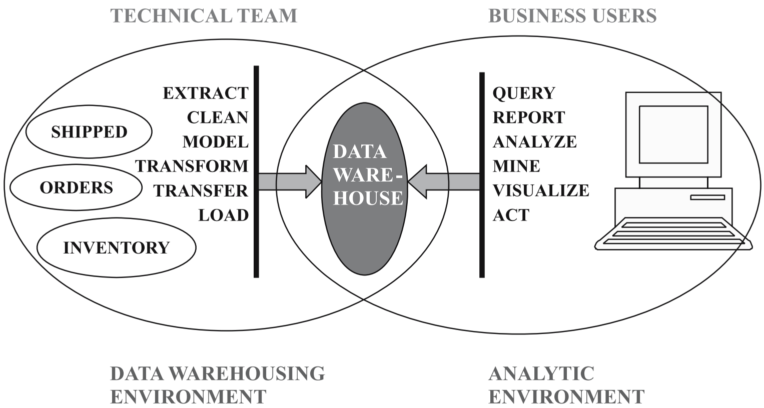


**Figure 2.** Relation between the data warehouse and the analytic environment

## 2.1 Origins of the Data Warehouse

The data warehouse is the result of two software solutions needing and finding one another. Database firms developed data warehouses, which they saw as a new market, and needed applications. DSS developers and vendors, who had concentrated on the model base and the interface (Sprague and Carlson 1982), needed to deal with the ever-increasing databases required for their systems.

## 2.2 Definition of the Data Warehouse

A data warehouse is a large database. It is defined as a subject oriented, integrated, time variant, non-volatile, collection of data in support of management decision processes (Table 1).

**Table 1.** Characteristics of the data warehouse

| Subject oriented | Data organized by how users refer to it |
|---|---|
| Integrated | Inconsistencies and conflicting information are removed to create a clean, single version of the truth |
| Nonvolatile | Read only. Data do not change over time |
| Time series | Data include history as well as current status |
| Summarized | Pre-defined summaries used to aid analysis |
| Larger | Time series imply much more data is stored |
| Non-normalized | Data can be redundant |
| Metadata | Contains data about the data |
| Input | Comes from un-integrated operational legacy systems |

## 2.3 Data Marts

Data warehouses can be quite large. For large organizations, they can quickly grow to many terabytes. Fortunately, not all the information in a data warehouse is used for BI. To speed response, a small data warehouse, called a data mart, is created for use by analysts. The data mart contains a subset of the data warehouse that contains most of the information used routinely for business intelligence. If information beyond what is stored in the BI data mart is needed, analysts can query the firm's data warehouse. For simplicity, in the rest of this chapter we use the term data warehouse to refer to both the data warehouse and the data mart.

## 2.4 The Technical Team

The technical team, which consists of data specialists, spends 60–80% of its time creating the single truth (that is, the single, coherent view of the business) needed by analysts. It is a tough job because data is rarely clean, consistent, or easy to integrate. The technical team needs to understand the data, the business, and the needs of the analysts.

# 3 Analytics

As was shown in Figure 1, BI uses the data warehouse as the input to its analytic environment. Being a data driven DSS, BI involves many of the analytic techniques of DSSs, including statistics, data and text mining, forecasting, econometrics, and optimization. Most of these techniques are discussed throughout this handbook. In this section we first discuss the importance and role of analytics in BI and then briefly describe five of the methods used for BI analytics: (1) reports, (2) slice-and-dice and drill down, (3) ad hoc queries, (4) real-time analysis, (5) forecasting and (6) scenarios. These methods of analysis, some quite simple, are used in addition to the many techniques of statistics and operations research.

## 3.1 Role of Analytics

Firms gather business intelligence information to help increase the firm's competitiveness. But information by itself is not enough to fulfill this mission. The information needs to be interpreted in terms of the strategic and tactical objectives of the firm. As Davenport and Harris (2007), in their important book *Competing on Analytics: The New Science of Winning* point out, the role of analytics is to drive managerial decisions and actions. Analytics are the input to human and automated decision making.

The simpler forms of analytics (standard and ad hoc reports, query and drill down, and alerts) answer questions such as: What happened? When and how much? Where does the problem occur? What requires action? These questions usually require answers at the operational level. The more complex forms (statistical analysis, forecasting and extrapolation, predictive modeling, and optimization) get at issues such as: Why is something happening? What if the trend continues? What is going to happen?, What is the best we can do in anticipating the future?

Analytic capability requires both people and organizational infrastructure. Good information management, usually supported by a data warehouse, is fundamental. BI professionals, who are skilled, computer-savvy professionals with advanced degrees in such fields as operations research, statistics, logistics, and marketing, work as staff people who create the models and methods that apply in the firm and who run specific studies. As discussed in Sections 6.3 and 7.1, to be effective, the ability to use analytic outputs should be widespread. Perhaps the most important group of people and organizational issue is senior management and its commitment to analytics (Davenport and Harris 2007), for without it, nothing happens.

## 3.2 Reports

Routine reports, produced on a heartbeat schedule such as weekly or monthly, are mostly created automatically by the data warehouse and distributed on a firm's intranet. Most users view automated reports statically as is. Analysts, however, also create and examine reports filtered by criteria (e. g., type of business, location, size of purchase), exception reports (e. g., high or low demand), requests for specific information from managers who use BI output, and customized data combinations (called cubes) for special projects. Eckerson (2003) estimates that 75% of users of historical data principally use routine reports that describe what happened.

## 3.3 Slice-and-Dice and Drill Down

The next level of usage beyond reporting is for analysis: to find out why something happened. Here spreadsheets, online analytic processing (OLAP, discussed in detail in Chapter 13), planning, and forecasting (Section 3.6) are involved. Much of this work involves slice-and-dice and drill down on reported data. In slice-and-dice, analysts can view data from many perspectives. For example, the revenue from, say, cereal, can be examined by brand, region, (e. g., New York, Washington, Sydney), time (last week versus this week), and combinations of parameters.

Drill down is used both to deal with exceptions and to find the components of a particular number or result. In drill down, the user navigates through the data to obtain more detail that helps explain why results are what they are. For example, if cereal in aggregate is selling well in Washington, which brands are doing better and which are doing poorly? It is also possible to drill up (e. g., consolidate data) and drill across (examine data at the same level for other products, such as milk or cookies).

As an example, consider a financial analyst who wants to determine the monthly changes in the balance sheet to assess trends and directions of growth or decline. The analyst also wants to determine the potential effects of changes (i. e., what-if) in the business environment (e. g., or in interest rate). Changes in payables (e. g., to whom and how much is owed) and receivables (including the length of the receivable cycle) indicate the health of both individual units and the firm as a whole. For the income statement, the analysis revolves around changes in the origins of revenue and operating expenses. The objective is to know which parts of the enterprise are producing financial resources and which are consuming them, and the variances between actuals and budgets. If anomalies (better or worse than expected values) occur, the analyst drills down to see which specific unit or product is the source of the anomaly.

## 3.4 Ad Hoc Queries

The most sophisticated analysis of warehouse data is used for predicting what will happen. Here techniques such as regression, optimization, data mining (Chapter 27), and simulation are used. These future-oriented BI studies usually result from ad hoc questions posed by users and analysts. The analyst uses a query language, such as structured query language (SQL) or MySQL to ask for the needed data from the data warehouse. In a typical situation, the analyst uses the metadata about the variables in the data warehouse to obtain the data needed for the study. The metadata shields the analyst from complexity in working with the warehouse. Analysts are given tools so they can work with the data directly. Prebuilt solutions are becoming available that address specific areas such as procurement.

## 3.5 Real-Time Analytics

With the ever-faster pace of business, BI is moving to real-time analytics. Real time does not necessarily mean zero latency; it does mean that data and analyses must be completed and available in time so that decisions can make a difference. As a result, a number of analysis aids are used, including dashboards to monitor the current situation, alerts to assemble the team needed to respond, and decision engines that give accurate answers quickly.

The Western Digital case, described in Section 5.3, is an example of real-time analytics.

## 3.6 Forecasting

Whereas real-time analysis is concerned with what is going on currently, forecasting is analysis concerned principally with the future. The term predictive analytics is widely used, but this term is often interpreted as forecasting based on data mining. Although one technique is to apply mining to existing data, other approaches can also be used.

Predictive analytics starts with what is in the data warehouse and applies algorithms, ranging from univariate and multivariate statistics to neural networks, decision trees, and optimization to the data. The results are used to identify patterns and trends and to forecast the broad directions in which the future is likely to move. As the art of forecasting improves, analytics are being applied to more and more situations (e. g., product demand, probability of customer defection, donations to a university). Accuracy of the forecasts depends on the complexity of the situation. As the number of variables increases, the forecast accuracy decreases. For example, the techniques are not yet good enough to forecast long-term changes in either individual stocks or the market as a whole. However, the techniques are sufficiently robust to be used by the Richmond, VA police to deploy task forces to counter specific crimes.

Although predictive analytics still requires intense use of analysts, it is likely to be imbedded in software in future years (Section 8).

## 3.7 Scenarios

Even though analysis techniques present large amounts of information and knowledge about a business, they are rarely in a form that the results can be communicated easily to managers. A standard BI technique to overcome the analysis communication gap is to use multiple scenarios to illustrate alternative outcomes (Ringland 2006). Scenarios are defined in the dictionary as an outline or a synopsis. In BI they are used as a way of telling alternative stories to decision makers because stories are usually much easier to comprehend than columns of figures or graphs.

In business, a scenario is a description of trends and events that describe a situation that might evolve. Scenarios include issues to be resolved, time relations, interactions, and logical consequences. A scenario is not a prediction of what will occur. Rather, it is based on detailed analysis. A scenario must satisfy three criteria:

- Possible: it could happen and does not violate a physical law such as traveling backward in time.
- Plausible: the listener must agree that the event could happen. For example, isolating all computers in a firm from the Internet is not plausible. Isolating computers from the Internet for privacy is usually not plausible.
- Internally consistent: for example, you cannot say at one point that the trend is up and at another that it is down.

### 3.7.1 Scenario Space

Multiple scenarios are used to bracket alternative futures. Typically you pick one or more values of specific parameters. For example, high growth or low growth of gross national product (GNP) and high growth or low growth of population would define four cases. The parameters population growth and GNP growth define a scenario space. If we add medium GNP and population growth, the cases increase to nine. In Table 2, five of the nine combinations are selected.

**Table 2.** Example scenario space

| | **Population growth** | | |
|---|---|---|---|
| GNP growth | High | Medium | Low |
| High | x | | x |
| Medium | | x | |
| Low | x | | x |

x = scenario selected for analysis

Since the number of cases grow combinatorially, it is necessary to select a subset of the options available. In Table 2, nine scenarios could be created in the scenario space. The x's indicate that only five scenarios were selected for analysis.

### 3.7.2 Development Process

The steps in developing and using scenarios for analysis are:

- Select the parameters of interest in the scenario space
- Create socioeconomic possibilities
- Determine the system values associated with each scenario
- Develop the scenarios
- Analyze the results and develop policies to cope with the outcome

### 3.7.3 Communicating the Scenarios

Once the scenarios are completed, they need to be communicated to decision makers. As indicated, scenarios, being stories, are invariably easier to communicate than reams of graphs and statistics. However, two limitations must be considered.

First, managers often confuse a scenario and an outcome. Scenarios are possibilities, not forecasts. It is often difficult for decision makers to recognize that the analysis is bounding the future, not specifying it. Second, by using a scenario space, all elements in a specific scenario follow the same theme. Yet, for example, even though GNP is growing as a whole, some parts of the economy will be better off and some worse. As a result the scenarios can be simplifications of future situations. Nonetheless, scenarios are a powerful communication tool that frames the discussions about the firm's future actions.

# 4 Software Implementations

Despite ongoing consolidation in the BI software market, a large number of companies offer services. These companies fall into two categories: specialized software companies that focus on BI (such as Business Objects, Cognos, Hyperion Solutions, Information Builders, and MicroStrategy) and more broadly based firms (such as Microsoft, Oracle, SAP, and SAS Institute). Most provide complete enterprise BI suites and BI platforms. In selecting BI software, its compatibility with the firm's data warehouse and other portions of the infrastructure needs to be considered.

The 2006 size of the worldwide BI market was estimated by Gartner to be \$2.5 billion (Information Week 2006). The traditional custom design, build, and integrate model for BI systems is lengthy (at least six months) and costly (\$2–3 million) and that does not account for ongoing licensing, personnel, space and maintenance costs. To reduce costs and to speed startup time, some firms are moving to web services where the software is located at a provider and calculations are performed on demand.

## 4.1 Dashboards

Like dashboards on an automobile or an airplane, digital dashboards provide information on the current and past status of a firm's key performance indicators (KPI). A typical dashboard uses simple visuals (gauges, charts, and tables) through a web browser interface to speed communication of BI results.

Dashboards are appealing because they:

- Present many different metrics in a single consolidated view on-screen
- Roll up details into high-level summaries
- Present intuitive indicators that are quickly understandable. For example, red indicates problem, yellow potential difficulty, and green everything is according to plan.

They tell the user what is going on but not why. However, dashboards can provide drill-down capabilities to put current data into historic context.

Because user's needs differ, dashboards can be customized to individual needs.

# 5 Case examples

This section presents four BI case examples. They range from a parking garage chain, to an airline, to a disk manufacturer, to a software house.

## 5.1 Parkway

Parkway Corporation runs 30,000 parking spots in 100 garages and parking lots in Philadelphia and along the East Coast of the US (Lindorff 2003). Basically a family owned real-estate development company with little technical skill, they faced new threats including a recession, consolidation in the industry, managing growth, price wars, soaring liability insurance, and a need to cut costs. Their clients were not only the drivers who park but also the owners of the garages whose lots they manage. They did not know which lots worked best, which garage designs or which type of customers were most profitable, which employees created damage claims, the sources of their overtime costs, the magnitude and location of employee theft, and even simple things like different names for the same lot by a garage owner and by Parkway.

With a new manager, they installed a data warehouse and a large BI software package. They obtained improvements in each of their problem areas. For example, the data on damage claims by location, employee, and garage design, led them to change signs in the garage and the mix of employees on duty. Revenue was increased 35% as they changed the mixes of pricing (short-term, long-term, monthly, and valet parking) and garage spacing. To reduce rampant theft, they automated systems, introduced digital payment systems (credit cards and smart cards), and wound up, as a side benefit, needing fewer people and reducing compensation claims. They eliminated spikes in overtime that resulted from bad managers at a garage and from new business openings generating demand. They gained a better basis for acquiring and disposing of specific lots. They found their most profitable customers. However, they still had to cope with cultural resistance to change and some garage owners who could not deal with the Web.

## 5.2 Continental Airlines

Continental Airlines, the seventh largest airline in the world, is a business that requires real-time, online BI to function (Anderson-Lehman et al. 2003). With 2300 daily flights to over 200 destinations, decisions must be made about each take-off and landing, each passenger’s fare, ground operations, detecting fraud, security, and customer relations. The airline was long rated at the bottom of major US airlines by almost all measures. In 1998 they implemented a real-time data warehouse and began their climb to being a top airline. For example, they integrated customer information, finance, flight information, seat inventory, and security to improve revenue. The warehouse data also allowed them to spot travel agent fraud.

They moved forward from there to real-time applications. For example, they began using optimization techniques to design fares based on current demand; they gave their gate agents and flight attendants details on customer experiences on previous flight segments and flights; if a connecting flight was late, they used dashboard displays so their high-value customers would be helped in making connections for themselves and for their baggage.

To make all this work, Continental built an 8 terabyte real-time data warehouse (called an operational data store or ODS) that coordinated 25 internal and two external operational systems. These systems include both Web and desktop BI.

The Continental Airlines case is discussed in detail in Chapter 57.

## 5.3 Western Digital

Western Digital manufactures over 100,000 digital personal computer (PC) memory drives per day in factories in Malaysia and Thailand. If the production goes down, huge losses can result. Their challenges included changing customer requirements, competitive price pressures, short product cycles, rapid obsolescence, and maintaining high product quality and reliability. In addition, they need to avoid business disruption when a factory production line goes down or a large amount of rework is required. Western Digital used both conventional and real-time BI to cope with these problems (Houghton et al. 2004).

At headquarters in California, they operated a large-scale BI system to create a series of dashboards that assisted in demand planning, distribution, and sales information. They also looked at billings, sell-through, weeks of inventory, and more.

For their overseas operations their dashboards monitored such quantities as yields, quality, and production output. The data had to be in real time because it warned them of impending production line failures. They showed key performance indicators (KPI), displayed quality metrics, allowed drill down to find sources of a problem, and issued alerts automatically so a team would be formed to deal with a problem. The real-time dashboards served as the nerve center for managing the firm's operations.

## 5.4 Comshare

Comshare (since bought by Exensity) of Ann Arbor, Michigan competed in the fourth-generation computer language market. Its chief executive, Richard Crandall, used a service that monitored all newspaper references to its competitors. One day in 1991, the service sent him a story from the Austin-American Statesman, the daily newspaper in Austin Texas, reporting an interview with Anderson, the CEO of Execucom, one of Comshare's major competitors. In the interview, Anderson complained bitterly about MPSI Systems, a Tulsa firm in the oil and mineral exploration services business, that had bought Execucom a few years earlier. Anderson felt that MPSI did not understand what they had in Execucom and vice versa. Crandall understood that, given the situation, Execucom could be bought at a reasonable price and did so.

# 6 Recent Developments

Business performance measurement (BPM) and its subset, business activity monitoring (BAM) came to the forefront in the 2000s. The basic idea is to find out how well (or poorly) a business is doing by using a combination of software, business processes, and measures of business success. BPM (Section 6.1) takes the long view whereas BAM (section 6.2) looks at the real-time component of business processes. Another important development is the expansion in who gains access to business intelligence outputs. This development (Section 6.3) is called BI for the masses.

## 6.1 Business Performance Measurement

In BPM, the firm is trying to understand its business performance, act on what it finds out, and influence change so it performs better. BPM was driven by the Sarbanes-Oxley Act passed by the US Congress in 2002 as a result of the Enron scandal (McLean and Elkind 2003) and by new measures of corporate performance that look beyond the conventional accounting ratios.

Sarbanes-Oxley put pressure on companies not only to improve the quality of the data they report but also made them report the data more quickly. The act requires the chief executive officer (CEO) personally to certify, at the end of each quarter, that the firm's published financial statements are correct. There is no waiting.

In addition, more firms were accepting and institutionalizing measures included in the balanced scorecard (which was linked to the firm's strategy) (Kaplan and Norton 1996) and key performance indicators (Eckerson 2006) as a way of determining how well they were doing. They were accumulating vast amounts of data from enterprise resource planning (ERP), customer relationship management (CRM), and supply chain management (SCM), and were tying these disparate data sources together. As a result, it was possible to build BPM on existing technologies (Table 3) and store them in a data mart. Note that only a few of the measures in BPM are real time.

In looking at BPM, recognize that it is the outcome of combining a series of developments over time. It started off with conventional business intelligence and its use of OLAP and other analysis techniques. It used collaborative software such as portals to help people communicate and to gain access to the data. It added metrics to put the numbers in context that led to action where and when needed.

**Table 3.** BPM data sources

| Key performance indicators | Scorecards | Dashboards |
|---|---|---|
| Online analytic processing | Planning | Consolidation |
| Extract, transfer and load (ETL) | Report and query tools | |

BPM vendors typically sell suites of software, although some companies start with one application and then grow to a full-fledged suite. For example, Winn-Dixie stores started with budgeting because contributors did not know what happened to their input in the final budget. Lockheed Martin started in finance to reduce costs, adopted a single accounting system, and used BPM for continual benchmarking against its competitors. It also developed new capital metrics around its assets, liabilities, and operations.

The bottom line comes from being performance oriented rather than process oriented and from greater awareness of the marketplace consequences of actions.

## 6.2 Business Activity Monitoring (BAM)

BAM is particularly useful to firms involved in high-volume production. It is oriented to determining business activity outputs and key performance indicators in close to real time so that corrective action can be taken when needed (see the Western Digital example, Section 5.3). As such it serves as a form of process control. For example, BAM is used to:

- Alert managers when performance is moving outside allowed quality bounds.
- Warn banks about money laundering.
- Warn hospitals when emergency room cases exceed preset levels.
- Compare available inventory and shipping time for available orders and uses operations research rules to reorder items when they go below preset levels.

To make BAM work, a typical firm will revise its business processes, use observation–orientation–decision–action (OODA) loops (see Figure 3) to sense and respond, create dashboards, and alert people that there is a problem.

The concept of observation–orientation–decision–action (OODA) loops was originated by US Air Force Colonel John Boyd (Boyd, 1986 quoted in Curtis & Campbell, 2001) who wanted to understand how fighter pilots won air combat engagements (dog fights) against other pilots despite aircraft with inferior maneuverability. Boyd found that winning pilots were able to compress the whole cycle of activities that happens in a dog fight and complete them quicker than their adversaries. Boyd's OODA loop of activities included:

- *Observation* (seeing situation and adversary)
- *Orientation* (sizing up vulnerabilities and opportunities)
- *Decision* (deciding which combat maneuver to take)
- *Action* (executing the maneuver)

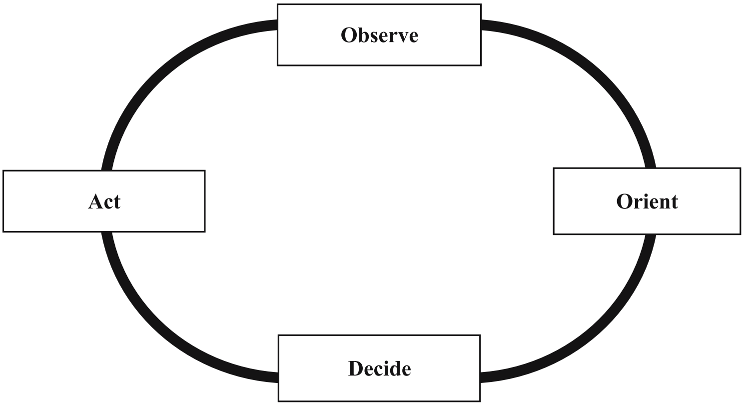


**Figure 3.** OODA loop

## 6.3 BI for the Masses

Until recently, business intelligence tools and outputs were made available only to BI specialists and BI outputs to senior managers and planners. That is changing. BI tools are moving to the mass of knowledge workers, not just the specialists. The gap between analysis and operations is being closed as BI moves to multiple levels in the organization. Where previously, typical use was for one-off analyst studies responding to specific queries, BI is seeing vast deployments such as access for 70,000 people at French Telecom and 50,000 at US military health systems. Systems with over 20,000 users are becoming more common.

# 7 People

Business intelligence is centralized in some firms and decentralized (e. g., in strategic business units) in others. Irrespective of which of these organizational forms is used, four types of skills are needed (Humphrey 2003): user, business systems analyst, data administrator, and developer.

## 7.1 Types of Personnel

The users are the people in the business who work with the BI outputs, do the analyses, sometimes validate the data, and generate new requirements. Their level of involvement can vary from occasional user to power user. The business systems analyst, usually a member of the information technology staff, manages the interface between the users and the data warehouse. The analyst needs to understand what data is available, the metadata, the predefined reports, and the analysis techniques being applied. The administrator manages the day-to-day operations of the data mart or data warehouse used for BI, making sure that the appropriate data is current and available. The developer creates or obtains new software as requirements change.

## 7.2 User Characteristics

Although power users want feature-packed BI tools beyond slice-and-dice and will learn complex interactions with the warehouse, ordinary (BI for the masses) users want simple interactions and are not interested in manipulating additional features (Sherman 2003a).

Users are familiar with spreadsheets, rely on them, and like them, although spreadsheets are inherently error prone (Panko 2006). Thus, by working with clean data from the data warehouse and paying careful attention to avoiding errors, spreadsheets become a useful tool for communicating BI results (Sherman 2003b).

Dashboards (Section 4.1), like spreadsheets, improve communication of BI results. Some dashboards provide real-time information but others do not. Except for users involved in real-time operations (e. g., Section 6.2 on BAM), dashboard users need only periodic snapshots. BI designs should be adaptable to both types of user needs.

# 8 What Still Needs to Be Done

Like all technologies, business intelligence is a work in progress. Much still remains to be done: improvement of current systems (Section 8.1) as well as long-term developments in the field (Section 8.2).

## 8.1 Improving Current Systems

With the fusion of better analysis with the data warehouse, business intelligence can do much more than in the past. Real-time business intelligence is now routine for many firms. Nonetheless, research and development are still needed in several directions, including:

- Managing semistructured and unstructured data. While databases are quiet good for dealing with structured, numerical data, they are less able to handle semistructured and unstructured data. Yet, in decision making, it is often the semistructured and unstructured data – the pieces of information that lead to knowledge – that are the key elements of major decisions.

- Bringing documents into business intelligence. In many parts of an organization, such as research and development, legal, consulting, government relations and more, much of the available information is in documents. Documents, of course, contain semistructured and unstructured data and are rarely in the same databases as structured data.
- Training knowledge workers to use BI. As business intelligence moves to being BI for the masses, knowledge workers need to be trained to retrieve and apply BI as part of the routine of their work.

Other areas include scalability as the volume of BI outputs increase, maintaining security as ever more people become involved, and advancing the state of the art of BPM and BAM.

## 8.2 Long-Term Improvements

In the long term, BI needs to bring its many analytic and operational applications together (Eckerson 2006). Composite applications would bring together process-driven BI, business activity and business process monitoring, operational dashboards, open source BI, and more. New development techniques would embed analytics into business processes and would make BI applications as simple as drag-and-drop. By embedding analytics, users would no longer be conscious of which BI tools they use.

Embedding not only would bring BI closer to operations and the processes that drive the ongoing business, but would also make BI easier to use and pervasive. The long-term goals of BI are ease of use and pervasiveness.

# 9 Conclusions

Business intelligence grew from being primarily a static, highly graphical presentation of simple aggregations and analyses of existing data to being a fully fledged analytic tool to support decisions about the future. It is the embodiment of the data-driven DSS.

The transformation is the result of advances in both the model base and the database components of DSSs (Sprague and Carlson 1982). In particular, the database component of DSSs, which had long been neglected in favor of the model base, was revived by the creation and use of data warehouses and data marts with their single view of the truth. In terms of analysis, the ongoing growth and adoption of methods for dealing with data, such as data mining, improved the model base component. Business intelligence also made use of the advances in human-computer interaction that improved the interface, although those improvements were mostly at the margin.

Business intelligence moved to real-time analysis, including the use of dashboards, while also expanding the time horizon through predictive analytics. New directions for support came with the introduction of business performance measurement (BPM) and business analysis monitoring (BAM). The technology is now available on the desktop, and companies are providing business intelligence to ever increasing numbers of their employees.

Some problems still need to be resolved. Systems need improvement in dealing with semi-structured and unstructured data. Documents contain large amounts of information that is not now incorporated into business intelligence. Improved training is required as more and more people become involved. These are short to medium-term problems. In the long term, business intelligence clearly promises to become imbedded in business processes so that knowledge workers will not even be aware that they are using it.

In summary, business intelligence is an important approach to decision support. It is not an oxymoron.

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# CHAPTER 46
# Competitive Intelligence Systems

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Competitive intelligence systems help decision makers identify opportunities to improve the company or organization's strategic position among competitors, customers, and suppliers. Such systems rely upon heavily qualitative information and the intuition of decision makers. This chapter discusses some strategies for adapting conventional DSS technology and web technologies to provide that support. A specific example developed for a tertiary hospital is used to illustrate the process.

**Keywords:** Strategic decision making; Business intelligence; Environmental scanning; Qualitative analyses

## 1 Introduction

Competitive intelligence (CI) produces knowledge about the external environment in which a firm works. It is a subset of business intelligence, discussed in the previous chapter, that is concerned with external pressures and influences. Thus CI is the process of monitoring the environment to help decision makers identify either problems to address or opportunities to exploit to improve their position. Specifically, it includes:

- the process of monitoring the competition and other environmental factors
- capturing essential measures of activity
- organizing the measures
- presenting that information to help decision makers detect and respond to changes in the environment quickly

Today's environment has a rapidly changing landscape where new competitors, suppliers, or customers are entering the marketplace, and where current competitors are offering new products. The need to be proactive is vital, and that requires monitoring of changes both within and outside the firm. Such monitoring can provide answers to questions such as: Which companies are going out of business? Which new products or services are being introduced? What products or services might be substitutes? What are customers or suppliers doing? The focus of CI is to obtain this kind of information so that decision makers can examine how the organization can exploit shifts in the environment to improve its own position (Fuld 2006, Imhoff 2003, Nordstrom and Pinkerton 1999).

## 2 The CI Industry

The CI industry is growing rapidly, now representing trillions of dollars world wide (Carr et al. 2003). Strategic planners, such as Porter (1998, 2002), say that good CI is more important now than ever. This growth is due, to some extent, to the increased size, complexity, and multinational operations of most firms. Said differently, increasingly large amounts of information need to be processed today than in the past. Also, with the use of electronic sources on the Internet, data is spreading quickly and managers must act on information more quickly than in the past.

The increased need for CI is also being fueled by the increasing mobility of the workforce. In the past, when managers began work as apprentices, and worked in the same (or similar) organizations with the same (or similar) products for their entire lifetimes, they gained experience, developed sources of information, and learned how to evaluate information. They developed ways of acquiring, evaluating, and processing information about their environment efficiently for their situation. Their decision making, based on a much greater historical perspective, generally was more open-ended, involving more speculation about unstated possibilities. In other words, they became more intuitive in their approach to understanding their environment, and thus less in need of CI support. Clearly in today's mobile workplace, the competitive intelligence system (CIS) needs not only to provide the data, but also the perspective on how to use this information effectively (Sauter 1999).

## 3 Collecting CI Input and the CIS

At the most basic level, collecting competitive intelligence data includes reading trade journals and newspapers, viewing advertising (including job advertising), and generally tracking other organizations' actions. It also includes monitoring web pages, blogs, news feeds, web listings, speech transcripts, government documents, news services, professional meetings, webcasts, and the like. Not only are the raw data about competitors, suppliers, customers and others from these sources important, but so is the processed information from these sources about what the raw indicators may mean. For example, Fuld (2006) notes that sometimes the information that is *not* presented tells decision makers the most about other organizations. The absence of information about a particular product might tell decision makers that competitors are developing plans for it; the appropriate response might be to take pre-emptive action (Salmela et al. 2000, Samamurthy et al. 1994, Sheng et al. 2005).

The goal of the CIS is to provide a *balanced* picture of the environment to the decision makers. The CIS supports *strategic* decision making, and that requires a reasonable assessment of the direction of the future and guidance from that assessment to outperform competitors. Such a reasonable assessment can only be obtained when the CIS casts a wide net for information. Limiting the set of sources, the time period, or the people involved is likely to skew the data available and thus the interpretation of likely events and conditions in the environment. Needless to say, this is undesirable. Fuld (2006) reminds us that it is the job of *all* employees to gather information for the CIS. Their wide range of sources and perspectives helps minimize bias in the estimation of the environment. In addition, as we will discuss later, constant electronic scanning of Internet sources also helps to provide the necessary perspective. In complex and dynamic markets, decision makers also need quick access to insights obtained from the data. (Nguyen et al. 2005). The information must be organized and digested systematically to determine not only what trends are present, but what responsive actions are suggested by those trends.

Many studies report the importance of CI in the organization (Fehringer et al. 2006, Holsapple and Jones 2004, Trim 2004), especially, as noted by Vedder et al. (1999) and Fuld (2006), to the chief executive officers (CEOs). CI without an accompanying support system runs the risk of providing information that is biased, incomplete, or poorly constructed. Even when the information may be presented to suggest actions, it often is not conducive to stimulating creative responses. Montgomery et al. (2005) and earlier studies (e. g., Reibstein and Chussil 1997, Urbany and Montgomery 1998) note that decision makers, when relying on their own informal processes and intuition, do not evaluate the impact of environmental factors well. Instead, management needs systematic support regarding information external to the organization as the basis for decision making, even when such data are qualitative in nature.

The number of factors that need scanning should not be limited by the industry, market, or organization's strategic plan. Although in the past it was not necessary to scan corporations that were not competitors, today's marketplace, with mergers and changing abilities, requires broader scanning. A company irrelevant today may, in fact, be tomorrow's supplier of raw or semi-processed materials and/or customers. The problem is complicated further by the kind of information needed to support such competitive decisions. Consider the nature of the information on which these decision makers need to act. Environmental information, by its nature, is information from outside the organization, and so may be difficult to accumulate. Clearly, some of the information is in the form of earnings, costs, market share and other facts that are easily processed for decision makers. However, other information is difficult to measure and represent. One category might be called rumors. Rumors include data about such factors as new products, mergers, problems, and expansion. While the rumors can, especially when they are from multiple sources, provide the first indicators of changes in the environment, they are not generally collected and processed in any systematic way. Another category might be called speculation. Speculation is a step removed from rumors in that it is based on someone having digested trends and information available to determine the patterns that exist in the environment.

Rumors and speculation only become useful in supporting decisions when they are broadly representative of the environment. So, the CIS must be developed to maximize the number of useful information channels. The more diverse the channels of information considered, the better the competitive intelligence that is derived (Chiasson and Loyato 2001, Fuld 2006, Fehringer 2006, Dean and Sharfman 1996). A good CIS will weave together information from diverse sources to help decision makers recognize the importance of the information to the decision and to the *organization's* goals (Nutt 1998, Trim 2004).

## 4 The Role of Competitive Intelligence Systems

Competitive intelligence systems, then, focus on the environment. By their nature, they provide information about entities other than the organization to provide support for decisions that have strategic implications. They should include the following:

- A mechanism to provide an early warning of threats *and* opportunities: what are competitors, customers, and suppliers doing? How will it help or hurt business?
- Support for the strategy development process: what are the current trends in the marketplace? What strategies will help the decision makers to capitalize on those trends?
- Assistance with instilling a sense of urgency and motivation toward action: What does the sales force know that the headquarter's decision makers do not know? How would this exchange of pertinent information affect business decision making?
- Support for strategic and operational decision making: What should the company do to compete effectively during the next five years? What changes would help us run the business better today?

Since the development of systems to handle well-structured factual information in decision support systems is well documented in this book, the remainder of this chapter focuses on other aspects of CIS support. In particular, this chapter focuses on how to collect and process both human sources and electronic sources of *qualitative* information to support strategic decisions.

## 5 Qualitative Data and CISs

Qualitative-based analyses to support decision making are more complicated because they do not fit in the black box associated with conventional models. In particular, qualitative-based analyses are characterized by the feature that relevant criteria cannot be quantified in a common measure. The evaluation of each piece of information for relevance and insight is unique. Further, since the process of evaluating the information lacks common units of consideration, inter-comparison of the meaningfulness of information often cannot be completed in a lexicographic manner, as is done with conventional decision support tools (Brugha 1998a, Brugha 2005). As such, it is impossible to provide even ordinal ranking of the relative importance of the information without subjecting it to the particular information processing routines of decision makers (often described as judgment, Brugha 2000). Said differently, qualitative decisions rely upon the wisdom, experience, and information-processing capabilities of the decision maker. Any analysis of the data outside of that processing system is not meaningful.

## 5.1 Collecting Data

That these distinctions cannot be made quantitatively, however, should *not* mean that decision makers should be left with nothing but fuzzy impressions. Brugha (1998a, 1998b) and Brugha and Bowen (2005) challenge us to incorporate a scientific approach to using and evaluating these qualitative data. Brugha's general approach is based on the philosophical premises of Hegel and what he calls decision research. In particular, he describes a need for labeling phenomena in terms of individual-oriented issues, context-oriented issues, and situation-oriented issues, to discover patterns and create directions for activity.

What the foregoing means is that CIS designers must think creatively about how to collect and share *useful* information with decision makers as well as shield them from the noise. To achieve this goal, let us think back to how the information itself might impact a decision maker. Sometimes decision makers are greatly influenced by information because of the source of the information (Sauter 1997). To paraphrase the old commercial, if a particular economic analyst speaks, the CEO listens. Hence, when that particular economic analyst makes a statement or prediction of relevance to the organization and/or its market, then the CIS should make that information available immediately. Some upper-level managers want to know when information comes in about a particular topic because they are already considering some action to respond to it. Other managers may want to know when lots of information on a topic or competitor (or customer or supplier) becomes available. Therefore, the output of a CIS should be customized to the decision maker and his/her specific needs.

## 5.2 Early Warning Signals

The system can also be used to generate early warning signals of a problem or opportunity. In particular, the system can generate regular reports summarizing entries made in the system during the previous week, month, six-month period, or

**July 1: Physician Report**

**Dr. Schremp**

| Date | Discoverer | Source | Public comment | Private record available | Status | Record | Related record |
|---|---|---|---|---|---|---|---|
| 1-May | Mathilda Moser | Medical Records | Doctor Schremp referred 5% of the patients in this specialty during the last fiscal year. | no | Verified | 987 | |
| 15-May | Representative Schmidt | Nurse Saluda | Doctor is nervous about recent mergers and affiliations and what they will mean to his practice. | yes | Noted | 1002 | |
| 30-May | Representative Schmidt | Doctor Schremp | Doctor noted in conversation that he is attempting to sell and/or affiliate practice. | no | Verified | 1010 | 1002 |
| 10-Jun | Representative Schmidt | Doctor Schremp | Doctor is negotiating with Quick Care Managed Care | no | Noted | 1020 | 1002 |
| 30-Jun | Representative Schmidt | Good Health administration | Doctor has just begun talking with Good Health Managed Care, and has noted interest. | yes | Disproved | 1028 | 1020 |

***Hospital-Linked Records***

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1-Jul | Vice President Gowdy | Doctor Armenta | Nelson's Hospital is in negotiations to sell to Quick Care Managed Care. Note: Dr. Schremp sends many of his less dramatic cases to Nelson's Hospital. | yes | Noted | 1057 | |

***Region-Linked Records***

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1-Jul | Department manager Hearris | | Quick Care Managed Care (QCMC) is increasing its presence in the region. This hospital does not have a contract with QCMC. | no | Verified | 1072 | |

**Figure 1.** Sample report for a CIS*

year. Of course, a decision maker does not want to view *all* entries during any of those intervals, only those that suggest action and relate to their (or the organization's) goals. The system should be set up to generate reports about those customers, competitors, suppliers, or others in the environment for which there are several entries in a given time interval. A default for the number of entries necessary to generate such reports should be set, but decision makers must be given the ability to override that limit if he or she finds a need for detailed information, or information over shorter or longer periods.

For example, the report shown in Figure 1 illustrates a CIS designed to help a hospital manage its operations in light of changing medical plans, affiliations, and regulations which, in turn, impacted the profitability of the hospital (Sauter and Free 2005). In this context, the hospital is concerned about affiliations of physicians with the hospital (since they feed the pipeline of the hospital) and the insurance plans with which those physicians are affiliated (since insurance also affects the profitability of the hospital). When physicians decide to share services, drop insurance plans, or move offices, the hospital (and its profitability) is impacted. Hence, hospital administrators need to track such changes and, where appropriate, respond by providing additional services, changing medical plan affiliations, or offering incentives to physicians to keep them supporting the hospital. In light of that interest, the hospital views physician behavior as important, and hence decision makers track that information for strategic changes. Figure 1

* adapted from Sauter, V.L. and D. L. Free, "Competitive Intelligence Systems: Qualitative DSS for Strategic Decision Making," The Database for Advances in Information Systems, 36(2), 2005, 43–57.

shows a typical regular report that is sorted by physician, and shows all entries regarding a particular physician that have been entered during the previous month.

The five entries relating to Dr. Schremp in the database over a six-week period are not the only information relevant in the system. Note there are two additional entries printed in this report, one for the hospital with which Dr. Schremp has his primary affiliation, and one for the region in which Dr. Schremp operates. These entries about Dr. Schremp are linked automatically not only to this report, but also to all physician reports for which the affiliation is the Nelson Hospital and that fall in the particular region. Similarly, if Dr. Schremp were affiliated with a managed care plan, or located in a state for which an entry was relevant, information about the managed care plan would also be printed on Dr. Schremp's report. In this way, the decision maker receives the benefit of the broader information source without needing to remember to check other reports.

Individually, none of the statements in Figure 1 provide any reason for action. However, when viewed as a group, they clearly note a need for action since they suggest that the hospital is in jeopardy of losing a certain percentage of its referrals in that particular specialty within a short time. It does not present the complete picture, because the summary only provides information for one doctor. The decision maker could run reports for the Nelson Hospital, and could link to affiliated physicians and print records for which there is an entry during the relevant period, or the decision maker could run reports for all physicians in a particular specialty to gain insight into what the impact might be.

The CIS does not provide a solution, but allows the decision maker to view all of the facts *in toto, and from different perspectives*, to come to his or her own conclusion. Without the system, however, the hospital administrator would likely not have access to all of this information simultaneously. Even if the information were available as rumors, the hospital administrator would need to accumulate them, link them together, and verify them. Considering the large number of physicians involved in the hospital, the odds are against the administrator knowing about, much less linking together, the relevant information about any particular physician in a timely fashion. In addition, deriving patterns from an internal system at the hospital provides decision makers with what has been referred to in the literature as the social desirability of appearing proactive, and not simply being reactive to external events.

In the hospital application, the summarization of data from many sources helped to legitimize the qualitative data in the decision makers' views. Many decision makers viewed the original anecdotal data as no more than rumors, and therefore not worthy of their attention, and not legitimate decision support. They had a different view of the system-generated report, and summary statistics associated with the report, which were viewed as useful. Once the data were entered into the system, and provided *from* the computer, it metamorphosed rumors into qualitative data, which were considered legitimate support for decision making (Sauter and Free 2005).

## 5.3 The Database and Data Entry Options

In order to achieve the advantages of CI, the system must:

- transform the qualitative information into an intelligence report, and
- provide some data summary that will help the decision maker know how to use the information.

Further, the CIS must:

- make the process easy
- get information to the people who can use it at the time of the earliest warning signals
- do it as cost effectively as possible.

To provide the necessary summary and analysis options, the CIS should be designed to store and transform the individual scraps of information, which we call anecdotes, into a pattern of information that identifies possible problems or opportunities on which a decision maker should act. To achieve that transformation, the CIS should categorize information to allow for effective search and summary later.

Categorizing requires that each entry be coded with the date and the source. Source information allows for later follow-up, as well as for auditing of the entries to determine the overall credibility of the source. In addition to the person entering the data, the entry needs to be coded for where the information originated. The source might, for example, be a newspaper, stock report, another client, or an employee of a client or supplier. It is critical that the categorization be customized to the organization and its view of the environment. For example, a hospital might have categories such as the person about whom the report is filed, another health care professional, a non-health-care professional, media, and other sources. On the other hand, an international manufacturing organization may need finer categories that include the country of origin of the source, as well as a variety of electronic sources, such as web pages, web summaries, blogs or newsgroups. In data entry terms, some form of closed-response, such as a drop-down box or radio buttons, is necessary to ensure uniformity of the responses to facilitate later analyses.

The anecdotes should also be coded for the topic for easy summarization. These topics should be customized for the industry or corporation being served. The topics might be as simple as customer, potential customer, competitor, potential competitor, supplier, potential supplier, and regulations. They might also include sub-topics such as location, mergers and acquisitions, spinoff plans, and executive changes. When developing such a system at a national level for security purposes, for example, categories would include economic, developmental, political, military, and aid. Here too, the subject of the anecdote should be close-ended and meaningful to decision makers to allow easy analysis.

Another important functionality is to code the anecdote by its status. For example, anecdotes might be coded as noted, verified, or disproved. As information is entered for the first time, the user can mark it as noted to show that the information was obtained, but that he or she has no knowledge of its accuracy. Later if evidence is provided by this source or another individual, the statement can be noted as verified to increase its credibility among decision makers. Such labeling also allows the decision makers to track the period of the evolution of the information from just rumors to facts. Finally, if the statement is shown to be false, it can be noted as disproved, again allowing users to understand the credibility level and track the time horizon during which it was thought to be true. While there may be reasons to drop the anecdote from the database once the information is identified as false, more often keeping the information in the system is appropriate; even disproved information may suggest a phenomenon that needs attention by decision makers. Further, it allows decision makers to evaluate the historical reliability of sources to help determine how much influence the source should have in the future.

Although the categorization of the anecdote is structured, the CIS must allow free-form entry of the anecdote itself. Fields in this section are free-form memo fields, encouraging the user to write about the information in any convenient manner, and with as much detail as the user feels is necessary.

## 5.4 Automatic Scanning and Populating the Database

In the past, the bulk of the population of the database behind a CIS would be entered by hand. As employees learned of something new, they would need to invoke the system and add the anecdote. This approach requires all the employees to be connected, and all the users to be trained. More importantly, since most of the users would not have a reason to care about such data, management would need to provide incentives to encourage employees to participate (e. g., Sauter and Free 2005).

An enormous amount of information is now available on the web. Most newspapers and magazines have at least some component that is available online. Websites, blogs, and newsgroups are sources for external business information. This information is now a component of CI to be exploited (Buono et al. 2002). Tools, such as bots, are available to extract information and populate the CI database automatically, thus freeing humans to analyze and respond to the anecdotes. Automation substantially streamlines the CI process since data collection is estimated to account for about 30% of the total time spent in CI (Prescott 1989).

Electronic bots can visit sites regularly and record changes to the information, or even bring the changed webpage to the attention of a human for evaluation (Hodges 2005). They can be set to search for particular words, particular kinds of changes, and/or new opportunities. Webcrawlers can be programmed to find new mentions of products, companies, patents, people, or other information. In fact, webcrawlers such as INSYDER can be programmed to find new CI information intelligently by learning relationships among items in the domain knowledge defined by decision makers (Reiterer et al. 2000). CI Spider finds relevant information in real time that focuses on precision and relatedness of documents to known items of interest (Chen et al. 2002). Similarly, other tools not only find the information, but intelligently display the information to help decision makers understand relationships (Buono et al. 2002, Porter 2001).

Automatically culled information can also be added to the CI database without human intervention. Intelligent systems can be developed to find key words for classification of the documents in a manner similar to that used by humans. Of course, since there can be any number of ways that web-based sources can harbor planted and/or unreliable data, CISs also need to provide validity information [such as the actual uniform resource locator (URL), updated date and source] and perhaps be trained to differentiate good from bad information. At the very least, automatically generated items need to be highlighted in the CIS to encourage decision makers to require validation of this information before using it.

## 5.5 Data-Mining Tools

Sometimes, especially in the light of automatic population of the database, CISs can provide so much information that users become lost in the enormity of possibilities and miss the proverbial forest for the trees. Data-mining tools facilitate analyses because users can define criteria for examining those data. Users can employ filters based upon specific qualifying criteria, such as changes in suppliers or customers. Or, users can define percentile and rank filtering. Using this option, decision makers could identify the source of the top 10% of their raw input, for example, and see what intelligence has been collected specific companies. Hence, users can specify information to be found regarding a particular company and compare that to other companies or to the industry as a whole. Sometimes scanning all relevant data can help the decision maker extract similarities among events, and hence pose hypotheses.

Data-mining tools are often combined with artificial intelligence techniques. These techniques can not only identify relevant data, but also relevant patterns in the data. In fact, if they work well, data-mining tools should suggest associations to spur intuition or to confirm or disconfirm intuition-based hypotheses. Data-mining tools find patterns in the data, infer rules from them, and then refine those rules based upon the examination of additional data. These patterns and rules might provide guidelines for decision making or identify the issues upon which the decision maker should focus during the choice process.

## 5.6 Specialized and Private CI Components

Even as decision makers gain experience with phenomena in the environment, they may need to record their reflections about the data, and be given a mechanism for organizing their notes. This process may include results from applying rules of thumb about sources, subjects, or processes. They may need to record decisions they make from the information, and the results of those decisions. They may also have data that they have collected privately that they want to incorporate into the CIS analyses. Sometimes, they simply need to keep notes of political processes in the organization and how they might influence, or be influenced by, a particular decision.

If a CIS is really going to provide this kind of support for industry decisions, then it must facilitate the development and maintenance of these private databases. That is, the systems will need to help the decision maker generate and populate these databases, as well as provide easy access to the data and a wide range of retrieval mechanisms. If the system resides in a distributed environment, it is possible to maintain private CI data only if sufficient security ensures that only the decision maker can access the information.

### 5.7 CIS Reports and Queries

Regardless of how the information is obtained, the CIS needs to be flexible in how it provides information to the decision makers. One approach is consistent reporting, discussed earlier. Having the system supply regular reports helps decision makers learn to rely more upon the system. For example, in the hospital-based application described earlier, although the system was easy to use, decision makers tended not to think of obtaining information from the system as their first option. Hence, rather than relying upon decision makers to query the system regularly, designers created a reporting mechanism that would bring ideas to the attention of the decision makers quickly and automatically. Reporting encouraged early adoption, because the information was chauffeured to the decision maker at the outset to help them experience the value of the information, and hence the system, before they learned the specifics of running the system (for themselves). Reports provided the extra value to encourage the decision makers to incorporate the system into their regular choice processes (Sauter and Free 2005).

Another approach is to allow users to query the system regarding particular topics of interest to them. For example, if the decision maker knew from regular news sources that a customer was changing some aspect of their operation, he or she could query the system. By accessing the comments available in the system, he or she can form a more-thorough picture of what is really happening regarding the customer, and so decide what impact this change is likely to have on their own business.

## 6 Additional Support

The chapter began with a view that decision makers needed CISs because of the increased complexity of most business decisions today *and* the increased mobility of the workforce. The chapter discussed employees entering data and having electronic surveillance of relevant online sites. This approach helps provide the decision maker with an unbiased and multifaceted perspective of the environment. That helps them make better decisions.

The CIS must do more though. Decision makers need information that illustrates trends in the environment, not simply a frozen view at some point in time. Therefore the system should be able to track the data by date and illustrate the results to decision makers. These data allow decision makers to see how factors have changed over time and how circumstances affect the issues considered. This, in turn, helps decision makers experience more aspects of the environment (Sauter 1999).

Decision makers need some assistance to help them understand what they do not yet understand about the environment. This help can be obtained by preparing summaries in the form of prepared analyses available for use by the decision maker (Sauter 1999). Or, it may include context-specific intelligent support tools that can help decision makers evaluate missing or biased information or changes in the patterns that are being observed. These techniques help decision makers develop intuition and thereby improve overall responsiveness to the CIS.

## 7 Ethics and the CIS

The formalization of CI activities and the creation of CISs do not give licence to organizations to conduct corporate espionage through dumpster diving or other covert actions in an attempt to steal trade secrets from their competitors. Sound business ethics prohibit companies from obtaining information through misrepresentation, coercion, or invasion of property. States in the U.S. differ in how they interpret industrial spying and inappropriate data collection activities that involve stealing corporate secrets. Within the U.S., these differences have been addressed by the passage of the Economic Espionage Act in 1996. Clearly there are also differences among nations.

Since the laws vary and are, in some cases, vague or unregulated, corporations can rely on corporate ethics and the desired corporate image to guide the decision of what activities are appropriate for CI. Experts in the field suggest the sniff test: if decision makers think it will look bad to see the data collection activities summarized on the front page of the morning paper, then those activities should be avoided (Burns 2002). There is plenty of (often overlooked) information available through overt methods that can paint a picture of competitors' activities when integrated and summarized. Ethical collection and careful analysis will serve the organization better in the long term.

## 8 Conclusion

At the beginning of this chapter, we defined competitive intelligence as the process of monitoring the environment to help decision makers identify either problems to address or opportunities to exploit to improve their position. To do so requires identifying situations and responses quickly and reliably. Competitive intelligence systems, then, are decision support systems that facilitate this process. They are different from conventional DSSs and from conventional business intelligence because they focus outside of the organization, and because they rely on qualitative data. The CIS should be designed to allow both human and electronic entries, data summaries, evaluation of sources, and broad functionality to help decision makers improve their intuition about the environment and its data. This chapter provided an overview of how conventional DSS technology can be adapted to provide this support.

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# PART VII

# Scopes of Decision Support

# CHAPTER 47
# Process-Based Decision Support

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Business decision- and process-modeling methodologies have developed largely independently. The existing lack of cross-discipline integration in the area of business modeling is not only counterproductive for future methodological advances, but also imposes unnecessary limits on the ability of the existing business modeling tools to reflect the complex integrated nature of a business enterprise adequately. Process models underlying integrated business systems are powerful tools addressing organizational efficiency objectives. The ability of a process to meet organizational objectives is a measure of organizational effectiveness. In order to meet both efficiency and effectiveness objectives of the business, it is essential to understand how functional, process, and overall organizational objectives interact. This chapter discusses the relationship between business decision-modeling and process-modeling methodologies and describes how decision support models can be used to enhance enterprise capacity to meet its overall objectives via more-effective business processes.

**Keywords**: Process; Decision support; Event-driven process chain (EPC); Modeling

## 1 Introduction

Business modeling, defined as "the use of models and methods to understand and change business operations together with information systems in organizations" by Nilsson et al. (1999, p. 1), has been the focus of extensive research effort within a variety of related disciplines, such as process and information modeling, decision analysis, business dynamics, and quantitative modeling. There is general agreement that business modeling must address both efficiency and effectiveness concerns of the business, but the strengths and weaknesses of each discipline dictate that models mainly focus on either efficiency or effectiveness. The objective of this chapter is to demonstrate how these efficiency and effectiveness concerns can be combined as a result of integration of decision models within the process engineering context.

A large number of techniques and tools have been developed to represent business processes. Hommes and Reijswoud (2000) identified in excess of 350 business process-modeling tools available in 2000. Some of these tools (e. g., Aguilar-Saven

2004, Bosilj-Vuksic, Giaglis and Hlupic 2000, Katzenstein and Lerch 2000, Powell et al. 2001, Rolland 1998, Scheer 1999, Yu 1999) were developed for a specific modeling purpose, while others are more generic, aimed at integrating a whole range of modeling tools under one roof. Generic tools such as the ARIS (Scheer 1999) environment are designed with the aim of providing a complete modeling environment for an organization, and are therefore a natural choice for a process-modeling environment that would benefit from integration with decision support tools.

In integrating process and decision models, care should be taken to understand different conations of the terms decision and decision support within different contexts. These differences are explored in section 2 of this chapter in order to explain the motivation for development of the decision-enabled extended event-driven process chain (de-EPC). Having explored the differences, the complementary nature of decision-modeling and business process-modeling tools is discussed in section 3, leading to a proposal for an integrated model in section 4. The benefits of the integrated model are discussed in section 5. The chapter is concluded with a brief summary.

## 2 Decision Versus Decision

To illustrate differences in terminology, consider advertising activity in a recruitment process. The decomposition of this activity is illustrated in Figure 1 with the help of the event-driven process chain (EPC) model. The EPC and extended EPC (e-EPC) are graphical representations or models of business processes in the ARIS House of Business Engineering (Scheer 1999, 2000).

Within an EPC model, business activities are represented as movements between states, with each activity originating from and resulting in *a change in the state* of a business as *described by the event* (Aalst 1999, p. 4). Each event provides a qualitative description of a change to one state variable that is important to the control flow of the process. Functions and events can be connected by logical rules (i. e., AND, OR, XOR) to represent different workflow patterns. To enable representation of other business flows and objects, ARIS House extends the EPC to include related business objects (e. g., information, objectives, organizational units, etc.) as illustrated in the e-EPC insert of Figure 1.

The EPC model provides a comprehensive description of the steps involved in the process and, as such, it is claimed to provide some decision support in so far as allowing the decision maker to identify the sequence of events and functions within a process, the functional inputs and outputs, and the stakeholders involved with the decision-making process (Davis 2001, Loos and Allweyer 1998, Scheer 1999, 2000). This may be sufficient for supporting straightforward decisions. For example, Figure 1 illustrates decomposition of the receive job applications functions, and provides a step-by-step process to decide whether to return a late application.

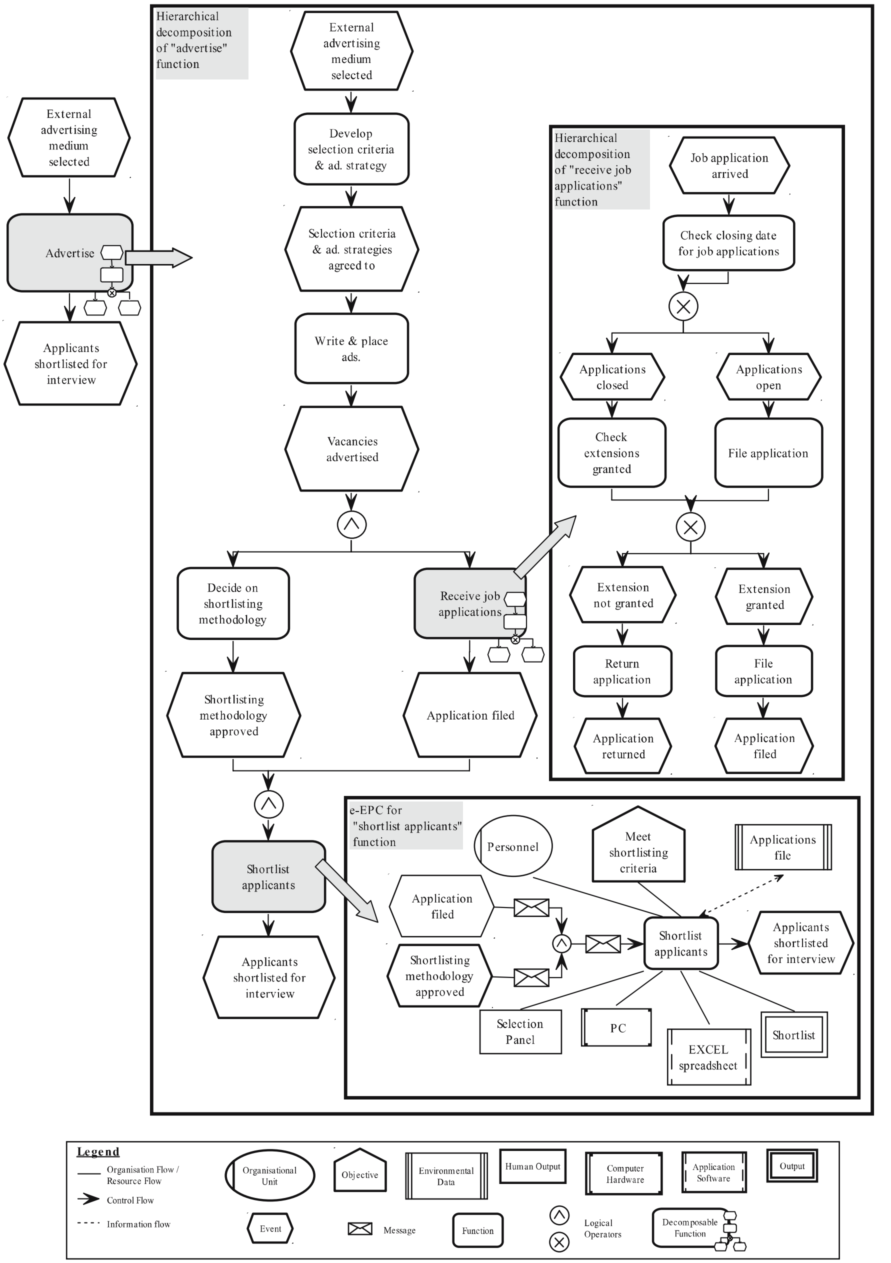


**Figure 1.** Illustration of different decisions

Within process engineering texts, the discussion of decisions is limited to these types of decisions (e. g., Davis 2001, pp. 120–127). For example, the OR-connector in Figure 1 is referred to as multi-choice (Aalst et al. 2003); in other words, at the time of process execution a choice must be made as to which process flow path should be followed next. These decisions are referred to as structured within the DSS literature (e. g., Sage 1991), as they can be easily decomposed into a sequence of steps.

Many business decisions do not fall into this category, as they require more-sophisticated structures and solution algorithms than are available within the operations research and management sciences (OR/MS) disciplines. For example, consider the shortlist-applicants function in Figure 1. Within the ARIS environment, the description of this function can be extended to include all relevant business objects and flows. For example, the personnel section is nominated as the organizational unit responsible for the execution of the shortlist-applicants function, the output of the function is the applications-assessment shortlist, and the choice of the selection panel for the interview (human output). The software used to perform the function is a spreadsheet package run on computer hardware (a PC) and uses environmental data contained in the applications file. While this information clearly helps with making this decision, it does not explain how to go about selecting the best *n* out of *N* available applicants according to a specified set of selection criteria in compliance with a multicriteria methodology. Unlike the case of a highly structured decision, it is neither practical nor beneficial to describe the multicriteria model as a process decomposition within the ARIS environment, especially since there are specialized tools available within the OR/MS discipline that have been developed to deal with this particular decision problem.

To differentiate between these very different types of decisions, Gorry and Scott Morton in 1971 (in Gorry and Scott Morton 1989) defined the continuum of unstructured, semistructured, and structured decisions. The exact position of a shortlisting decision on an unstructured-structured continuum is debatable. At the initial stages, this decision is likely to be a highly unstructured decision. However as various elements of the problem become resolved, the decision becomes increasingly structured until finally it is solved and, therefore, can in principle be described as a sequence of steps leading to the solution.

Therefore, to structure the decision, an underlying decision model has to be defined. A generic decision model is described in Table 1.

As can be seen, a generic model consists of a set of elements including alternatives, constraints, states of the world, consequences or outcomes, optimality criteria, and a choice of modeling routine (Clemen and Reilly 2001, Mallach 2000, Winston 1994). Whilst not every element is required for each decision model (e. g., optimality criteria or states of the world may not be applicable for some decisions), the process-based decision-modeling tool must have the capability to support all elements if required, as different decision models may be called upon in different parts of the business process.

**Table 1.** Decision situation components

| Component | Description |
|---|---|
| Alternatives | Generally speaking, a set of possible *actions* or *choices* defines the *decision variable space*. To construct a *decision model*, *decision variables* should be selected to adequately quantify a set of possible *actions*. The decision variables could be discrete or continuous, and could take on positive, negative or integer values depending on a specific decision situation. |
| Constraints | *Functional constraints* on the *decision variables* define a feasible set of possible actions. Constraint functions could be quite complex including linear, nonlinear, and probabilistic functions. |
| States of the world | Depending on the decision situation, there may be one or more *states of the world* describing circumstances that affect the consequences of the decision and are completely outside of the decision maker's control. Some decision-making situations, such as a team assignment problem, require the decision maker to choose an optimal combination of staff to achieve a pre-specified mix of skills and levels within a team. Such situations are fully deterministic and, therefore, do not explicitly specify the state of the world. In a decision model, *states of the world* are usually described by a set of *environmental variables*. |
| Consequences or outcomes | One of the essential elements of a decision situation is the *consequence* or *outcome* of the decision. In a decision made *under uncertainty*, the *outcome* would depend on the *states of the world* as well as the *action* chosen. In some cases, *uncertainty* could be associated with *outcomes* as well as *states of the world*. In a *decision model*, *utilities* are used to quantitatively describe the outcome of the action via *utility functions* that model the *objectives* of the decision. |
| Optimality criteria | Most decision-making situations and models include *optimality criteria* that specify utility preference such as maximum profit or minimum costs. However, there are some models, such as *feasibility* or *constraint satisfaction* models that do not require optimality criteria to be specified. |

Given the dynamic nature of decision making, the classification of a decision is time dependent as the process of identifying (applicable) decision model elements moves decisions along the unstructured-structured continuum – the more we know about a decision the closer it is to a structured decision. At a point in time, the term ***structured decision*** is used in this paper to describe decisions for which the relevant decision model components described in Table 1 are easily identified by a decision maker. The term ***unstructured decision*** refers to decisions for which none of the decision model components are readily apparent, with the term ***semi-structured decision*** being used for decisions where some (but not all) of the components are clearly defined.

This classification deviates from some definitions of decision structures (e. g., Eom 2000, p. 124) in that it allows problems with conflicting objectives, uncertainty, and complex variable structure to be classified as structured, provided a well-defined decision routine exists that can provide a solution to the problem. This is consistent with the decision classification based on "whether the decision making process can be explicitly described prior to the time when it is necessary to make a decision" (Sage 1991, p. 2) as the availability of a well-defined decision routine (along with other decision model elements) guarantees that the decision process can be explicitly described (although it would not necessarily be the most effective way of making a decision in the business context).

## 2.1 Decision Support Systems

Having clarified what is meant by the term decision, it is now possible to explain different types of decision support systems in the context of addressing the efficiency and effectiveness concerns of the business.

Similarly to business models, business information systems are also developed to assist businesses to do the right thing (effectiveness) and/or to do things right (efficiency) (Daellenbach 1994, p. 15). Systems that are primarily aimed at supporting business effectiveness are developed in order to: (1) facilitate identification, communication and structuring of business objectives; (2) gather and report information to enable measurement of how well objectives are achieved; and/or (3) facilitate decision making that leads to the achievement of objectives. A system may have a narrow scope to enable it to support just one of these goals fully (or even a subset of a goal). For example, certain decision-modeling programs find solutions to well-defined business problems such as selection or product mix problems, or may be more generic, providing support for multiple goals, for example, a database can be used to both gather and process information and to provide measurements (e. g., management information reports) that facilitate decisions with respect to the achievement of certain business objectives. Mallach (2000, Chap. 1) refers to systems that facilitate decision making within an organization as having decision support capabilities. Systems that are developed to improve decision-making effectiveness are referred to as decision support systems (Mallach 2000, p. 8, Figures 1–3). According to Mallach (2000, p. 8, Figures 1–3) these systems generally have a low emphasis on processing efficiency.

The OR/MS discipline provides the tools for decision making within this context. Within this paradigm, information is considered primarily as an input of or an output from the model, rather than as part of the information flow interacting with other functions of the business. As a result, it has long been recognized (e. g., Rosenhead 1989, p. 10) that systems within this category often fail to model the interactions between the decisions and other business processes required for a holistic solution.

Systems that are aimed at assisting a business to do things right are developed in order to: (1) facilitate identification and structuring of business processes; (2)

automate business transactions; and (3) facilitate execution of business processes to minimize costs while maximizing returns. Similarly to systems that are aimed at doing the right things, systems that are aimed at doing things right can be specialized or generic. For example, an optical character-recognition system is aimed solely at automating data entry, while a university enrolment system will have components of automation (e. g., generating acceptance letters) and workflow control (e. g., the system will not allocate a student number until the enrolment fees are paid). These systems are limited in that there is no guarantee that the process execution is in accordance with business objectives and constraints even when they aim at improving decision processes and outcomes and, therefore, provide some level of decision support (Briggs and Arnott 2002). For example, we do not know whether the process modeled in Figure 1 will result in the selection of the best applicant, and that it will be conducted within legislative constraints such as equal-opportunity employment.

While it can be argued that most systems include elements that cater towards increasing efficiency and effectiveness, the degree of decision support usually decreases as the focus on efficiency increases and vice versa (Mallach 2000, p. 8, Figures 1–3). For example, most transaction systems include some sort of management information that can be used for decision making, and decision support systems automate certain tasks such as calculations.

To illustrate the trend, consider human-resource (HR) management systems. The focus of the HR information systems architecture and associated tools is on operational processes and functions such as administration of payroll and benefits, recruitment, and personnel management (e. g., Oracle-PeopleSoft 2005). On the other hand, decision support tools focus mainly on decisions narrowly defined to fit within the specific techniques such as Markov chains (manpower planning), linear and integer programming (scheduling), multicriteria decision analysis (selection), etc. (e. g., Winston 1994). The implementation paths of the two methodologies rarely cross due to the differences in paradigms and terminology used by the respective disciplines.

An integrated decision- and process-modeling framework overcomes this limitation. Within this framework, the overall business context can be integrated with the decision model that assists with structuring a decision problem and/or delivery of the solution for a decision model that has already been structured. Furthermore, decisions become an integral part of the business process, reducing the risk of conflicting or inappropriate (from the overall business perspective) decisions.

# 3 Relationship Between Business Decision-Modeling and Business Process-Modeling Tools

The complementary nature of the decision-modeling and business process-modeling tools is highlighted when one considers that they are both aimed at achieving an efficient business outcome, and are often concerned with the same business functions (e. g., Aalst et al. 2003, Clemen and Reilly 2001, French 1989, Muehlen 2004, Santos et al. 2001, Sterman 2000, Winston 1994). Furthermore, decision models require enterprise-wide information available within integrated business information systems, while process models of an information systems nature require decision-making capabilities of the OR/MS type for efficient information management purposes.

The shortlist-applicants function is used to illustrate the relationship between the tools supporting process and decision modeling. As business objectives modeling is fundamental to both approaches, the relationship between objectives is discussed first.

## 3.1 Objectives

It is interesting to note that business objectives at the strategic level are essentially the same irrespective of whether a process- or decision-modeling approach is used. To continue with the HR management (HRM) example, business objectives such maximizing the value of HR services and maximizing the well-being of employees are fundamental to both decision- and process-modeling methods, and it is not possible to determine which method has been used to model the functions simply by examining these objectives.

As the objectives hierarchies are built to separate various levels of objectives, the differences between methods begin to emerge. To illustrate this point, consider the shortlist-applicants function in the context of the recruitment process. At the higher level of the recruitment process, strategic objectives may include maximum efficiency and the effectiveness of the recruitment process, whilst at the lower level of the shortlist-applicants function, the specific functional goal is to meet shortlisting criteria (Figure 1). This functional goal reflects the process approach as it focuses on the process outcomes and outputs. A decision objective for the same function would be expressed as criteria (e. g., relevant employment experience, relevant academic qualifications) subject to the constraints (e. g., equal-opportunity legislation, affirmative action practices, etc.), or as an optimization function (e. g., choose the candidate with the highest relevance value) reflecting differences in the process- and decision-modeling methodologies.

Superficially, it appears that the two methods are addressing separate and independent goals and objectives. However, on a closer examination, it becomes clear that the decision objectives are a subset of functional goals with decision objectives of relevant employment experience and of relevant academic qualifications, explaining what is meant by the criteria in the functional goal of meeting shortlisting criteria. This type of relationship is common for functions that include decisions (e. g., Agrell and Steuer 2000).

Process objectives can also be used as constraints for decision objectives. For example, the process objective of minimizing response time would limit the amount of time that can be spend on arriving at a choice of applicants in the recruitment example and, therefore, affecting the choice of a decision-modeling method to be used. A similar situation is illustrated by Gardiner and Armstrong-Wright (2000).

Linking the functional goals, decision objectives, and strategic objectives enriches one's understanding of both the process and the decision, and ensures that the strategic objectives are met. Furthermore, identifying the dependencies between objectives allows for dynamic and efficient updating of both models to reflect changes in circumstances. For example, by identifying the dependency between the decision objectives of the shortlist-applicants function and the objectives of the recruitment process, it can be ensured that changes in the recruitment requirements are immediately reflected in the shortlisting decision objectives, thus avoiding time delays and misalignment between the two sets of objectives. This approach facilitates the development of a more-holistic business model that can be dynamically updated to remain relevant and contemporary.

Once the strategic objectives are defined, both modeling methods focus on the functions aimed at achieving these objectives. The relationships between the decision and process views of the function will be considered next.

## 3.2 Functions

Some functions (such as filing an application) include only a trivial decision component, and while they are included in the process model, they are of no further interest for the purposes of this discussion. Functions that do have a nontrivial decision component (such as shortlisting applicants) have two dimensions – the process and the decision dimension.

A process model is concerned primarily with the how component of the business operations, in other words, the order of functions required to achieve specific process objectives. The process view is a bird's-eye view of the function and functional flows. This view provides a description of the function, its inputs, outputs, and resources in the context of the rest of the process. In a process model, the shortlist-applicants function will be one of a number of other functions linked together to form an event-driven process chain describing the sequence of steps in the recruitment process.

As discussed in the previous section, there is no shortage of HRM process models. In Figure 1, a process model using an EPC (Scheer 1999) is provided for a recruitment process. When complemented by the data, organization, and output views (as illustrated for the shortlist-applicants function), this model can be expanded into an e-EPC to provide an integrated business process model (Sheer 1999).

A decision model, on the other hand, is concerned with the *what* component of business operations. In other words, what choice to make among available alternatives in order to achieve the desired objective. This view of the function provides an internal or X-ray view of the function. A decision model for the shortlist-applicants function would be a prescriptive model, such as, for example, a multi-criteria decision analysis model aimed at supporting the specific decision of shortlisting applicants by defining selection criteria, decision constraints, and the mathematical technique to be used to satisfy these criteria subject to the constraints (Bouyssouet al. 2000; Gardiner and Armstrong-Wright 2000, Moshkovich et al. 1998, Olson 1996). Examples of other decision-modeling techniques within the HRM context include, in particular, multi-knapsack and network flow methods used for team composition and assignment, multi-criteria decision analysis used for staff selection, and Markov chains and dynamic programming used for HR planning (e. g., Bartholomew et al. 1991, Gardiner and Armstrong-Wright 2000, Gass 1991, Khoong 1996, Winston 1994, Zeffane and Mayo 1994).

By looking at the external and internal views in isolation (as is normally the case due to disciplinary and conceptual boundaries between the process- and decision-modeling methodologies), the fact that both views support the same objectives in a different but complementary way is easily overlooked, resulting in an incomplete model of the business. Ironically, information that provides the link between the two modeling methods is essential for the effective operation of the business.

## 3.3 Information

Differences in modeling methodologies lead to differences in the role information plays in the corresponding models. Transparency of information flows is one of the objectives of an extended process model of an e-EPC type, however, the links between information inputs and outputs are not apparent from process models. A decision model, on the other hand, is primarily concerned with the transformation of existing information into new information with little reference as to where the existing information is coming from or how the new information is going to be used. The information requirements of decision models are usually well defined and specific, however, there is no guarantee that this information is available as required unless these requirements are incorporated into the process model. Similarly, the decision model needs to be an integrated part of the process, to generate the information required by the process to fulfill its objectives. Gaps in the information or extraneous information resulting from the lack of communication between the models may cause process delays and costs to the business.

# 4 Integration Model

The conceptual model for a process-based view of a decision model in Figure 2 retains the ability of the process model to deliver a holistic business model through providing an external view of the business function. At the same time, the model is decision-enabled as it includes an internal view of the function with the focus on the decision objective. Information is included in both external and

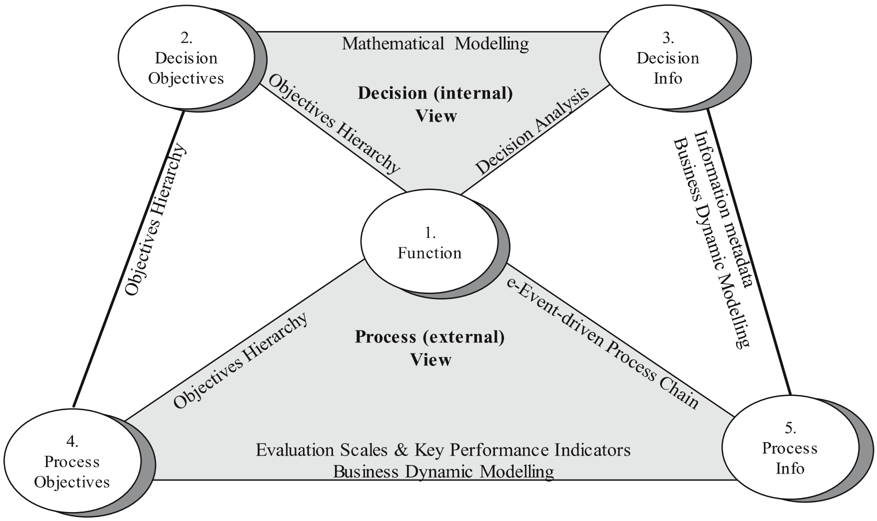


**Figure 2.** Integration model

internal views of the model, as it is essential for successful integration (Ackermann et al. 1999).

The contribution of the model towards further integration of the two methods is in the links between the two views of the function. By establishing the links, the dependencies between modeling approaches have been made transparent, thus enabling an optimal outcome. Existing methods (discussed in the previous sections) that can be used to model dependencies and interactions between the elements are shown on each of the links. Each structural element of the model is numbered for easier reference. The structural links are referred to by the start and end elements of the link. For instance, the link between elements 1 and 2 is referred to as link 1−2. The shortlist-applicants function in the context of the recruitment process is used to illustrate the conceptual model presented in Figure 2.

## 4.1 Process View

The shortlist-applicants function (element 1) is one of the functions in the recruitment process (Figure 1). The goals of this function are contained (link 1−4) within the overall recruitment process objectives (element 4). Recruitment process objectives interact with each other and can be modeled with business dynamic tools (Sterman 2000) once they are quantified (link 4−5) using the available information (element 5). The flow of information between process functions (link 1−5) is modeled by the e-EPC (Scheer 1999).

## 4.2 Decision View

In this view, the functional goals are sub-divided (link 1−2) into the specific decision objectives (element 2), such as selecting applicants with relevant employment experience and relevant educational qualifications. Decision variables (e. g., number of years in relevant employment, educational relevance scale, etc.) are populated by the decision information (element 3) and are used by mathematical models (link 2−3) to provide solutions to decision objectives (Williams 1993, Winston 1994). Decision analysis tools (link 1−3) such as influence diagrams (Clemen and Reilly 2001) can be used to identify the inputs and outputs of the decision.

## 4.3 Links Between Process and Decision Views: Objectives (Link 2−4)

This relationship between process and objectives modeling, established in the previous chapters, enables the link between decision and process objectives to be made via the objective hierarchy (Clemen and Reilly 2001). For example, the process objective of equitable recruitment could be expressed as a decision objective for the shortlist-applicants function.

A decision-enabled e-EPC (de-EPC) is proposed as a tool that facilitates integration of existing business modeling tools by using quantitative decision models to complement the descriptive power of the e-EPC.

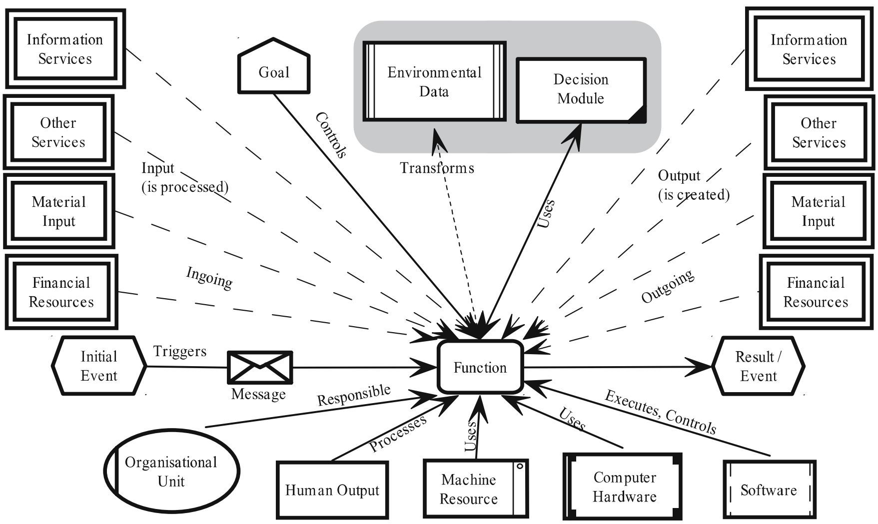


**Figure 3.** Decision view of a de-EPC, adapted from Scheer (1999, pp. 34–35)

The de-EPC is formed by identifying decision objectives as a subset of functional goals and adding a decision dimension or decision view (as illustrated in Figure 3) to the e-EPC. As a result, the de-EPC enables appropriate decision-modeling techniques to be applied to provide the decision maker with an optimal decision for a particular function within a wider business context.
Keller and Teufel (1998, Chapter 4.3) provided a declarative description of the syntax of EPC models describing elements of the EPC graph and characteristics of a correct model (Keller and Teufel 1998, p. 158) using a generic 7-tuple $g_t^{Id} = \left\langle Id_t, \nu_t, \kappa_t, \tau_t, \tau_t^{\kappa}, \alpha_t, \alpha_t^{\kappa} \right\rangle$ defined as follows:

- $t$ is type of the model being described by the tuple (e. g., $e$ is used for an EPC).
- $Id_t$ is a unique identifier of a model type $t$.
- $\nu_t$ is the non-empty, finite set of nodes of a model type $t$.
- $\kappa_t$ is the link relationship, which describes the connections between the various types of nodes, $\kappa$ is defined as $\kappa \subseteq \nu \times \nu$ .
- $\tau_t, \tau_t^{\kappa}$ are representations that assign a type to every node or link.
- $\alpha_t, \alpha_t^{\kappa}$ are representations that assign attributes to every node or link type.

This formalism is extended here to include a decision view into the environment by defining the necessary elements of a decision model such as alternatives, constraints, states of the world, consequences or outcomes, optimality criteria, and decision-modeling routine as follows using the 7-tuple:

- The $t$-subscript of the tuple takes the values of $d$ (for a decision model); and
- $\tau, \tau^{\kappa}$ representations are defined as follows:

$$\begin{aligned} &\tau_d : \nu_d \rightarrow \left\{ \begin{matrix} \text{alternative, decision module, state of the world,} \\ \text{constraint, consequence, objective} \end{matrix} \right\} \\ &\tau_d^{\kappa} : \kappa_d \rightarrow \{\text{assignment link}\} \end{aligned} \tag{1}$$

Definitions in (1) reflect a generic decision-making situation that can be typically characterised by a set of actions, constraints, states of the world, outcomes, optimality criteria, and objectives. Depending on a particular situation, some of these elements may be absent; however, sets of actions, constraints, outcomes, and objectives must be non-empty. A rational model typically used for decision support is aimed at modeling *a choice from possible actions or alternatives to satisfy one or several decision objectives within the context of a decision situation* (Clemen and Reilly 2001, Winston 1994).

Mathematical techniques and programming routines that are used to solve decision models constitute the subject of extensive operations research literature. For

**Table 2.** Recruitment process KPIs based on Fitz-enz and Davison (2002)

| Recruitment activities | KPIs corresponding to components of the efficient and effective recruitment process | | | | |
|---|---|---|---|---|---|
| | **Maximum quality of hire** | **Minimum cost per hire** | **Minimum response time** | **Minimum time to fill** | **Maximum hit rate** |
| Decide on advertising method | | Source costs, e. g., managers costs | Response time, e. g., number of days from request | | |
| Advertise | | Source costs, e. g., managers costs + ad fees + miscellaneous costs | Response time, e. g., number of days from when the decision regarding the advertising method is made | | Hit rate, e. g., 40% referrals hired |
| Contact recruitment agencies | | Source costs, e. g., agency costs | Response time, e. g., number of days from request to shortlist of applicants | | Hit rate, e. g., 75% referrals hired |
| Schedule interviews | | Interview costs, e. g., travel + misc. | Response time, e. g., number of days to complete the schedule | Time to fill, e. g., elapsed time scheduled for interviews | |
| Interview | Quality of hire, e. g., percentage of recommendations promoted within the first 12 months | Cost per hire, e. g., panel costs + admin costs | | Time to fill, e. g., number of days from the last interview to final decision | Hit rate, e. g., 95% of recommended applicants hired |
| Refer | Quality of hire, e. g., percentage of hired applicants promoted within the first 12 months | Cost per hire, e. g., admin. and management costs | | Time to fill, e. g., number of days before clients receive documentation | |
| Make offer | | Cost per hire, e. g., relocation cost + agency fees + misc. costs | | | Hit rate, e. g., number of rejections |
| Notify rejections | | Cost per hire, e. g., admin costs | | | |

the purpose of this chapter, it is assumed that once the *decision model* is formulated, it can be solved using one of the existing mathematical and/or programming routines. Due to the complex technical nature of these models, they are often prescriptive, addressing simplified decision problems with narrow decision objectives. More-user-friendly decision models dealing with the structure of and interactions between the decisions (e. g., decision analysis and system dynamics tools) provide a more-holistic view of the decision situation at the expense of their ability to support specific decisions (Clemen and Reilly 2001, French 1989, Sterman 2000).

Assignment links connect decision objectives with other elements of the decision model. Neiger and Churilov (Neiger and Churilov 2004) showed that decision objectives are connected to functional objectives via objectives decomposition links. This enables the rest of the elements of the decision module to be linked to the individual functions responsible for the achievement of these objectives. Furthermore, information objects and flows that are used by the function also become accessible to the decision model.

Having designed the process in accordance with business goals, the goal-oriented business pattern can be used to link the key performance indicators (KPIs) to business activities, enabling ongoing evaluation of business processes thus facilitating the steering of business process instances towards their goals. Components decomposition of the higher level objectives determines the relevant KPIs for each function. For example, the overall objective of the recruitment process can be expressed as an efficient and effective recruitment process, and may be decomposed into five components in accordance with Fitz-enz and Davison (2002): *maximum quality of hire*, *minimum cost per hire*, *minimum response time*, *minimum time to fill*, and *maximum hit rate*. Table 2 is populated by KPIs for each function that contributes to one of these components.

Note that some KPIs are cumulative, e. g., costs of each function and time taken by each function contribute to the overall costs and duration of the process, while the relationship of other functional KPIs to the corresponding process KPI may be more complex. For example, the hit-rate KPI of the recruitment process (i. e., the proportion hired) may be calculated as the total number of applicants to the total number hired, or the total number interviewed to the total number hired, or as a function of both. Irrespective of the method, by defining KPIs at the function level in accordance with the components of the process objectives, the information required to assemble the process KPIs is made available to the process.

## 4.4 Links Between Process and Decision Views: Information (Link 3–5)

As discussed in the previous section, information inputs and outputs of a specific function are dependent on the information flows in the rest of the process and vice versa. In some cases a simple list of decision variables side-by-side with functional inputs and outputs sourced from the e-EPC will be sufficient to identify information gaps and unnecessary information. For more-complex interactions, a system-dynamics model (such as a causal loop or stock and flow diagram) can be used to identify information dependencies (Sterman 2000). A combination of these tools will allow interactions between decision and process information to be identified and taken into account by the modeler. For example, consider a causal-loop diagram for the recruitment decision illustrated in Figure 4.

The causal diagram shows causal links between variables that are relevant to the recruitment decision irrespective of the process. For example, a positive arrow from work program to budget indicates that as the work program increases so does the budget. Even though these quantities are outside of the recruitment process, they have a direct influence on the requirements and outcomes of the recruitment process as these increases will result in the increased number of vacant positions and resources available for recruitment, as well as the costs and time constraints of the recruitment process. As illustrated in the diagram, the greater the number of vacancies, the larger the recruitment effort, which in turn would cause high costs of recruitment and lower budget. On the other hand, the larger the recruitment effort, the more applications are likely to be received. The number of applications

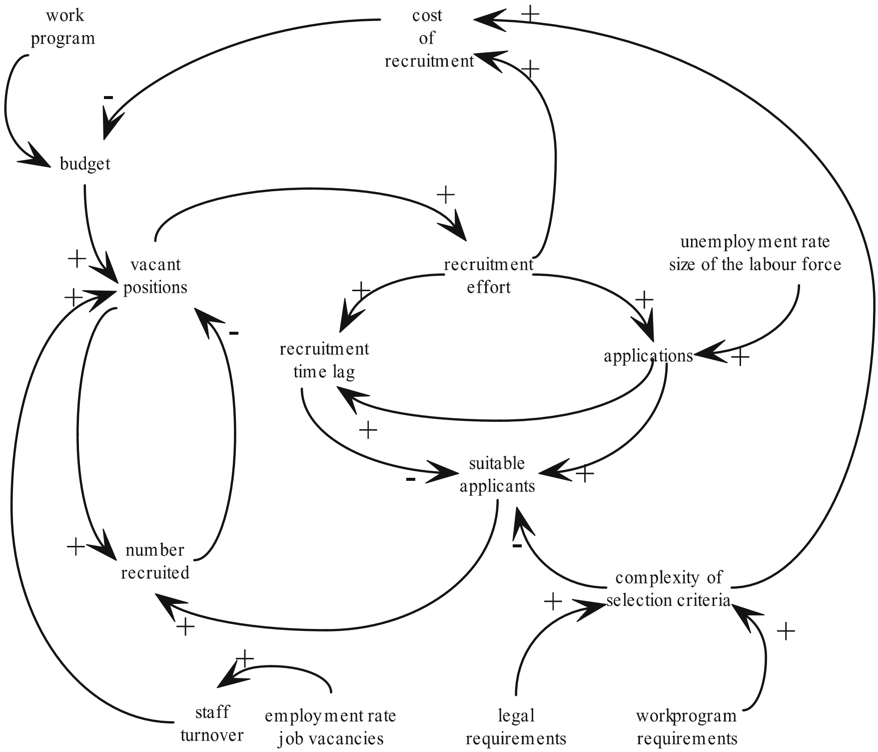


**Figure 4.** Recruitment causal loop

would also be larger as the labor force and/or unemployment rate increases, although the labor force would have to increase substantially for it to be reflected in the number of applications. More applications is likely to result in more suitable applicants, however the number of applicants would reduce as the complexity of the selection requirements increases and the recruitment time lag increases (as good applicants accept other job offers). This relationship highlights the need for the timeliness in the recruitment process, a factor that has not been made evident elsewhere.

The information link is enriched by this diagram, as causal links in the diagram demonstrate that the selection criteria are dictated by work program and legal requirements. Therefore, these data must flow into the advertise function to ensure that job advertisements meet the requirements of the client areas.

The integration model presented in this section provides the framework for the integration of the process- and decision-modeling approaches with the resulting modeling tools having the capability to:

- include functions and their descriptions;
- provide a static view of the functions including functional goals, resources that are used by the function to achieve these goals, and functional output;
- provide a dynamic view of the functions presenting a coherent process that brings the functions together and ensures transparency across functional and information flows;
- include decision objects such as decision objectives, mathematical models used to analyze the information, and decision variables including decision constraints; and ideally
- include reinforcement mechanisms for all the links.

To illustrate, let's assume that the functional goal of the shortlist-applicants function is to select the 10 best applicants for the interview. In order to satisfy the strategic objectives of the recruitment process, however, the functional goal should include decision objectives that can be expressed as: selecting 10 applicants according to a set of criteria (relevant employment, relevant education, etc), subject to a set of constraints (time, equity, etc.). This decision objective is specific to the decision module in charge of its realization [typically, one or more suitable OR/MS models with corresponding objective(s)] and is formulated by utilizing information about functional goals and process objectives.

The specific decision problem with respect to the shortlisting of applicants can be resolved using multi-criteria decision-analysis tools. The variables required for this decision are already available as part of the environmental data of the function (Figures 3 and 4). By introducing a decision module/object (Figure 5) that includes the decision model and the decision objective, it is possible to link the mathematical-programming-based model to the function creating a de-EPC.

The functional goals in the de-EPC include decision objectives. These decision objectives, together with the decision variables that form part of the de-EPC information flows, provide inputs into a decision model. The output of the decision

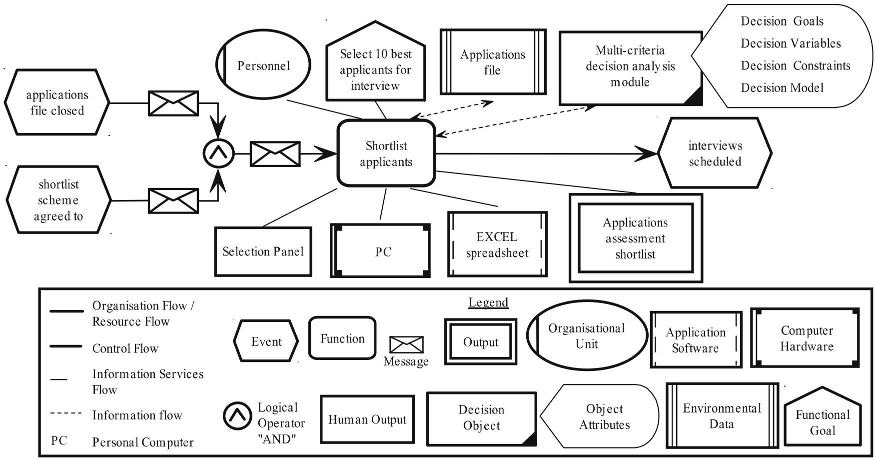


**Figure 5.** de-EPC of the shortlist-applicants function

model provides the decision maker with an optimal path to satisfy the decision objective and, if required, contributes to the functional outputs which become available to the rest of the process.

In general, the power and flexibility of this integrated modeling tool is that it allows us to utilize the abundance of existing generic quantitative OR/MS models as objects within the comprehensive process-modeling framework. According to the object-oriented methodology (Loos and Allweyer 1998, Scheer 1999), this means that we are not confined to dealing with technical aspects of solving the quantitative models, but rather can treat them as black boxes with known sets of properties. This approach enhances the decision capabilities of process modeling by linking the library of OR/MS models to the process-oriented view of the enterprise, hence creating a more-comprehensive and flexible model of a business enterprise.

# 5 Benefits of Process-Based Decision Support

Since the benefits of process modeling and decision modeling and support have been well documented within the relevant disciplines (Davis 2001, Keen 1981, Mallach 2000, Sterman 1991), the purpose of this section is to explore how the combination of the two approaches could benefit a business. This is illustrated in Figure 6.

Process modeling allows "the documentation, analysis and design of the structure of business processes, their relationships with the resources needed to implement them and the environment in which they will be used" (Davis 2001, p. 2). This has many advantages for a business, including improved documentation and

| ***Benefit categories[1] for*** | | | | | |
|---|---|---|---|---|---|
| | **Process modeling[2]** | ⇒ | **Decision-enabled process** | ⇐ | **Decision modeling and support[3]** |
| *Efficient and effective use of resources to meet organizational objectives* | | | | | |
| | Integration and rapid process engineering | ⇒ | Efficient processes focused on effective solutions to organizational problems | ⇐ | Personal efficiency in decision making, solving problems faster or better |
| *Communication* | | | | | |
| | Single and consistent record, multiple view points | ⇒ | Transparency of decision making mechanisms as well as processes | ⇐ | Group decisions, explicit assumptions and decision model |
| *Learning and training* | | | | | |
| | Validation, walk-through, testing, evaluation of scenarios | ⇒ | Evaluation of flow on effect from process changes to decision alternatives, feedback mechanisms | ⇐ | Expert systems, simulation models, feedback models |
| *Organizational control* | | | | | |
| | Rigor, method | ⇒ | Common standards for process and decision making activities | ⇐ | Management information, standard modeling tools |

**Figure 6.** Benefits of decision-enabled processes ([1]Mallach (2000, p. 22), Daellenbach (1994, p. 13); [2]Davis (2001, p. 4), Scheer (2000, p. 7); [3]Mallach (2000, p. 22), Sterman (1991))

rigor, integration of processes, systems, and information, and increased capability for validation and testing (Davis 2001, p. 4).

While there is no universally accepted method for summarizing the benefits of these complex and varied modeling paradigms, the framework provided by Mallach (2000, p. 22) is concise, complete, and can be applied across the disciplines. This framework is used in Figure 6 to summarize the benefits of process and decision modeling and support, and benefits resulting from their integration into a decision-enabled process model. As noted by Mallach (2000, p. 23), the categories in Figure 6 are not independent, as changes in one necessarily affect the others.

A perfect process model would meet resource, process, and market efficiency demands (Scheer 2000, p. 7) but, as mentioned earlier, it does not guarantee that the demand for rational or effective decision making, as required for business goals, is going to be met. For example, a selection process model would describe the steps used in the selection process but would not guarantee that the choice of applicants was optimal given the objectives of the selection process. This latter demand can only be met through the use of a process model for decisions where there are a few well-defined and easily eliminated alternatives or trivial decisions that can be evaluated explicitly at the level of the human decision maker without the assistance of decision-modeling aids. Other types of decisions require the use of models to ensure that "logical consequences of the modeler's assumptions" (Sterman 1991, p. 4) are computed. With the use of decision modeling and support tools the efficiency and quality of rational decision-making within business processes is improved (Mallach 2000, pp. 18–23).

As example of this; multicriteria decision analysis and support have been demonstrated to improve selection processes (e. g., Gardiner and Armstrong-Wright 2000); the use of Markovian models and supporting software is often necessary to solve planning problems; data envelopment analysis enables better assessment of performance management (Tsai and Mar Molinero 2002); and efficiency of shift assignment and scheduling is substantially improved with the use of optimization techniques (e. g., Winston 1994), etc.

Both process modeling and decision support tools improve communication by providing a common basis for business processes (Davis 2001, p. 4) and decision making (Mallach 2000, p. 21), respectively. By linking process and decision stakeholders and requirements, a decision-enabled process will facilitate more-effective communication by articulating what problems need to be solved, when, and what information and methods are available to solve these problems in order to achieve overall organizational objectives.

The promotion of learning and training is a benefit of some decision support systems (Mallach 2000, p. 22) and is an accepted advantage of both analytical modeling (Savage 1998, p. 3) and process modeling (Davis 2001, p. 4). For example, evaluating what-if scenarios within a business process model facilitates learning about critical time lines, resources, information, and data requirements. Learning from such evaluation is substantially enhanced if the impact of these changes on decisions such as shift assignments and future forecasts is simultaneously evaluated with simulation models and fed back using system dynamics models into the appropriate processes, such as budget and resource allocation (Sterman 1991).

Another important benefit of process modeling (Davis 2001, p. 4), decision modeling (Sterman 1991, p. 4), and decision support (Mallach 2000, p. 22) is increased organizational control through enforcement of common standards resulting in consistency. However, as businesses are not separated along decision and process lines, the organizational control requires common standards to be applied across process and decision-making activities (as well as within them). The use of an integrated modeling tool will minimize occurrences of disparate requirements, incompatibilities, and contradictory instructions.

Process-modeling tools have the potential to incorporate functionality from many different systems, such as workflow, decision modeling, artificial intelligence, and others. Becker et al. (1999) developed a framework for the evaluation of the workflow modeling potential of a business process. This framework is adapted to the decision-modeling context to facilitate the identification of the decision-enabling potential of a business process.

Consistent with Becker et al (1999), the decision-enabling potential of a business process is measured by the benefit the organization is expected to derive from the decision support provided by a decision-enabled process. While not all benefits discussed in this section would be realized for each decision-enabled process and there may be other benefits that have not be included, Figure 6 provides the basis for an initial set of operational criteria for evaluation of the decision-enabling potential of a process (Sandoe et al. 2001, Chapter 3). The specific operational criteria would vary from business to business, reflecting individual business requirements, resources, and time constraints. It is expected that some criteria could be easily measured (e. g., cost savings from an improved staff roster) and, therefore, be used in a cost-benefit analysis, while others would be more intangible (e. g., transparency of decisions in a selection process) and would require analysis of value rather than cost (e. g., Keen 1981).

The capability of the process to support a decision model from a technical perspective is discussed by Neiger and Churilov (2004). The availability of resources, cost, and timing associated with the implementation of software functionality necessary for the integration of two methodologies and corresponding systems are the key factors in assessing the decision-enabling potential of the business process.

People issues are one of the significant obstacles towards successful implementation of integrated systems (Sandoe et al. 2001, Chap. 3). The criteria relating to people issues presented by Becker et al (1999) within the workflow context as organizational criteria are transferable to the decision-modeling context. A conceptual framework presented in Figure 7 as an entity relationship diagram combines operational, technical, and organizational criteria to determine the decision-enabling potential of a process.

The framework is based on the workflow potential of the business process framework proposed by Becker et al. (1999) in order to:

- enable emphasis of the discussion to be on the decision-enabling context rather than technical aspects of the framework; and
- facilitate cost-benefit comparison of add-on functionalities for process-modeling tools by ensuring consistency between conceptual frameworks.

The framework includes the following elements: the *decision module* using the data, provided by the *business process* enables decision support (through a *decision model*) for the business *process goals* that in turn support *organizational objectives*. The degree of support is dependent on the *decision-enabling potential* of the process. The decision-enabling potential of the process is the result of the match between the business process and a given set of *criteria* that can be *weighted* to enable *evaluation* of the overall decision-enabling potential of the process. The weights may vary, depending on the *process goals* associated with the *business process* being modeled. The criteria relate to the *decision capability* of the business process supported by the decision model. The decision model also supports *information* and *operational capability* of the business process through quantitative output and operational directives, respectively.

The decision-enabled process model combines the descriptive power of integrated enterprise architecture tools with the quantitative power of decision-modeling tools by linking external (process) and internal (decision) views of business activities. Within this framework the library of OR/MS models is linked to functions within business processes to ensure that specific decision objectives can be met effectively and efficiently within broader organizational constraints, and that the information requirements of both models are met.

The evaluation framework introduced in this section is crucial to understand *why* integration of process and decision modeling is beneficial to an organization and *when* these benefits are likely to outweigh the complexities and costs associated with the integration of information systems. As the benefits and costs vary between organizations, it is not possible to provide a universal answer to these questions. Rather, the framework described in this section provides the tools to assist organizations to recognize benefits of integrating process and decision modeling and to evaluate the decision-enabling potential of a business process as a guide towards understanding the trade-offs between the benefits and costs of implementing a decision-enabled process model.

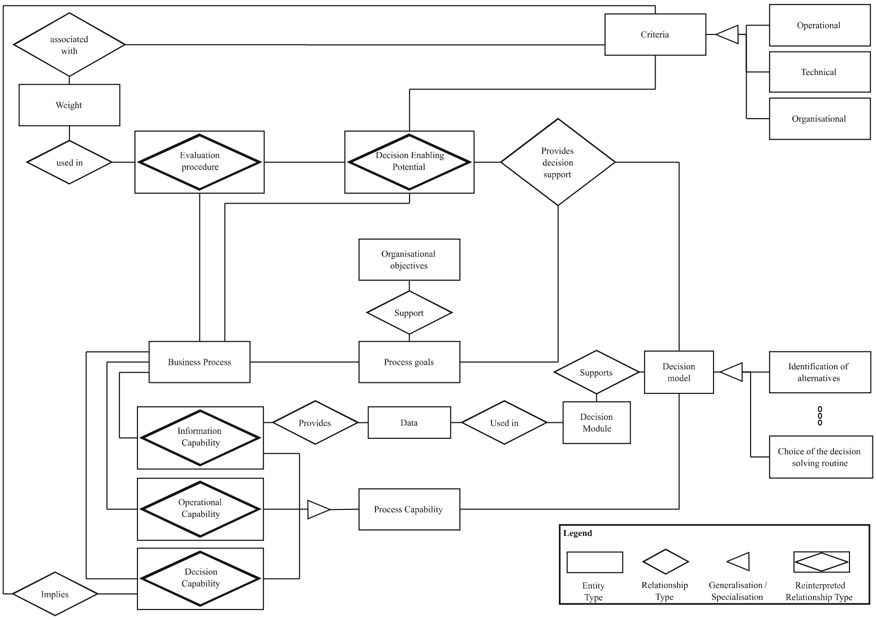


**Figure 7.** Framework for identification of decision-enabling potential of a business process

# 6 Summary

The need for integration of process- and decision-modeling approaches has been well-recognised in the respective research communities (Ackermann et al. 1999, Brans et al. 1998, Khoong 1996, Mehrotra 1999, Nilsson et al. 1999, Parker and Caine 1996, Rosemann 2003, Sandoe et al. 2001, Zeffane and Mayo 1994), but due to the differences in basic concepts, terminology, development history, and methodologies of these areas, integration has been limited to date.

The contribution of this chapter has been twofold:

- to reflect upon the issues of similarities and differences between business process- and decision-modeling methodologies and potential benefits of their integration; and
- to suggest practical and formal ways for such integration by introducing a notion of a decision-enabled e-EPC (de-EPC) that provides process context to decision models.

The discussion of the relationship between the two types of business modeling tools has highlighted the duality currently existing in the field of business modeling. This duality can be formulated as follows: the more descriptive and contextual the business model, the less decision enabled it is. Integration of the two paradigms results in a more-complete picture of the whole business and a more-powerful business model. This allows logical progression from the representation of the mental picture of the business to precise and quantifiable knowledge, enabling the best local decisions to be made in the context of the strategic objectives of the business. Although considerable future research effort (especially in the areas of reinforcement of links and application of the methodology to real life processes) is required to provide full integration of process and decision-oriented modeling paradigms and corresponding modeling tools, it is believed that the concept of the de-EPC, introduced in this chapter, provides the solid basis for this effort.

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# CHAPTER 48
# A Framework for Supporting Decisions in a Global Context – The Case of a Global DSS for Financial Planning

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Internet technologies are enabling firms to become distributed across the globe and compete in international markets. Decision makers, hence, have to deal with differences in national policies and social cultures, as well as various international management strategies (global, multinational, and transnational). While advanced technologies such as intelligent agents, search engines, and collaborative technologies can provide support for global teams making decisions, it is critical that the nature and intensity of information shared is well understood before developing such support. This paper develops a framework to characterize decisions under different strategies and presents a global decision support system (g-DSS) architecture to support these decisions. The case of a corporate financial planning model is used to illustrate this architecture.

**Keywords:** Equivocality; Financial planning; Global decision support systems; International corporations; Uncertainty

## 1 Introduction

Anthony (1965) classified the decision-making process at various levels of granularity: strategic planning, management control, and operational control, implying that as one moves up the organizational hierarchy, the decision-making process complexity increases. In the late 1970s and early 1980s, much of the focus was in developing models that captured the essential features of a decision-making process, and evaluating alternatives using various management science techniques. Often classified as semistructured, depending on the degree of programmability (Keen and Scott Morton 1978), these decisions are supported by a decision support system (DSS) architecture that separated data from models, and used an interactive dialog component to support human-computer interaction (Sprague and Carlson 1982). The DSS architecture components are intended to flexibly address increased uncertainty in the intelligence, design, and choice phases of the decision-making process (Simon 1960). Various models were developed to support decisions at a functional level (Keen and Scott Morton 1978) and at the corporate level (Moormann and Holtgreven 1993, Pinston et al. 1997) using optimization or simulation models.

As organizations became larger in size and distributed across many geographical regions in the late 1980s and 1990s, intraorganizational support through computer-mediated communication took on greater importance. Group decision support and knowledge-based technologies have started to provide asynchronous and synchronous communication, algorithmic and heuristic model integration, and assumption surfacing for conflict resolution. With Internet technologies enabling firms in the 21st century to become highly distributed across the globe and compete in international markets, the decision processes have to deal with differences in national policies and social cultures, as well as the various international management strategies (Carlsson and Turban 2002). For example, an international firm may feature centralized management planning and control strategy (called global), decentralized management and operations control strategy (called multinational), or a hybrid strategy (called transnational, Bartlett and Ghoshal 1989). These varied organizational strategies in a distributed environment can add complexity to the decision process. Couple this with the complexity of managing global teams and we have a major challenge. While advanced technologies such as intelligent agents, search engines, and collaborative technologies have started to provide opportunities for global teams to share information and interact to make decisions, it is critical that the nature and intensity of information that is to be shared is well understood before developing effective decision support.

This chapter develops a framework that characterizes decisions in the international arena and then presents ways in which advanced information technology (IT) can help support decisions. The next section discusses the DSS framework using a financial planning example. The research on international business and its characterization of decision making is discussed in section three. The fourth section extends the DSS framework to support financial planning decisions in an international context. The last section provides some discussion and makes some concluding remarks.

## 2 Evolution of DSSs to Support Financial Planning

If we formally represent decision processes (normative or descriptive) as models that transform decision inputs to outputs so they may influence management action, then the lack of structure or complexity in these processes contribute to by both uncertainty and equivocality (Choo 1991). More information is viewed as critical to reduce uncertainty and a richer set of information is considered necessary to reduce equivocality. Within the context of decision models, equivocality is said to occur if the environment or decision variables (model inputs) that can influence management action are *not* known in advance, thus impeding our ability to construct a model. However, uncertainty is said to exist if we know the variables (model inputs) that influence our decision and can construct a model,

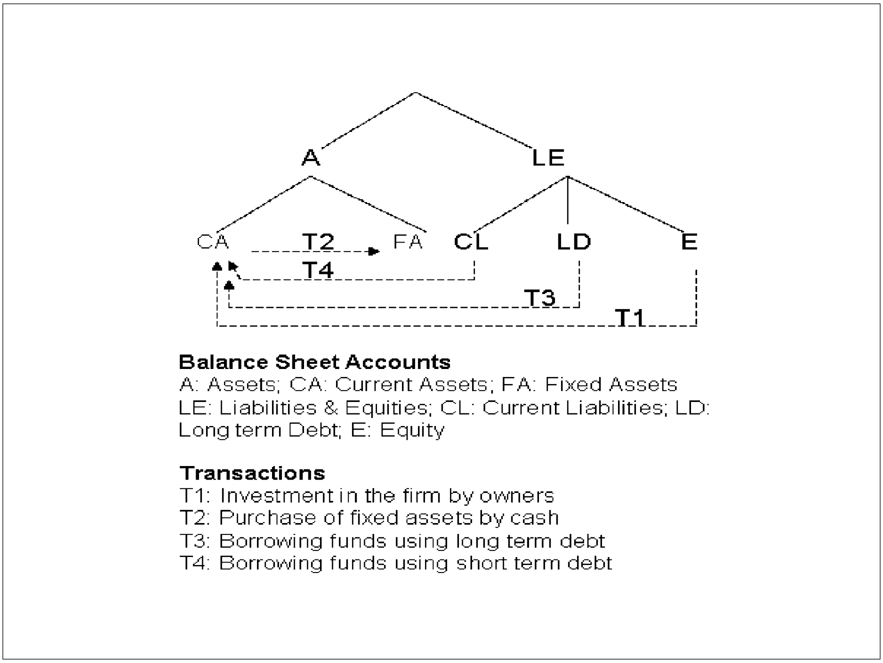


**Figure 1.** Relationship of financial states and transactions

but cannot estimate the values of these input variables (Chang and Tien 2006). While uncertainty in decision making can be reduced with more information, equivocality often calls for not more, but a richer set of information from multiple sources (Daft and Lengl 1986). Equivocality in decision making increases as the decision scope changes from operational control to strategic planning. Similarly, equivocality increases when many individuals are involved in decision making in a distributed environment, often dealing with different levels of environmental complexity (customers, suppliers, labor, etc.). With the aid of a financial planning example, the rest of this section illustrates the decision complexity attributed to increasing equivocality.

Within the context of corporate planning, specifically financial planning and budgeting, early decision support system research focused on integrating decisions made by the functional units, either explicitly through the integration of models developed by functional units or implicitly through decision parameters estimated by these units (Blin et al. 1979). In Figure 1, several financial transactions (T) are related to nodes or states in a financial statement (B). The pro-forma financial statement and financial ratios can be calculated from estimated financial transaction values. The accounting identities and credit/debit conventions (S) are used to project a new financial state from the current financial state (see Figure 2) using financial transactions, and these financial transactions are related to decisions made at the functional unit level (see Figure 3). For example, cash sales and cost of

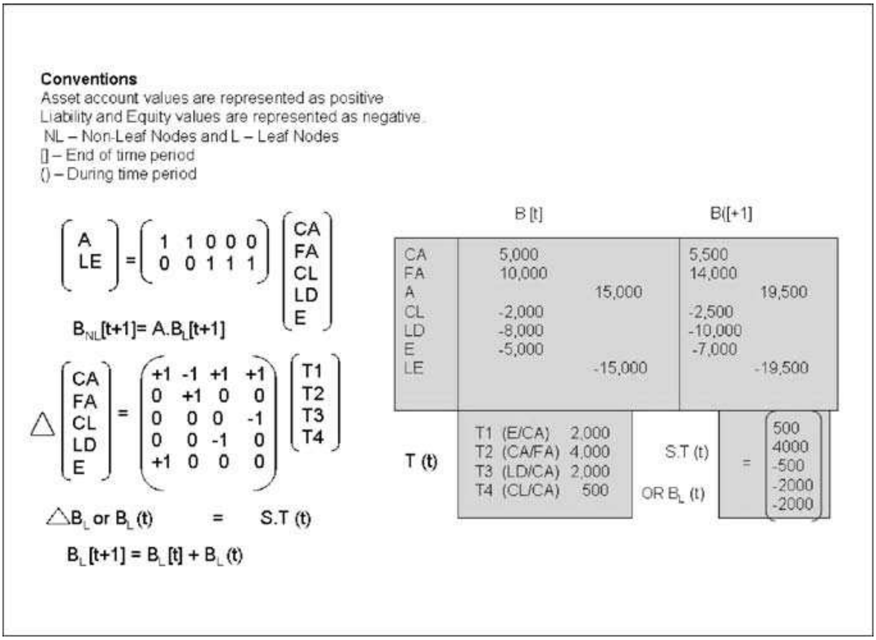


**Figure 2.** Corporate financial Model (CFM) using state transition matrix (refer to Figure 1)

goods sold (T1–T2) can be estimated based on unit sales projections, prices, and standard cost. Similarly, accounting or administrative policies such as payable schedule and tax policies can impact transactions (T4–T6). A firm can *estimate* the transaction values based on functional decisions (e. g., sales forecasts, production and financial plans) and use these estimates to project financial statements/ratios for goal setting. Alternately, a firm can first establish certain financial goals (e. g., return on sales or assets) and allow the functional units to use these as targets as they plan their decisions (e. g., cash and credit sales, and earnings after taxes).

The complexity of decision support in financial planning varies depending on the degree of dependency among functional decisions: pooled, sequentially interdependent, or reciprocally interdependent (Thompson 1967). For example, in sequential interdependency, sales decisions can impact production and they can both, in turn, impact administration and finance. In reciprocal interdependency, *sales projections* can impact production and financial costs, and these costs can together influence the calculation of the standard cost of each product sold, which in turn impacts the *sales projections*. Reciprocal interdependency is the most complex situation and calls for iterative decision making between corporate and functional models (Blin et al. 1979) and sensitivity analysis of these models for varying inputs calls for complex data base management (Stohr and Tanniru 1980). Independent of the nature of dependency, the general assumption in all these planning decisions is that models can be developed and integrated, and input variables for these models can be estimated and tested to reduce uncertainty.

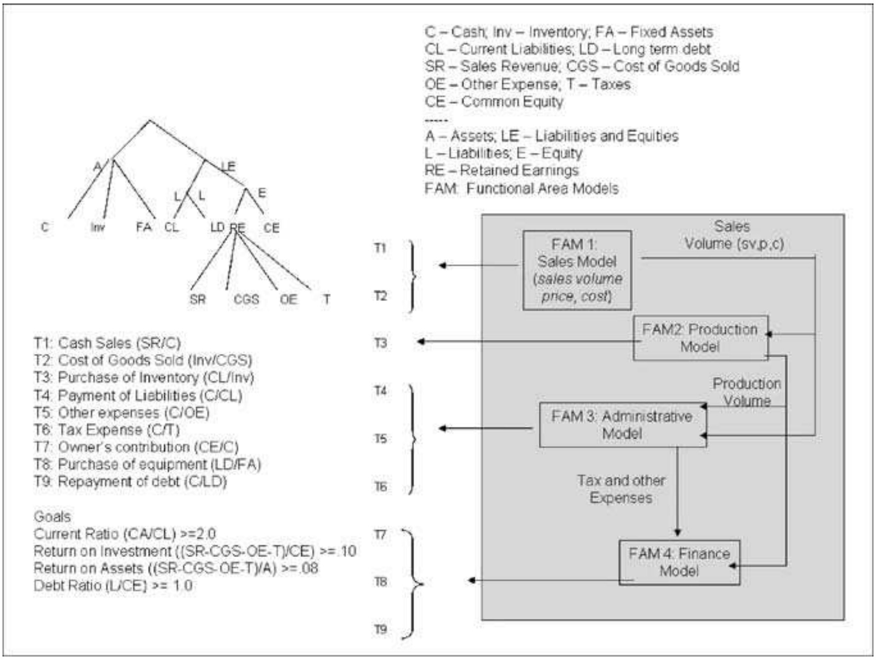


**Figure 3.** Functional area models (FAM) used to estimate transaction values

Increasingly, group decision support systems (GDSSs) and knowledge-based technologies have started to play an important role in support of both model integration and model validation in distributed environments (Tanniru and Jain 1989). At the functional level, artificial intelligence/knowledge-based technologies have allowed decision makers to model qualitative decisions using heuristic models, and also select models from repositories and integrate them intelligently to solve a problem (Bonczek et al. 1981). In some cases, GDSS technologies have supported a synthesis of qualitative and quantitative decision making, while implicitly addressing some conflicts in interpretation and communication, i. e., reduce equivocality (Agarwal et al. 1995, Bonczek et al. 1981, Lee and Lee 1987). Many of these group systems assume that the models used to arrive at individual decisions are local to that functional unit only, and GDSS technology should focus primarily on communication among groups. So, GDSS research has focused on group communication for conflict resolution, anonymous assumption surfacing, and the rank ordering of ideas (DeSanctis and Gallupe 1987, Malone and Crowston 1994, Walther and Bargoon 1992), all to address a certain degree of equivocality that surfaces when people with varying perspectives are involved in the decision-making process.

Referring back to the case of financial planning, interdependency in a distributed environment requires functional groups to communicate decision outcomes and transactions in order to assess their impacts on the financial performance of a firm. This is done in two ways. An explicit approach may use knowledge-based technology to validate accounting identities (e. g., assets = current assets + fixed assets) and the input/output interdependencies of a functional model, by comparing them against repositories during model integration. This allows functional units to uncover any missing information as well as correct the use of any organizational parameters (e. g., tax rates, interest rates, Tanniru and Jain 1989). An implicit approach calls for the use of a decision guidance system that makes model repositories available to functional units during their model construction. Such unobtrusive validation by the system lets a decision maker compare his/her model against a library of similar models and identify gaps for additional analysis (Agarwal et al. 1995).

The Internet revolution enabled firms to operate across the globe and distribute decisions even further, spanning multiple countries (Shim et al. 2002, Warketin et al. 1997). Advanced DSS tools (e. g., data warehouse, online analytical processing, data mining) and Web-based tools are being used to reduce technological barriers. For example, data mining tools are helping analyze customer data, advanced operations research modeling (e. g., tabu-search, genetic algorithms, neural networks) is supporting analysis, and intelligent agents are helping integrate information from distributed decision makers in a global setting (Pinston et al. 1997). However, decision-making processes have to cross regional and national boundaries and bridge cultural, social, and political differences (Mitroff and Linstone 1993). The systems have to synthesize organizational, personal, and technical perspectives associated with differing mental models and varying ethical and aesthetic factors. In other words, the decision-making process has become even more equivocal, and DSS research calls for the use of many rich artificial intelligence (AI)-based, Internet-enabled, collaborative technologies to support global decision making (Carlsson and Turban 2002). However, it provides no specific guidance on how they may be applied. To address this gap, the next section defines a set of decision-making characteristics unique in the international arena, and the fourth section develops DSS features that are most applicable to support these characteristics.

## 3 Characterizing the Decision Process within an International Context

Within an international context, the first and foremost issue that surfaces is the complexity of data and knowledge that have to be transferred across networks to connect subsidiaries with the corporate headquarters and support the regulatory, technological, and country-oriented policies and procedures (Lai and Chung 2002). Such transfer, of course, depends on the nature of interaction needed to support operational as well as decision-making needs of both the subsidiaries and corporate headquarters. This, in turn, depends on the type of responsiveness the firm would like to maintain downstream (at the subsidiary level to meet customer needs) and the degree of standardization the firm desires upstream (at the corporate level to maintain efficiencies). This is a part of the organization's differentiation strategy to compete in an international arena (Bartlett 1986).

*Strategy*: A firm may choose global cost leadership as a differentiation strategy (i. e., standardize its products or a line of products and use brand dominance for differentiation). This strategy is used to develop and exploit innovations worldwide and seek global efficiency using high economies of scale. Under this scenario, the managers locally have limited local autonomy to make decisions and primarily implement the strategy of the *global firm* (or domestic-extension) through increased operations control.

A *multinational (or multidomestic) firm,* on the other hand, uses a strategy that recognizes national differences and differentiates its products to meet customer preferences. Under this scenario, local managers have considerable autonomy in decision making and are self-sufficient in the way they apply resources to implement the strategic plan of the firm.

*Transnational firms* focus on a strategy that is a mix of global efficiency and local responsiveness, leveraging the learning potential from different national operations through centralization, decentralization, and ex-centralization (concentration of activities in other than the home country) using a strong web of interdependencies (Bartlett and Ghoshal 1989). From a decision-making perspective, there is tighter integration at the middle-management level across the network of subsidiaries to support learning and sharing, while allowing each subsidiary to control its operations to address local responsiveness and using strategic planning to address resource planning and global efficiency.

*Planning:* If the strategies that international firms follow are viewed in terms of two dimensions (forces for global integration and forces for national differentiation), global firm subsidiaries operate in a high integration-low responsiveness quadrant (*receptive subsidiary).* On the other hand, low integration and high responsiveness (*autonomous subsidiary*) represents a multinational organization, and a transnational firm emphasizes high integration and high responsiveness (*active subsidiary*, Bartlett 1986, Chang and Pangarkar 2000).

These strategic differences influence coordination of strategies for *decision integration, national responsiveness,* and *administrative coordination* (Doz 1980, Prahlad 1976) at each subsidiary. The global firms call for worldwide decision integration with significant managerial interdependence, with decisions flowing mostly from corporate to subsidiary units. Multinational firms call for high national responsiveness with support for managerial diversity and independence, and the only decisions that flow from the corporate level to subsidiaries are strategic in nature. The transnational firm calls for administrative coordination especially at the middle-management level. This group has the responsibility for resolving conflicts and supporting knowledge sharing, while making resource allocation decisions at the strategic level and administrative adjustments at the operational level (Taggert 1998).

*Control:* While the performance of a subsidiary is controlled using output controls, these controls can be explicit (data extracted to ensure targets are met) or implicit (place people in management positions who understand corporate values and goals). Two such management controls are behavior and socialization. Behavior controls help specify and monitor actions and are implemented by having a parent company manager assigned to key management positions of the subsidiary. This is often suitable for a multinational firm that has to operate with relative autonomy. On the other hand, socialization controls allow for alignment of the subsidiary manager's values with those of the parent company, thus reducing the need for evaluating management performance frequently. This is often appropriate for a transnational firm.

These differences in control have an impact on the nature of data that has to flow from the subsidiary to the corporate level. Within a global firm, there is significant operational data flow from the subsidiary to the corporation to ensure operational-level integration and greater knowledge inflow from the corporate to the subsidiary to ensure decision and policy consistency. Within a multinational corporation, the relative autonomy means minimal operational data transfer. The financial controls can ensure the alignment of the subsidiary with the corporation, and these financial flows move from the subsidiary to the corporate. The transnational firm may see a greater amount of knowledge flow into and out of the subsidiary in support of both managerial coordination and shared learning.

*Knowledge flow*: Subsidiary performance and competence development of an international corporation can be influenced by a subsidiary's network (Andersson et al. 2002). Such a network can help move a firm from an arms-length relationship to relationships that are built on adaptation and trust (Larson 1992). Such a relationship can be a strategic resource, helping a firm in its future capability and expected performance. The relationships embedded in a network can be business focused or technology focused. Business-focused relationships are captured by people who have known each other for a long time and transacted sufficiently enough to adapt their business conduct to market information. Technology-focused relationships emphasize information exchange that occurs among constituencies in the network. Prior research shows that technology-focused relationships are needed for forming business-focused relationships, and the more technically embedded a subsidiary is within its network of relationships, the greater its ability to contribute to the corporation's competence (Dess et al. 1995, Hawzing 2000). While the relationships established by a firm with its customers, suppliers, and competitors can help extract fine-grained information about the local markets and environment, such information typically has local context embedded with it and may not be transportable. However, any negative impact associated with such a context can be reduced or eliminated by successful management of knowledge that flows from the subsidiaries to corporate headquarters or other subsidiaries (Gulati 1998).

Both transnational and multinational firms develop relationships to become responsive to local needs, but significant management intervention is needed to abstract knowledge from these relationships for corporate level use, even though this is more of a necessity for a transnational firm. There can be a knowledge flow from the corporation to the subsidiary for all firms, especially for global firms, to ensure consistency in management operations. Global firms on the other hand extract much of the knowledge about markets at the subsidiary level through data analysis.

Table 1 summarizes some of these observations. A transnational firm calls for a greater level of integration of middle-level management decisions and contributes most to, or benefits from, knowledge flows among the subsidiaries. Multinational firms need greater integration at the strategic planning level for goal setting, while global firms need significant knowledge inflow (from the corporation to the subsidiary units to support operational implementation) and significant data outflow (from subsidiary to corporate for performance control). Given the diversity of nationality and cultures involved, better understanding of data and knowledge that are moving across the network is essential. The complexity of information exchanged is high due to the support needed for higher-level management decisions, and the diversity of cultures is high due to the differences in cultures (east vs. west, or economic development: developed vs. developing). Both of these contribute to increased equivocality.

In summary, as we move from the departmental to the interorganizational to the international arena, or as decisions move from operational to strategic, there is

**Table 1.** Decision characteristics

| International firm type | Global | Multidomestic OR multinational | Transnational |
|---|---|---|---|
| **Strategy** | | | |
| *Responsiveness and differentiation* | Cost advantage and low responsiveness (receptive subsidiary) | Product differentiation and high responsiveness (autonomous subsidiary) | Mix of standardization for efficiency and some differentiation through local responsiveness (active subsidiary) |
| **Planning** | | | |
| *Decision integration* | High: implement corporate strategy | Low: develop divisional strategy | Moderate: alignment |
| *National responsiveness* | Limited autonomy | Significant autonomy | Tighter middle management |
| *Administrative coordination* | Operational plan | Strategic plan | Management control |
| **Control** | | | |
| *Data, financial, and knowledge flows* | Performance through increased data outflow | Performance through behavior control and financial controls | Performance through socialization control and knowledge flows |
| | Knowledge in-flow to ensure consistency | Knowledge outflows are low | Knowledge outflow is high to support firm's and other subsidiary competence |

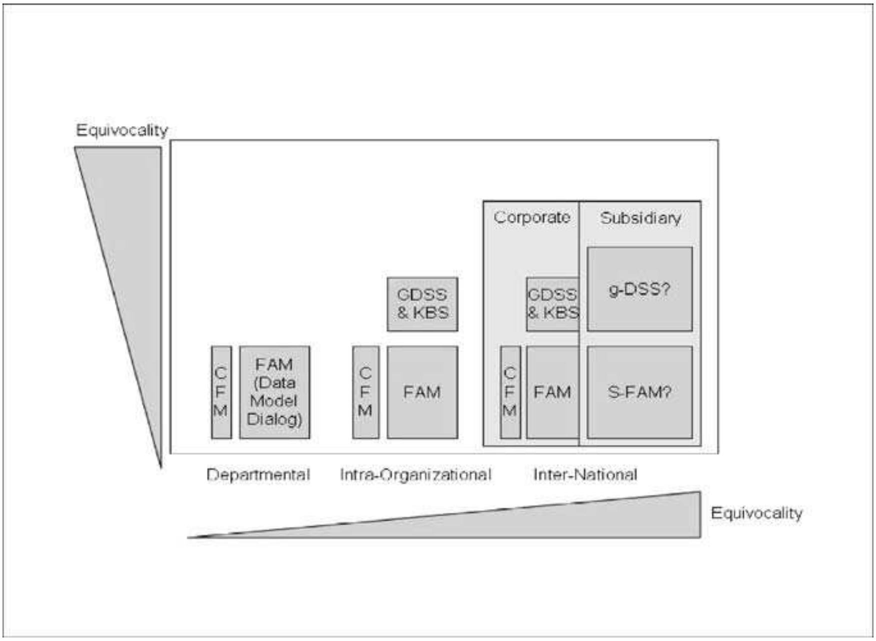


**Figure 4.** DSS architecture evolution

increased equivocality in the decision-making process (see Figure 4). The DSS architecture used should address this increased equivocality by ensuring that the right technology is used to support the source and intensity of this equivocality. The next section suggests the technology features of global DSSs (g-DSSs) that can address the equivocality, specifically in support of financial planning.

# 4 Global Decision Support Systems Architecture in the International Arena

The management decision processes shown in Table 1 requires different degrees of technology support and we will use three different case scenarios of financial planning to assess how the functional area models (FAMs) interact with the corporate financial model (CFM). These cases will help us develop an IT architecture in support of the last column in Figure 4.

*Case 1*: An automotive electronic parts supplier purchases material from a supplier in Taiwan, ships it to Ireland and Mexico for separate processing steps (chip design and resoldering), and brings these two items to the US for assembly and shipment to an automotive firm. Here, the firm makes all the decisions on what to buy and when to buy based on part forecasts provided by the original equipment manufacturer (OEM, e. g., GM or Ford) and determines its suppliers based on the part quality requirements. In other words, the firm here acts like a global entity, centrally developing a marketing strategy, determining production targets, determining buyers at different locations, and planning its production processes for each country. These decisions are then sent to each subsidiary for execution. While each subsidiary has to engage in some degree of operational control (hiring people and operating the capital) and transfer data for the purposes of integration (e. g., weekly sales, purchases, shipments), there is very little management-level integration and knowledge flow from subsidiary network to corporate headquarters for competence development.

The decision support system for financial planning is shown in Figure 5a. Here, the operational control model (OCM) for each subsidiary is distinctly different and is used to execute plans dictated by corporate headquarters. The financial models (CFM and FAM) are centrally managed and decisions from these models are transferred from corporate headquarters to subsidiaries. The operational data is transmitted from subsidiaries to the corporate headquarters for integration. The technology support here calls for:

1. *Richer communication for accurate interpretation*: Given the diversity in culture, language, and interpretation even in global firms, equivocality in communicating the decisions can contribute to ineffectiveness. For example, how effectively are the part forecasts communicated between Taiwan and Mexico, given the work, social habit, and time differences? So, richer communication [face-to-face or interactive mechanisms using instant messaging or voice-over-Internet protocol (VOIP), with richer feedback mechanisms to support clarification on interpretations] is needed at both strategic and management level decisions.
2. *Knowledge base repositories and intelligent translation/consistency checks*: It is critical to ensure consistency in the way business policies are translated and interpreted at the subsidiary level, and data are mapped as they are sent from subsidiary to corporate units. For example, the corporate payment policies or special discounts allowed for early shipment or payment can be made available through a repository. Exchange rates, on the other hand, may be used automatically to revise transaction values as they move across countries. This became important for an automotive firm that moves parts manufactured in multiple regions to a central facility for proper local and corporate accounting and tax computations. The same process became essential for a consulting firm that uses people from multiple countries to complete a project and bill for it appropriately.
3. *Advanced data analysis techniques*: Given the significant volume of operational data transmitted from subsidiary to corporate for analysis and decision making, we need effective data transfer mechanisms with wider bandwidth, and data mining/analysis techniques to understand remote markets.

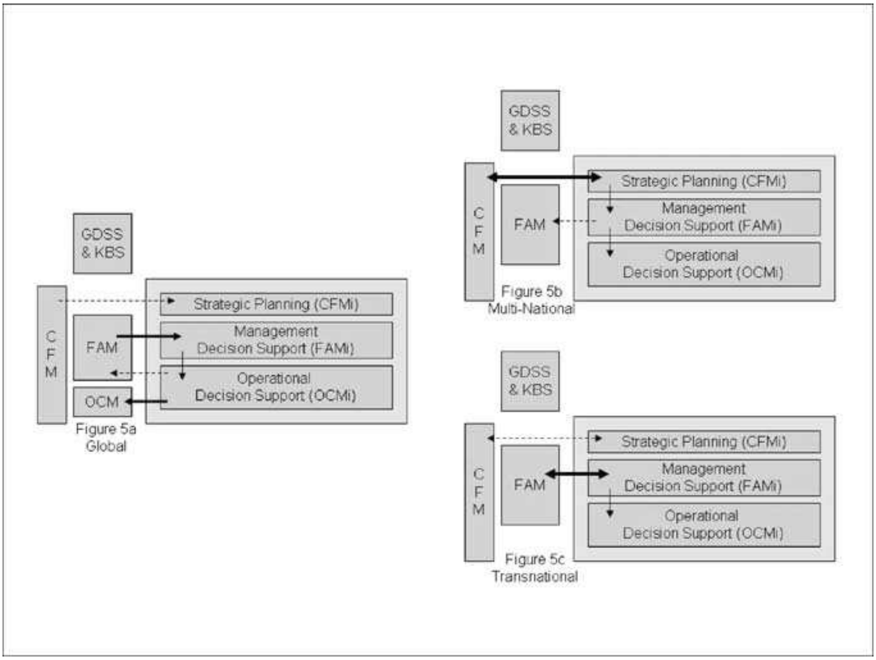


**Figure 5.** DSS support under different international interfaces

*Case 2*: Consider a firm that manufactures air-conditioning units. It manages international operations in Brazil, China, and the US. Using agreed-upon higher-level designs and product-mix levels, each plant plans its own manufacturing to meet its sales targets, seeks resources to hire people and acquire capital, and manages payments to its suppliers. Given the diversity of the customer needs, each unit operates as an independent unit, a characteristic of a multinational firm. While there may be an agreement on some broader goals (e. g., financial targets, product mix), most of the management and operational control is left to the subsidiary. As seen in Figure 5b, the subsidiary interaction at the strategic level is high and each subsidiary makes its own management and operational control decisions to implement the strategies. Most of the feedback is through financial controls (e. g., transaction targets and actual values) and are transmitted to corporate headquarters for consolidation and evaluation.

The strategic planning here is accomplished using higher-level goal reconciliation through idea generation and rank ordering/prioritization of specific strategies. These become inputs for the individual divisions and the rest of the financial modeling is local to the firm. Each subsidiary may use model integration and other types of support that are unique to support its operations. The corporate financial model (CFM) may provide targets for transactional levels, which are then used as guidelines for functional area modeling. The technology support here includes:

1. *Face-to-face interaction*: Equivocality at the strategic level makes the decision process highly complex. So, richer face-to-face interaction or a teleconferencing facility that supports synchronous communication is needed to help formulate goals, set strategic targets, and so forth. In fact, in the case discussed, early interaction between strategic partners was done using teleconferencing facilities and followed up with frequent meetings through Web-based video-based interactions. Many advanced collaborative and GDSS technologies may also be used to support such interaction.
2. *Reusable model integration and analysis libraries*: Individual subsidiaries, depending on the level of technological maturity, may rely on technologies that support model integration at various levels, and tools used at the corporate level may be reconfigured to support the subsidiaries. Access to prior models used in decision making may be appropriate, especially when people involved in the decision-making process move from region to region over time.
3. *Communities of practice*: Certain knowledge on best practices or market trends becomes a part of knowledge outflow. These are captured and communicated either through knowledge repositories, or shared as communities of practice.

*Case 3:* The third case is an automotive firm that manufactures different models of automobiles each year. As a part of its international strategy, it decided to let each subsidiary in a given region be responsible for an automotive model (e.g. Japan, China, Europe, US). In other words, there was some strategic level of interaction in target setting and strategic planning, but the middle-level managers are given the autonomy to execute these plans by responding to local sensitivities. Each subsidiary is fully responsible for the product design of the automobile and is asked to leverage the corporation-wide network of resources (suppliers, engineers, dealerships, and so on) to manufacture and distribute these to relevant markets. The subsidiaries may collaborate or seek input among themselves to forecast sales, decide on options, realize efficiencies using corporate suppliers for common parts, sell the product using international dealerships, and manage shipment/service to realize economies of scale. This enables the corporation to leverage competencies developed at one location for the benefit of the another, leverage relationships embedded in a subsidiary for branding corporate-wide products, and gain economies of scale at the operational level. This type of interaction calls for extensive knowledge flow exchange at the middle-management level, and collaboration among global teams of managers.

The decision support, as shown in Figure 5c, involves cross-subsidiary interaction across functional units (such as sales, production, purchasing), and intra-subsidiary interaction between strategic and operational levels for plan execution. The decision integration at this level must support a high degree of equivocality in the way policies and environmental factors are interpreted for relevancy within the local decision-making context. The technology support specifically involves:

1. *Multimodal communication*: Multiple middle-management teams have to interact frequently to share their knowledge and leverage best practices. While certain face-to-face and teleconference-based interactions are needed when the complexity of interaction is high (e. g., product design, manufacturing), other interactions (e. g., human resource, procurement, and distribution) may be supported through group interaction in an asynchronous mode. In other words, task complexity dictates the richness of the communication used.
2. *Semantic mapping and knowledge validation:* Knowledge flows across countries can be highly context based, and certain validation or semantic mapping of the knowledge to corporate-wide standards is needed, if this knowledge is to be shared and managed by the corporate unit.
3. *Communities of practice enriched with social interactions*: Given the degree of middle-management interaction and the contextual experience they bring to their operations, there is a need for significant socialization control. While there is a need to support frequent communication through the use of repositories and communities of practice, they should be blended with social interaction and face-to-face communication to address language and cultural differences. This is essential given the degree to which corporate and subsidiary operations are controlled by this group.

In conclusion, within the setting of financial planning in an international marketplace, it is clear that the tools used to support decision integration and administrative coordination need to support communication of significant data and knowledge with varying levels of intensity and at different levels of granularity. Table 2 provides a quick summary of decision support under each international strategy.

**Table 2.** Technology characteristics

| International firm type | Global | Multi-domestic OR multi-national | Transnational |
|---|---|---|---|
| Collaborative technologies for planning | Richer (peer-to-peer or interactive) feedback for accurate interpretation | Face-to-face communication | Communities of practice – enriched with social interactions |
| Shared knowledge for control | Knowledge repositories and intelligent agents for verification of data communicated across networks | Reusable model libraries and knowledge libraries of goals and targets | Semantic mapping with knowledge validation |

In summary:

- Rich communication technologies of varying degrees are needed to support global teams for goal setting, operational level coordination, or middle management planning and control;
- Knowledge repositories and communities of practice are critical to enable effective sharing of data, knowledge and competence across the network of subsidiaries and the parent organization.

These two key technologies are essential if a firm is to support its financial plans successfully. This support has to address both interactions under varying degrees of equivocality (face-to-face, intertwined with social interactions, and occasional feedback) and modeling to analyze varying levels of stored expertise (communities of practice that seek peer advice in real time, searchable knowledge repositories, reusable model libraries, semantic maps for knowledge/data translation, and data analysis tools that will help mine knowledge from data). Of course, intelligent agent technology can help support both active and passive validation of knowledge as it is transported across the units. These model and interface libraries are shown as a part of the g-DSS architecture in Figure 6.

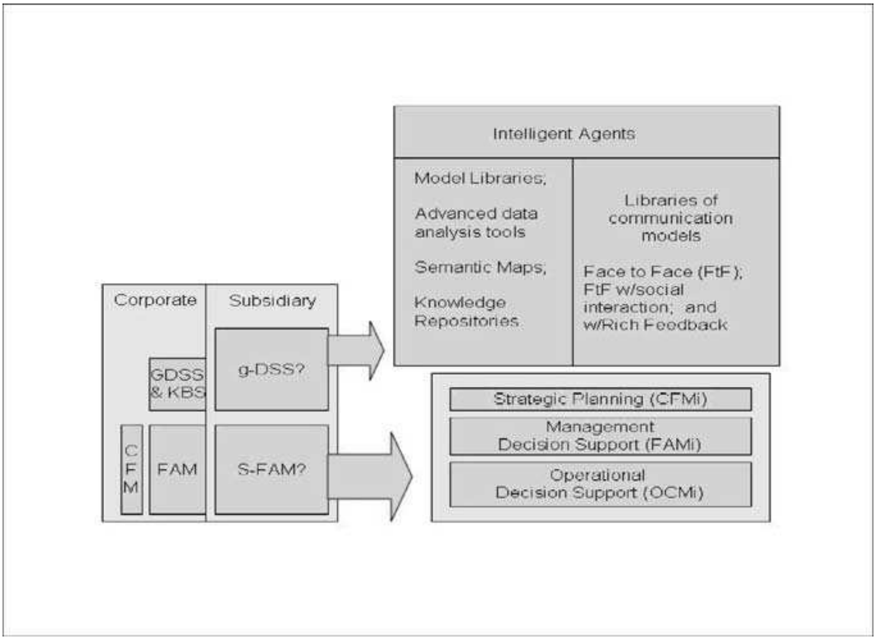


**Figure 6.** Global DSS framework

# 5 Discussion and Conclusions

As noted in the previous section, the complexity of technology support varies depending on how a firm articulates its product differentiation strategy in a global setting – specifically in the way subsidiaries interact, deal with environmental uncertainty, and address physical and cultural proximity of the subsidiary to the parent organization (Boudreau et al. 1998, Chung et al. 2000). In addition to technologies, however, it is the management of global teams that will make g-DSS work effectively. In other words, the role of both people (language, culture, and IT proficiency) and technology (accessibility and appropriateness) have to be considered together when managing international organizations (Dube and Pare 2001). For example, intense knowledge sharing and interaction will most likely occur among people with higher levels of IT maturity in a transnational firm and they need both face-to-face and teleconferencing types of interaction to resolve conflicts. On the other hand, a global firm focusing on operational coordination (e. g., parts used to produce a product are moved from one region to another) may use a mix of asynchronous and synchronous computer-mediated communication to engender trust among the people involved in such coordination (McDonough et al. 2001). For example, a mix of email, peer-to-peer interaction through communities of practice and online chat rooms may be used to help support coordination among supervisors, as they deal with unexpected shipment releases or supplier disruptions.

The issue of trust is both fragile and temporal, especially when there is significant turnover among global teams that are formed and disbanded with each project (Jarvenpa and Leidner 1999). This can be true both in the case of global firms (e. g., supervisory level employees) or transnational firms (e. g., product design engineers). In such cases, adding richness to global communication through social interaction or occasional face-to-face communication may increase this trust. An interspersing of rich communication (face-to-face) with computer-mediated support is also suggested for global teams (Maznevski and Chudoba 2000) and especially for a transnational firm (Boudreau et al. 1998). Such a mix might include information integration and communication tools to manage local stakeholder networks as well as language translation, groupware, and organizational memory systems to support knowledge flow across the network.

In summary, this chapter uses financial planning in an international arena to illustrate how firm-level strategy and the resulting network of interactions often dictate the nature of decision support. In arriving at such support, a firm needs to consider its differentiating strategy (columns of Table 1), the task it has to support (i. e., the level of interaction and its frequency), and the people involved in performing this task (i. e., their familiarity with such interactions, the diversity of the firm: language, cultural background). These in turn should help the firm determine the mix of asynchronous and synchronous tools (rich, face-to-face communications) needed to reduce equivocality and the modeling tools (repository, communities of practice) needed to reduce uncertainty.

While the focus of much of the discussion was on financial planning, the concepts are applicable to other application domains. The conceptual framework develops a mix of tools that can integrate technologies with people. However, the effectiveness of the tools (i. e., decision quality, satisfaction with the decisions, time taken to make decisions, and so on) and their cost (frequency of face-to-face meetings vis-à-vis teleconferencing, asynchronous communication) are still unresolved issues and need further research. While both value and costs may be contextually dependent on the task supported, research needs to address some of the factors that can help determine the quality of the global decisions and cost of supporting such decisions using technologies such as those identified under g-DSS.

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# PART VIII

# Developing and Managing Decision Support Systems

# CHAPTER 49
# On the Design Features of Decision Support Systems: The Role of System Restrictiveness and Decisional Guidance

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This chapter is about the substantive design of DSS features. It begins with a set of five premises that are fundamental for designing DSSs yet are often neglected in the prescriptive literature. Because a DSS is an intervention into the processes by which decisions are made, and because the ultimate outcome of DSS design is not the system itself but the system's consequences, the key question for designers to keep in mind is this: What will the decision maker do with the system? Contemplating this question leads to two key design features of DSS: system restrictiveness and decisional guidance. System restrictiveness refers to how a DSS limits decision makers who rely on it to a subset of all possible decision-making processes. Decisional guidance refers to how a DSS enlightens, sways, or directs decision makers as they choose and use its functional capabilities. Together these two features play a significant role in determining whether a DSS will successfully achieve its design objectives while avoiding undesirable side-effects. The chapter explores how a system's restrictiveness and decisional guidance can be defined by designers to achieve their design objectives as well as how DSS features can restrict and guide.

**Keywords:** Decision support system; Decision-making process; Restrictiveness; Decisional guidance; Design; Consequences; Constraints; Features

## 1 Introduction

This chapter addresses the design of computer-based information systems intended to support human decision makers, commonly referred to as decision support systems (DSSs). The chapter is written with those who develop such systems in mind. Most of what is written here is not inconsistent with conventional thinking on DSS design, but the emphasis here is not what one typically finds in the prescriptive DSS design literature and my perspective differs from that which is most commonly adopted in practice. Since the discussion here is limited by the constraints of a single chapter, interested readers – practitioners or researchers – can turn to Silver (1991b) for a more formal and extensive treatment of this material.

Design is both a process and a product (Walls et al. 1992, Hevner et al. 2004). The design *process* consists of those activities that system builders perform while developing systems, whereas the design *product* is the DSS that results from those efforts. Although process and product are certainly connected, this chapter concentrates on the product. To distinguish it from the design process, the design product might be termed the system's *substantive design*. The substantive design of a DSS comprises the system's *design features*.

Any use of the terms ***features*** or ***design features*** requires some qualification, because these words mean different things to different people. Some use the term features to refer to a system's functional capabilities — its information-processing features. Others would include among a system's features the elements of its human-machine interface, such as its menu structures and dialog styles. Some use the term features narrowly to refer to what others (DeSanctis et al. 1994, Griffith 1999) more specifically call optional or tangential features, functions that might or might not be present in a given system of a given type. Still others think of features as the bells and whistles that implementers and vendors use to embellish the systems they produce. Additional meanings abound. Given these many meanings, I use the terms features and design features in the broadest sense possible, to refer to all of a decision support system's components, characteristics, and properties, including, but not limited to, its information-processing functions and elements of its user interface.

Much of the prescriptive literature on DSS design addresses the process, not the product of design. Such classic works as those by Keen and Scott Morton (1978), Sprague and Carlson (1982), and Bennett (1983) concentrate on distinguishing how systems that support decision makers should be designed from how other systems of the time were being developed. But these works, and those that followed in the subsequent decades, tell DSS developers little about the substantive design of DSS — about the appropriate design features for a given DSS. Over the years we have also seen, and we continue to see, a great volume of design research focused on specific decision-aiding technologies. While this literature does address substance rather than process, it too offers little substantive advice for developers on which decision aids to employ in a given situation and how best to package that collection of aids into an effective system.

For DSS developers, whose very purpose in building a DSS is almost always to improve decision making, a key design objective is to create a system whose features promote desired or desirable decisional consequences while avoiding adverse effects. The lack of substantive guidance on which design features — functional capabilities, interface elements, and so forth — are appropriate for a given system is therefore problematic. Providing such advice is admittedly challenging, because such counsel must be general enough to be broadly applicable while sufficiently specific to be meaningful in a given situation. For this reason, prescribing a design process is easier than offering substantive design advice. Nonetheless, this chapter confronts the challenge by identifying and exploring two attributes of DSSs that have broad-based design significance. The first attribute, *system restrictiveness*, characterizes what decision makers can and cannot do with a given DSS.

System restrictiveness has implications for various substantive design decisions, including which functional capabilities to include in a DSS, which options to provide with each of those capabilities, and how to package the capabilities into a system. The second attribute, *decisional guidance*, reflects those aspects of the system that influence (intentionally or not) the selections decision makers make as they employ the discretionary power afforded them by the DSS.

The chapter is organized as follows. I begin by discussing five premises upon which the subsequent material rests. I present these premises to construct a foundation for what follows, but I would contend that adopting these premises can, in and of itself, lead to better DSS design. With this foundation in place, I next explore the connection between substantive design features and the consequences of DSS use. This analysis identifies the two system attributes of special interest: system restrictiveness and decisional guidance. Each of these can be viewed as a design variable under the control of the designer. For each, the questions of interest become how does this attribute affect decision-making behavior (that is, how does it lead to consequences) and how can designers use it to accomplish their design objectives (that is, to produce the consequences they desire). I conclude by considering design objectives at a higher level of generality, contrasting two views of the role of DSSs as agents of change and considering the differential implications of these views for designing system restrictiveness and decisional guidance.

## 2 Premises

The chapter rests on several premises that discussions of DSSs often neglect. Most of these premises are based on the process view of decision making, the recognition that decision making is not a point event but a sequence of decisional activities[1]. Each premise has important implications for the substantive design of DSSs.

> **Premise 1:** *A DSS is an intervention into the process through which decisions are made* (Silver 1991b).

Unlike those computer-based systems intended to replace people, DSSs are constructed to assist human decision makers. Indeed, the defining element of a DSS for most commentators is that the system supports, rather than replaces, the human decision maker. But a DSS is not just an information-processing assistant. Because system use will likely change the way decisions are made, the DSS is an intervention into the process through which decisions are made. The computer-supported process will differ – perhaps dramatically – from the unaided one. The implication of this observation for DSS design is that designers must contemplate

[1] Strictly speaking, the set of decisional activities may not be linear—several activities might be performed in parallel.

how the features they design are likely to affect the path decision makers will follow in arriving at a decision.

Consider, for example, decision makers confronting a multi-attribute decision-making task, such as locating a warehouse, renting an apartment, or buying a vehicle. This classic decision problem is characterized by the need to choose among a (possibly large) set of alternatives, each described by a set of attributes. Many solution strategies – sometimes called choice rules – for tackling this problem have been observed and classified. DSSs can intervene in the multi-attribute decision-making process by affecting which of the many strategies users employ (Todd and Benbasat 2000).

**Premise 2:** *The ultimate outcome of the DSS design process is not the computer-based system but its effects.*

Contrary to widespread belief, the DSS itself is not what should be of greatest importance to DSS designers. After all, DSSs are not built to be admired or exhibited; they are constructed to be used by decision makers. Of ultimate interest, therefore, are the system's consequences for its users and for others. These consequences include the system's effects on the decision-making process, the decisions made through that process, and the ramifications of those decisions[2]. These consequences need to be the true foci of DSS design. The substantive design implication is that designers must focus on system features not for their own sake but for their anticipated consequences.

Consider, once again the multi-attribute decision-making problem and the many choice rules that could be used to solve it. Some of these choice rules are compensatory, allowing high scores on one attribute to compensate for low scores on another, whereas others are non-compensatory. Employing a compensatory approach would likely lead to a different choice than would a non-compensatory rule – for instance, a different warehouse location. And this decision could have many ramifications, such as how delivery trucks are routed and how well retail outlets are stocked. Since the mix of decision aids included in a DSS would likely affect which choice rule (or combination of rules) the user of such a system adopts (Todd and Benbasat 2000), this design decision can have significant consequences. These consequences are the ultimate outcome of the design process.

**Premise 3**: *The consequences of a DSS are not necessarily those intended by the designer.*

System designers may try to engender a given set of consequences when they construct features, but since decision makers may not behave as designers expect (Griffith 1999), the intended consequences may not be realized. Moreover, even if the designer's intended effects are realized, the decision-maker's behavior may

[2] Sometimes DSSs have consequences of interest that are not directly related to the decisions that emerge from their use, such as shifts in organizational power, structure, or culture.

also lead to unanticipated side-effects. The substantive design implication is that focusing only on achieving planned consequences is not sufficient.

One of the early DSSs documented in the literature (Gerrity 1971, Stabell 1974) was a portfolio management system intended to improve the performance of portfolio managers by enabling them to look at buy/sell decisions from the perspective of the entire portfolio rather than that of individual securities. The system was considered successful, although the system did not succeed in changing the decision-making behavior of the account executives. The system's success was an unplanned side-effect, as the company obtained a competitive advantage from the system for other reasons.

This premise reminds us that the consequences of a DSS are not necessarily positive. Not only might the hoped-for positive effects not be realized, but system use may even lead to negative consequences. Various studies (for instance, Fripp 1985, Kottemann and Remus 1987, Elam and Mead 1990) have found evidence of degraded or dysfunctional performance using a DSS. So the downside risk of building a DSS is not just that it may fail to achieve its intended benefits; the greater risk is that intervening in a decision-making process may be deleterious. When one thinks of design objectives, one tends to think of the positive accomplishments pursued by the designer. But more completely, the designer wants to achieve the intended effects without incurring negative side-effects. While designers understandably may tend to focus on achieving the effects they desire, paying attention to only these consequences is ill-advised. Designers must also anticipate and avoid undesirable consequences.

**Premise 4:** *DSSs can affect the structure or the execution of the decision-making process.*

Since many decision-making tasks can be performed in more than one way, an important element of decision making is deciding how to decide – choosing among the different decision-making processes that can be followed. This strategy selection might be made at the outset or it might evolve as the decision maker confronts the problem. Either way, DSS designers must differentiate this structuring of the decision-making process from the execution of the process – actually engaging in the information-processing activities that lead to the decision. For instance, when confronting a multi-attribute decision task, structuring the process consists of selecting a choice rule or constructing a hybrid of such rules. Applying the chosen rule(s) – for instance, selecting attributes, setting cutoff values, and eliminating alternatives in the elimination-by-aspects approach – constitutes executing the process. Each of these activities – structuring and executing the process – can be the source of degraded decision-making behavior and each can be amenable to computer-based support. Many designers take the structuring for granted and focus only on process execution, which can lead to unexpected effects as decision makers use the DSS to follow strategies not anticipated by the designer.

**Premise 5:** *The design features of a DSS — or any computer-based information system, for that matter — are not limited to the technical properties of the artifact.*

While system builders typically concentrate on a system's technical features, such other elements of the DSS as usage policies, training, ongoing support, and cost are also design features of the system that can be defined by the design process. Considering this more complete set of features matters, because consequences follow not just from the technological properties of the system but also from the social and economic factors that surround it. For instance, if using a system is voluntary, some decision makers might use it and others might not. Training and ongoing support might have an effect on whether or not people use the system and how they perform if they use it. Alternatively, a policy of mandatory use might address the problem of non-use but might lead to misuse or abuse of the same technical system.

Table 1 summarizes these five premises and their implications for DSS design. Taken together they lead us to see DSS design this way:

> DSS design is a process wherein designers define a system's (technical and non-technical) features in an attempt to affect the structure and execution of the decision-making process so as to achieve desired design objectives while avoiding undesirable side-effects. In short, the DSS design process is about producing a substantive design whose consequences will conform to the project's design objectives.

**Table 1.** Key premises and their implications for DSS design

| Premise | Implications for substantive design |
|---|---|
| A DSS is an intervention into the process through which decisions are made. | Designers must contemplate how the features they design are likely to affect the path decision makers follow in arriving at a decision. |
| The ultimate outcome of the DSS design process is not the computer-based system but its effects. | Designers must focus on system features not for their own sake but for their anticipated consequences. |
| The consequences of a DSS are not necessarily those intended by the designer. | Designers must contemplate how substantive design features are likely to affect whether or not design objectives are achieved as well as how those features may lead to undesirable side-effects. |
| DSS can affect the *structure* or the *execution* of the decision-making process. | Designers must distinguish the structuring of the decision-making process from its execution and consider how the system features will likely affect each. |
| The design features of a DSS are not limited to its technical properties. They include social and economic elements as well. | Designers must pay attention to these non-technical features, recognizing that, in combination with the technical features, they can influence consequences. |

# 3 DSS Design Features and Decision-Making Behavior

When considering a system's technical features, it is natural for DSS designers and users alike to focus on the system's functional capabilities, asking, what can the system do? But because what ultimately matter are the system's consequences, the real question is this:

What will the decision maker do with the system?

This question decomposes into a sequence of two more focused ones:

1. What is the decision maker capable of doing with the system?
2. Given those capabilities, what will he or she do?

The answers to these questions are tightly linked to the system's design features. The first question reminds us that the system's features affect both what a decision maker *can and cannot* do with the system. We tend to think of DSSs as enabling, because their functional capabilities augment the human decision maker's limited information-processing capabilities. But DSSs are both enabling and constraining. Since any given system has a finite set of functional capabilities, when decision makers rely on a given system to support their decision making that system's feature set limits what they can do. Designers who are concerned about the consequences of the systems they build — and that should be all DSS designers — need to look at the design from both perspectives — from that of empowerment and from that of restrictiveness.

The second question highlights that, despite the system's constraints, decision makers are still likely to have significant opportunities for exercising discretion. For instance, decision makers can typically choose among functional capabilities, supply inputs to those capabilities, and select display formats for viewing the outputs. Indeed, any system so limiting as to allow the decision maker no discretion would not qualify as a support system. So, just as some design features affect what the decision maker *can* do, other features affect what the decision maker *does* do while exercising the discretion he or she is granted. Designers who are concerned about the consequences of the systems they build must also consider, therefore, how the system's features may influence the way that decision makers choose among and use the system's functional capabilities.

Taken together, the answers to these two questions bring us to the central relationship between substantive design features and decision-making behavior:

**The design features of a DSS can play a role: (1) in restricting what a decision maker can do when employing a given system, and (2) in guiding what he or she opts to do within the limits of those restrictions.**

This reasonably intuitive conclusion conflicts with the typical designer view of a system. Designers typically focus on providing useful functionality — that is, defining things the decision maker can do with the system — without paying much attention either to what the decision maker cannot do or to what the decision maker will opt to do. This overly narrow analytic focus can lead to systems whose consequences are not those intended by the designer, are undesirable, or both. Treating the system's restrictiveness and its guidance as key design variables is therefore a better developmental approach.

# 4 System Restrictiveness

Because DSSs enhance the human's own limited information-processing capabilities with a set of computer-based capabilities, one can easily contemplate DSSs only in terms of their enabling power. But since DSSs provide decision makers with a given set of functional capabilities, DSSs enable some decision-making processes while restricting other processes[3]. For instance, a DSS might implement only a few of the many algorithms for time-series forecasting. Or a DSS might support currency conversions among dollars, euros, and yen, but not pounds sterling. Similarly, a DSS might accept only non-negative input values for growth rates, disallowing the possibility of contraction.

Since enablement and constraint are essentially inverses — what is constrained is not enabled and what is enabled is not constrained — considering both sides of this coin explicitly might seem unnecessary when designing a DSS. By this logic, focusing on one will take care of the other. In particular, since defining what the system can do is a necessary design task — the functional capabilities are, after all, the sine qua non of the system — one could develop a DSS without paying any attention to how it constrains. Although this exclusive focus on enablement is often seen in practice, several factors suggest that paying design attention to a system's restrictiveness is also essential.

Contemplating a system's restrictiveness encourages designers to ask key questions that might otherwise go unasked, such as, "Should this capability be restricted?" or "Would it be a mistake to restrict that function?" Put differently, focusing on the constraints makes the designer explicitly consider what should and what should not be constrained, which may be essential for achieving desired consequences or for avoiding undesirable side-effects. Since the designer is actively building features into the system, he or she might very well fail to think in terms of what has been, or should be, excluded. Focusing on restrictiveness can help avoid these type I and type II design errors (omitting capabilities that should be included or including capabilities that should be omitted).

Consider a DSS that is used as part of a planning process and that embeds a simulation model. Since decision makers often fall prey to the wishful thinking bias, whereby their predictions are overly optimistic, one design objective might be to produce more realistic predictions by preventing such bias. A system

[3] I defer until later in this section the matter of a given DSS restricting different decision makers differently.

designed to meet this objective might restrict the allowable values of some inputs and might also limit the number of times the model can be run (to prevent gaming of the system). Even if such debiasing were not an explicit objective of the system, designers might want to build these restrictions into the system to prevent the wishful thinking bias from cropping up as an undesirable side-effect of model use. In this example, the system's constraints — what cannot be done with the system — are critical design features.

Restrictiveness can directly affect system consequences, since the absence of a function or an option may force decision makers to follow different decision-making processes than they would otherwise have selected. But system restrictiveness can also affect behavior and outcomes by influencing a decision maker's attitude toward the system. On the one hand, a decision maker might choose not to use a highly restrictive DSS if he or she finds it overly constraining. On the other hand, a decision maker might abandon a minimally restrictive DSS if its many functions and options make it difficult for him or her to use[4].

System restrictiveness is a design variable — a system feature under the control of the designer — that must be carefully set. Much of the early literature on DSS development prescribed flexibility (Sprague and Carlson 1982) — the opposite of restrictiveness. Later work (Silver 1990, 1991b) argued that a balance between flexibility and restrictiveness is required, where the balance depends on the objectives of the specific DSS being developed. Some design objectives favor greater flexibility (enablement) whereas others favor greater restrictiveness.

Exploring the role of system restrictiveness as a design variable has two parts: (1) considering how a given DSS design objective can be met by enabling or restricting decision makers, and (2) contemplating how the system's technical properties can accomplish the desired enablement or restriction. But before engaging either of these issues, a formal definition of system restrictiveness is in order.

> **System restrictiveness:** the manner in which a decision support system limits its users' decision-making processes to a subset of all possible processes.

Restrictiveness thus defined is a multifaceted quality of a DSS, because systems can restrict in many ways and because many aspects of decision-making processes can be restricted. Indeed, one often cannot say which of two DSSs is the more restrictive, except in those cases where the processes supported by one system are a proper subset of those supported by the other. Consider, for example, one DSS that supports time-series forecasting and another that supports multi-attribute decision making. The processes supported by the two systems are so different that it might not make sense to refer to one system as more restrictive than the other. Even given two DSSs for the same task — say time-series forecasting — one cannot generally identify the more restrictive of the two. Suppose that one DSS supports several forecasting methods while the other supports several different

[4] The technology acceptance model (Davis et al. 1989), for example, posits that perceived usefulness and perceived ease-of-use will affect intention to adopt an information system.

methods. It would not be appropriate to characterize either as more restrictive than the other. As it turns out, however, DSS designers commonly find themselves in situations where one proposed design is strictly more restrictive than the other because designers frequently are in the position of choosing between more restrictive and less restrictive versions of the same system. Given an initial design, for example, the designer may contemplate adding or removing functional capabilities or options, thereby making the design less or more restrictive, respectively.

## 4.1 Designing System Restrictiveness

In many — perhaps, most — contexts, restrictions are considered bad. People generally do not like blackout dates on discount airline travel or 15-minute limits on parking meters. One might conclude, therefore, that system restrictiveness is an undesirable quality and that DSS designers should avoid restricting. Indeed, users of early DSSs rebelled against the inflexibility of those systems. But the claim that restrictiveness is inherently bad is mistaken. Sometimes restrictiveness is bad, in the sense that it works against a designer's objectives, and sometimes it is good, in the sense that it promotes those objectives. Moreover, whether we like it or not, whether we choose to think about it or not, systems are inherently restrictive. Any computer-based system — other than a Turing machine — has a limited set of capabilities. So the design question is not so much whether or not to restrict, but how, and how much, to restrict. Table 2 summarizes the factors that favor lesser restrictiveness and those that favor greater restrictiveness. The following discussion introduces these factors; more extensive discussions can be found in Silver (1991b).

**Table 2.** Design objectives favoring greater and lesser restrictiveness (Based on Silver 1991b)

| Design objectives favoring greater restrictiveness | Design objectives favoring lesser restrictiveness |
|---|---|
| • Promoting use<br>• Prescription<br>• Proscription<br>• Providing structure<br>• Promoting ease of system learning and use<br>• Fostering structured learning | • Promoting use<br>• Meeting unspecified needs<br>• Supporting changing decision-making environments<br>• Supporting multiple decision makers and tasks<br>• Allowing users discretion<br>• Fostering creativity<br>• Fostering exploratory learning |

### 4.1.1 Objectives Favoring Lesser Restrictiveness

The groundbreaking work on DSSs by Keen (1980), Sprague and Carlson (1982), and others offers several reasons for designing less restrictive DSSs. Much of this work recognized that the rigidity of the failed management information systems (MISs) and even the early DSSs was not conducive to supporting human decision makers engaged in problem-solving activities. Effective support for human decision makers in many cases favors less restrictiveness.

**Meeting unspecified needs**. Decision makers often are unable to express their needs adequately during the analysis and design stages of system development. They may only be able to determine which functional capabilities are useful and which are not by actually using the DSS. This difficulty may be due, in part, to the unstructured nature of decision-making tasks. One way that system builders can cope with underspecified needs is to build a generalized and flexible system that provides a broad spectrum of capabilities from which decision makers can choose. This approach leads to minimally restrictive systems. After all, designers would be unable, or unwise, to produce a very limited system in a situation where specific needs cannot be defined a priori.

**Supporting changing decision-making environments.** Over time, decision makers, the problems they confront, and the organizational and industrial settings within which they operate all change. Indeed, the DSS itself may contribute to some of these changes as decision makers' understanding of their tasks and situations evolves through use of the system (Keen 1980). If the DSS is intended to have longevity — to continue to be useful as the elements of the decision-making environment change — the DSS must be sufficiently robust to support both the current and future decision-making environments. Such durability will require more flexibility and less restrictiveness in the system's design.

**Supporting multiple decision makers and tasks.** Some DSSs are custom designed for a given task and, possibly, for a small set of specific individuals. But such highly tailored DSSs — once a hallmark of computer-based decision support — are increasingly giving way to more generalized systems intended to support multiple tasks and decision makers. If a DSS is to support a wide range of tasks, each with its own information-processing requirements, and a wide range of decision makers, each with his or her own individual characteristics, the system will likely need to be less restrictive rather than more.

**Allowing discretion.** Computer-based support systems attempt to combine the information-processing power of the computer with the strengths of the human decision maker. Taking advantage of these human strengths requires granting the decision maker opportunities to exercise his or her discretion. This discretion may relate to structuring the decision-making process — deciding how to decide — or to executing that process. Since increased restrictiveness reduces the opportunities for exercising discretion, designers may want to create less restrictive systems to allow for the expression of more human judgment and preferences. For instance, they might build systems that support more than one approach to solving the problem or that provide more opportunities for human input into the process as it proceeds.

**Fostering creativity**. For many decision-making tasks, especially those where decision makers formulate their own solutions as opposed to choosing among ready-made alternatives, fostering the creativity of the human decision maker is an important objective. Highly restrictive systems are likely to stifle such creativity, so this design objective, too, favors more flexibility and less restrictiveness.

**Fostering exploratory learning.** Since the early days of DSSs (see, for instance, Alter 1980), gaining a better understanding of the tasks they confront has been recognized as a potentially valuable byproduct of DSS use for decision makers. Allowing users to experiment with a system's functionality can foster such understanding through exploratory learning. For example, giving a decision maker a free hand to examine the contents of a data warehouse — slicing, dicing, drilling down, and so forth — may be a useful way to help him or her understand the business better. Running a broad range of scenarios through a simulation model similarly can help someone get a better feel for the dynamics of the business. So flexibility, rather than restrictiveness, may be most appropriate when builders desire to promote such exploratory learning.

### 4.1.2 Design Objectives Favoring Greater Restrictiveness

If one views a decision support system merely as an information-processing assistant, one might have difficulty seeing why designers would want to restrict the decision-making process. But recognizing that a DSS is also an intervention into the process through which decisions are made, we find several significant reasons designers might want, or need, to restrict those processes.

**Prescription.** DSS interventions are often intended to impose a given decision-making process. Several different reasons for prescribing can be identified. Sometimes the intent is to prescribe a normative or preferred approach. For instance, a portfolio management system might prescribe processes consistent with normative portfolio theory or a DSS for multi-attribute decision-making tasks might prescribe the normative linear additive model. Similarly, some managers may have their own preferred way of performing a task — say, predicting sales or selecting products to promote — and those managers may require that their subordinates follow the preferred approach. Even in the absence of a normative or preferred process, prescribing a single process may benefit the organization by creating consistency or standardization of decision making. A bank may want to ensure that all of its many loan officers follow the same, standard procedure for granting or denying loans, thus reducing risk. The given method may not be deemed superior to other, equally acceptable methods, but the uniformity of decision making is beneficial to the bank.

**Proscription.** Some DSSs restrict for the opposite reason, not to require but to preclude various forms of decisional behavior — especially, current behavior. For instance, a DSS might be intended to move managers away from the flawed process they are currently following, or it might be designed to break managers out of their routines and make them more innovative and creative. In both these cases, a DSS could be constructed that constrains its users from following the current process. Proscription, however, is not always for the sake of changing current behavior; it may be intended to prevent detrimental use of a system's capabilities — that is, system use that would degrade decision-making performance. A DSS might try to prevent its users from stumbling into some of the many pitfalls to which human decision makers are vulnerable. Human decision makers, for instance, are known to fall prey to numerous systematic cognitive biases (Tversky and Kahneman 1974) that distort their judgment. A system could limit its users' opportunities for making such biased judgments and choices.

**Promoting structure.** Deciding how to decide is often one of the most difficult aspects of decision making. Given a powerful DSS with many functions and options, decision makers may struggle to structure an effective decision-making process. They may suffer from information overload if too many information sources are available. They may similarly be overwhelmed if too many functional capabilities are available. A more-restrictive DSS that provides the decision maker with a specific path to follow may sometimes be more effective than a less-restrictive system that requires the decision maker to structure his or her own process.

**Promoting ease of system learning and use.** One of the tenets of DSS development is that DSSs should be easy to learn and use. But highly flexible, minimally restrictive systems tend to be more complex with more features that the decision maker needs to learn, remember, and be able to use effectively. One way to make such DSS easier to learn, remember, and use is to make them more restrictive, limiting the functions, options, and so forth.

**Fostering structured learning.** While exploratory learning, where decision makers gain knowledge of their environment by experimenting with a system, is sometimes an added objective of DSS design, other times DSS are intended to help decision makers in a more structured way to understand their decision-making environment and the decisions they confront. Greater restrictiveness may be valuable in providing users with a structured learning experience. For instance, a restrictive system could march decision makers through a given solution approach. Or it could take decision makers on a structured tour of a database, helping them understand how to analyze the data that are available to them.

### 4.1.3 Restrictiveness and Promoting Use: A Double-Edged Sword

One obvious objective common to virtually all information systems is that the system be used. Promoting use is especially significant for DSSs because, unlike transaction-processing systems, use of DSSs is often discretionary (Bennett 1983). In terms of promoting use, restrictiveness can be a double-edged sword. Too little or too much restrictiveness might inhibit use. Too much restrictiveness may make the decision maker feel overly constrained and reject the system. For instance, the system might preclude the decision maker from following his or her favorite process. Or the many constraints imposed by the system might frustrate him or her. Since one can easily see how great restrictions may inhibit use, one might assume that great flexibility would promote use. Indeed, this idea was a theme of the early DSS literature. However, unlimited flexibility also has its shortcomings. A decision maker given a very powerful and flexible system may be overwhelmed by its capabilities. Just as decision makers can suffer from information overload, they might suffer from an overload of functional capabilities or an excess of options while using those capabilities. Learning, remembering, and using the system may be made more effortful by the complexity that follows from the lack of restrictiveness. Here, too, users may choose not to use the system.

Table 2 therefore categorizes promoting use both as a factor favoring greater and as a factor favoring lesser restrictiveness. Positioning the restrictiveness properly to promote use may be challenging. Setting the restrictiveness appropriately may be even more challenging if promoting use conflicts with other design objectives. The more specific decisional objectives of the system may call for more, or less, restrictiveness than is desirable to promote use and may, consequently, inhibit use. For instance, building a restrictive system to prescribe a given behavior may be fruitless if that restrictiveness inhibits use. This conundrum creates a difficult situation for the designer, to which I shall return later.

## 4.2 How do DSS Design Features Restrict Decision Makers?

Deciding which process restrictions and how much process restrictiveness are appropriate to achieve design objectives is one thing; designing the system to restrict the decision-making process as desired is another. How do DSS design features restrict decision makers? In general, constraints imposed on the technological properties of the DSS restrict the decision-making behavior of those who use the system. A system's technological properties can be constrained in various ways.

**Information-processing functions (information-processing capabilities).** Any given DSS makes available to its users some set of information-processing capabilities, such as searching for information, analyzing data sets statistically, solving optimization problems, calculating financial indicators, graphing trends, and so forth. This set of functional capabilities – functions, for short – is constrained in the sense that it is a proper subset of the infinite set of information-processing capabilities that could possibly be built into a system. And since these constraints on the set of functional capabilities restrict what the decision maker can do with the system; they restrict his or her decision-making process. If the system does not support a given information-processing function, then decision makers who rely on the system cannot follow a process that requires that capability[5]. In the case of time-series forecasting, for example, many forecasting methods have been proposed, but only a subset of the many methods might be included in the system. In the case of multi-attribute decision-making tasks, only a subset of the many possible choice rules might be included. An electronic spreadsheet package might be provided to users without such add-ins as linear regression.

In addition to limiting the *set* of functional capabilities available, the design of a DSS may also impose constraints on how those functional capabilities are used in combination one with another. Such restrictions may prohibit some uses or require others. The most restrictive systems — relatively uncommon today — require users to march through the system's capabilities in a predefined order as a fixed sequence of steps. Other, less-restrictive systems constrain in various ways how decision makers combine functions. Some functions may be prerequisites for others; use of the second function may depend on the successful completion of the first. Some functions may be alternatives; if the decision maker uses one, he or she cannot use the other. Some functions may be incompatible; here, too, decision makers who use one cannot use the other. In many cases, the dependencies between functions may be conditional. Decision makers who project unbalanced budgets may be required to run the projection again or to invoke a budget-balancing procedure. Decision makers who want to run a multiple regression analysis on autocorrelated data may be required to transform the data first. Ever since researchers, practitioners, and users rebelled against the inflexibility of the first interactive systems, this design dimension (restrictions on combining functions) has largely been neglected. But such restrictions can play significant roles in how the DSS affects decision-making behavior and, therefore, in the ultimate success or failure of the system.

**Data sets**. The data processed by the functional capabilities come from essentially three sources. The data may be provided by the system, the data may be entered directly by the user, or the data may be imported by the user from elsewhere[6]. Each of these data sources can be restricted. The most restrictive systems in this regard provide decision makers with no choice concerning the data to be

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[5] Understanding the constraints of a system's functional capabilities is made more complicated by the distinction between low- and high-level functions. If a system provides access to low-level functions that provide basic computational power—perhaps an embedded macro language or a matrix algebra processor—then an enterprising user might employ those functions to implement higher-level capabilities not directly supported by the system. For instance, matrix algebra could be used to perform a least-squares regression in the absence of a dedicated regression function and an electronic spreadsheet formula could be built to calculate multi-attribute utility in the absence of such a built-in function. Designers who intend to restrict high-level functions need to consider whether decision makers can work around these constraints by employing lower-level functions.

[6] When the DSS provides the data it may get these data from various sources. Where a DSS gets these data raises a complex set of design issues that does not matter for our purposes here. All data that are provided by the system, rather than the user, are therefore grouped together in this discussion.

employed, limiting them to a single data set provided by the system. Most DSSs, however, are not so restrictive. Systems can be less constraining by including multiple data sets, by allowing decision makers to enter their own data, or by enabling them to import external data. When decision makers are allowed to enter or import data, restrictiveness may still be operative. For instance, decision makers might be limited in the number of datasets they can create, the size of those datasets, or even their contents.

In addition to limiting data sources, DSSs can also constrain data use. A DSS might not allow all data to be used with all functional capabilities. Some data sets might be local to particular functions – for their use only – while other data sets might be global to the entire system. Conversely, some functions might accept data from any of the three sources, while others might be limited to a single source, such as data embedded in the function. Restrictions can be even more detailed; some specific data sets might be allowed with one function and not another. Specific restrictions might be due to technical factors, such as non-conformance between the data structure and the function, but decisional reasons may also drive such restrictions. For instance, a system intended to foster forward-looking, rather than backward-looking, analyses might allow certain data to be used by forecasting models but not to be perused directly by users. To encourage more environmental scanning, some functions might work only with external data as opposed to internal corporate data. For different tasks, data with different attributes (for instance, different levels of aggregation or time horizons) may be appropriate (Gorry and Scott Morton 1971). Data access might also be limited for organizational reasons. Some data may be deemed confidential and viewable by some decision makers and not others. For instance, as corporate executive support systems were migrated to divisional levels, issues arose concerning who should be allowed to see which data (Houdeshel and Watson 1987).

**Models.** Many DSSs offer model-based functions, such as solvers for linear programs or forecasters of time-series data. DSS models vary widely, including optimization models, simulation models, statistical models, and choice models (choice rules), among others. To discuss how model-based functions can be restrictive it is useful to distinguish model types from a specific instance of a model type. For our purposes, a model type refers to a class of models that have similar mathematical properties and, in particular, can be operated upon by the same functional capabilities[7]. For instance, linear programs are a type of model, whereas a given linear program is an instance of that model type. An implementation of the simplex algorithm can work on any linear program – that is, any specific instance of this model type. Electronic spreadsheets are another model type, and a given spreadsheet model is an instance of that type. Some types of models are highly structured, such as linear programs. All models of this type have the same basic structure; one instance differs from another only in terms of its specific objective function and

[7] See Geoffrion (1989) for a more formal discussion of model classes and Silver (1991b) for a more formal discussion of models in the context of DSSs.

constraints. Other model types – spreadsheet models come to mind – are less structured. Two spreadsheet models can be very different one from another.

Model-based functions can vary greatly in their restrictiveness. The most restrictive embed a specific instance of a model, allowing the decision maker to provide, at most, a few parameter values. A little less restrictive are functions that allow decision makers to select among a set of provided model instances. Still less restrictive are functions that allow decision makers to modify the models provided by the system or to supply their own model instances. For example, a function that implements the classic economic order quantity (EOQ) model for inventory management is highly restrictive, allowing decision makers only to provide values for the annual demand, cost per order, and holding cost. A specific linear program tailored to a specific corporate decision-making task might be predefined and embedded in a DSS function such that the decision maker would only be empowered to change a few of the coefficients. This, too, would be highly restrictive. A less restrictive function would allow the decision maker to change the structure of the embedded linear program or even to provide a new one. Similarly, a spreadsheet model would be highly restrictive if its formula cells were protected so that users could change inputs but not the structure of the model. By itself, however, an electronic spreadsheet package provides a highly non-restrictive modeling capability.

**Parameters.** Parameters that provide option settings or values for key variables often play important roles in determining the information-processing behavior of a functional capability. For instance, a statistical function that performs hypothesis testing needs to be given the level at which to reject the null hypothesis. A stepwise multiple regression is driven by the critical *t*-value. Database searches are controlled by a set of search options. The elimination by aspects choice rule requires an ordered set of attributes and associated cutoff values. Highly restrictive systems may predefine these values and options, granting the decision maker no ability to alter them. Less-restrictive systems may empower the decision maker to set or change these parameters. The setting of options and key variables is often an integral part of the decision-making process, since human decision makers often bring their judgments and preferences to bear through the setting of these parameters. Constraining a function's parameterization limits the decision maker's discretion and his or her ability to make judgments and express preferences. Such constraints are likely to affect the decisions made and their consequences.

DSSs that empower decision makers to set parameters may still restrict the decision makers by constraining the selection they can make. For instance, a function might limit the range of acceptable values for a numeric variable. Such restrictions might reflect technical limitations of the function, reasonableness checks on the inputs, or attempts to constrain the decision maker's discretion.

**Visual representations.** A large body of research has found that how the information provided by a DSS is displayed visually can have a significant impact on the behavior of decision makers and on the decisions they make. Much of this research has focused on the differential effects of tabular versus graphical display of information, but within each of these two broad categories one finds much room for variability of display formats. Microsoft Excel, for example, offers not only a large selection of chart types but a great many variants and options for each of those types. The consequences of a given display format — for instance, the performance of the decision maker — may depend on such factors as the characteristics of the task and of the decision maker.

DSSs vary in terms of how they constrain the visual representations available to decision makers. Some DSSs are highly restrictive, predefining displays that decision makers cannot change. This approach typified the early executive information systems, which enabled senior executives to peruse hundreds of unalterable information-packed predefined displays. Other DSSs give users greater flexibility, allowing them to select among alternative displays or even to create their own. For instance, someone who is not satisfied with any of Excel's many formats for displaying numerical values can devise his or her own format. Since the fit between the display, the task, and the decision maker may affect performance (Vessey 2006, Goodhue 2006, Te'eni 2006), one can easily see how limitations on visual

**Table 3.** Sources of restrictiveness: constraints on DSS technical features

| |
|---|
| **Constraints on functional (information-processing) capabilities**<br>• Constraints on the set of functional capabilities<br>• Constraints on combining functional capabilities |
| **Constraints on Data Sets**<br>• Constraints on Sources of Data<br>    • Constraints on Data Provided with the System<br>    • Constraints on Data Entered by the Decision Maker<br>    • Constraints on Data Imported by the Decision Maker<br>• Constraints on Data Use (which data can be used with which functions) |
| **Constraints on models**<br>• Decision maker has no control over the models<br>• Decision maker can only supply a few parameter values for the specific model instance provided by the system<br>• Decision maker can select among a set of model instances provided by the system and can supply parameter values for them, but cannot provide alternative model instances or modify the models |
| **Constraints on parameters (input variables and options)**<br>• Constraints on which parameters the decision maker can set<br>• Constraints on variable values and settings of options |
| **Constraints on visual representations**<br>• Decision maker has no control<br>• Decision maker can select basic representation, but cannot set display parameters<br>• Decision maker can set display parameters, but cannot select basic representation<br>• Decision maker can select basic representation and set display parameters |

representations can be consequential. On the one hand, allowing decision makers to select their own representations might increase the fit of the system with the person. But on the other hand, restricting the display to those that fit the task might be more beneficial. Visual representations present a good example of both the significance and the challenge of restrictiveness as a design variable.

Table 3 summarizes the principal ways in which a system's technical properties can be constrained. These constraints on the system's technical features might have the effect of restricting the structure of the decision-making process, its execution, or both. Constraints on the system's information-processing capabilities generally restrict the structure of the decision-making process — that is, how the decision maker goes about making the decision. Similarly, constraints on the data sets and models that the functions employ, as well as constraints on the visual representations they produce, also tend to limit the process structure. Constraints on parameters, however, such as limits on setting values and selecting options, which essentially restrict a decision maker's discretion when using a functional capability, usually restrict the execution of the process — that is, what the decision maker does as he or she proceeds along the decision-making path.

## 4.3 Absolute Versus Actual Restrictiveness: A Paradox

Thus far, I have treated system restrictiveness in absolute terms as a property of the system without considering what a given user experiences. But a given DSS might restrict different decision makers differently. For instance, a given decision maker might be unaware of some of the system's capabilities. Another decision maker might be incapable of operating a given function. Still another might find learning or using a given function too effortful to be worthwhile. The decision maker in each of these cases is more restricted than another decision maker who takes full advantage of the system's capabilities. So when discussing system restrictiveness, absolute restrictiveness, what the hypothetically least-restricted individual experiences, must be distinguished from actual restrictiveness, what a given individual experiences.

The relationship between absolute and actual restrictiveness can be paradoxical. As one decreases the absolute restrictiveness of a system, by reducing the constraints on its technical properties, one may be increasing the system's complexity. This increased complexity may degrade usability, as the effort required to learn and use the system is increased. This decrease in usability may increase the restrictiveness of the system as experienced by many users, as these users may be unable to operate some of the system's capabilities. So reducing absolute restrictiveness may, in some cases, increase actual restrictiveness. We might refer to this as the restrictiveness paradox.

Figure 1 captures somewhat abstractly the likely relationship between absolute and actual restrictiveness, although the precise relationship would vary from one person to another. A highly restrictive system in absolute terms (on the far right)

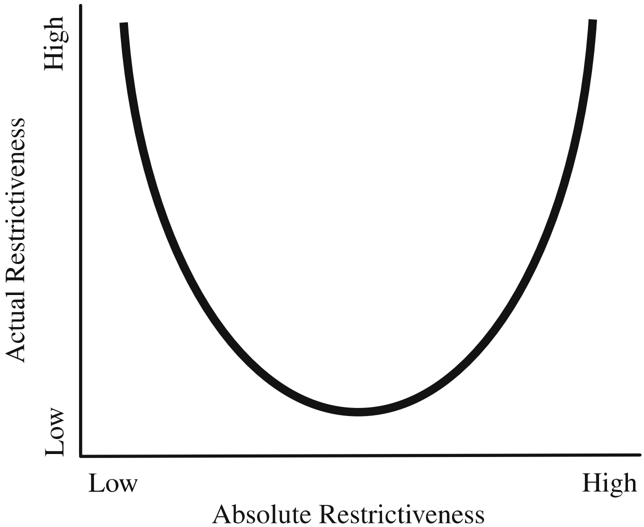


**Figure 1.** Hypothesized relationship between absolute and actual restrictiveness (based on Silver 1991b)

will also be experienced as highly restrictive by most people. After all, if the system has highly constrained capabilities, all users will be greatly limited in what they can do. Reducing the absolute restrictiveness (moving to the left) should, up to some point, be expected to reduce the restrictiveness actually experienced by most people as the system's constraints are loosened. But at some point — which could well differ from person to person — the effect is likely to be reversed. Beyond that point (shown, for simplicity, as the midpoint in the diagram), further decreases in absolute restrictiveness will lead to so much increased effort for the decision maker that he or she will experience a return to a higher level of actual restrictiveness. The restrictiveness paradox produces a likely U-shaped relationship between absolute and actual restrictiveness. These observations may help explain why promoting use is an objective that can favor lesser as well as greater restrictiveness (Table 2). Since either too much or too little absolute restrictiveness can lead to substantial actual restrictiveness, either can inhibit use.

The restrictiveness paradox makes designing DSSs especially challenging, because designers may think they are enabling decision makers with enhanced power and flexibility but may actually be restricting those decision makers by degrading usability. Designing a system to support many decision makers may be even more challenging given differences in their perceptions of the system's restrictiveness. Such non-technical features of the system as training and ongoing technical support may be useful for bringing absolute and actual restrictiveness more in line with each other. For instance, training can be used to make decision makers aware of the full set of system capabilities as well as to reduce the effort required to learn and use the system. So a system's actual restrictiveness may be influenced by non-technical features as well as the system's technical properties.

While restrictiveness can obviously play a significant role in determining effects – since it defines what a decision maker can and cannot do with the system – it is not the only design variable that matters. It leaves open the question of what the decision maker will actually do (given what the system allows). To address this question we need to consider another design feature – decisional guidance.

## 5 Decisional Guidance

One way to think of restrictiveness is that it limits the decision maker's ability to exercise discretion while using the system. But all support systems grant decision makers some discretion — otherwise they would not be support systems — and many systems grant substantial discretion. DSSs grant decision makers discretion in structuring their decision-making processes when they allow them to choose functional capabilities, data sets, models, and visual representations. DSSs grant decision makers discretion in executing those processes when they allow them to interact with the functional capabilities — for instance, by supplying parameter values and selecting options. The system's effects on the decision-making process, on the decisions that follow from it, and on the repercussions of those decisions, will be influenced by how decision makers use the discretion they are granted, which, in turn, will be influenced by elements of the system's design. Collectively, those elements that play a role in this influence are referred to as the system's decisional guidance. Like system restrictiveness, decisional guidance is a multifaceted design feature. It is defined formally as follows:

> **Decisional guidance:** The manner in which a DSS, intentionally or not, enlightens, sways, or directs its users as those users exercise the discretion the system grants them to structure and execute their decision-making processes (adapted from Silver 1991a, 1991b, 2006).

The definition of decisional guidance is noteworthy for several reasons. First, note the modifier ***decisional***. Its purpose is to distinguish decisional guidance, which plays a substantive role in the choices decision makers make, from such mechanical guidance as help screens and other interface features that assist users with the mechanics of operating the system. Second, note the role of intention — or lack thereof. Decisional guidance need not be intentional. Like system restrictiveness, decisional guidance is a design variable. However, just as systems restrict even if the designer does not contemplate the system's restrictiveness, systems may guide even if the designer does not intend to. For instance, menu items are often arranged alphabetically to enhance usability, but this order might increase the likelihood of decision makers selecting those items that appear earlier in the alphabetical listing. Some systems place the most recently used menu items at the top of the list – again to enhance usability – but this design might have the unintended effect of reinforcing the human tendency to use the same approach repeatedly rather than to consider alternatives. So designers must acknowledge both inadvertent and deliberate guidance.

Third, even when decisional guidance is deliberate, it does not necessarily direct decision makers. Decisional guidance might be directive, strongly pointing the decision maker toward a given action, or it might be milder, intending to sway the decision maker, or it might be neither of these. The purpose of the guidance might be to enlighten decision makers, allowing them to make a more-informed selection without trying to bias them. This, too, is a form of decisional guidance because it can affect how a decision maker exercises discretion. In common usage, guidance is often thought of as directive, but the term is used here more broadly to include the informative as well as the suggestive.

Lastly, the relationship between a system's restrictiveness and its decisional guidance is well defined. Restrictiveness defines what decision makers *can do*. Subject to those restrictions, decisional guidance affects what decision makers actually *do*. One sometimes hears people – even information system (IS) designers and researchers — speak of system constraints guiding behavior. Strictly speaking, however, constraints restrict rather than guide — they limit what is possible. Guidance influences how decision makers behave subject to those constraints. *Failing to heed the distinction between restrictiveness and guidance can lead to great confusion in discussions of system design.* Figure 2 shows the relationship; in short, *restrictiveness* limits the opportunities for *guiding*.

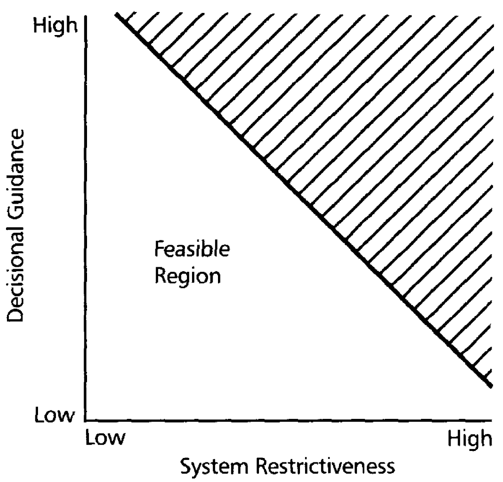


**Figure 2.** The relationship between system restrictiveness and decisional guidance
Note: Reprinted by permission. Silver, M.S., "Decision Support Systems: Directed and Nondirected change," *Inform Syst Res*, 1(1), 1990, 47–70. Copyright © 1990, the Institute for Operations Research and the Management Sciences, 7240 Parkway Drive, Suite 310, Hanover, MD 21076 USA.

Although system restrictiveness and decisional guidance are two different design dimensions, decisional guidance raises a pair of questions analogous to those raised by restrictiveness: "What objectives would motivate a DSS designer to deliberately try to guide decision makers?" and "How can a system's design features guide decision makers, deliberately or inadvertently?"

## 5.1 Objectives that Motivate Providing Deliberate Decisional Guidance

The design objectives that might motivate designers to build deliberate decisional guidance into a DSS, summarized in Table 4, are quite varied. Notice that these objectives include, but are not limited to, most of the design objectives that favor greater restrictiveness, since guidance is sometimes an alternative means of achieving the same design objectives as restrictiveness.

**Table 4.** Objectives that motivate providing deliberate decisional guidance

- Providing greater support
- Prescribing, proscribing, structuring, and fostering structured learning
- Promoting usability
- Avoiding inadvertent guidance

### 5.1.1 Providing Greater Support

The human-machine partnership that characterizes DSS use is often viewed as follows: The human decision maker controls the information processing, provides judgments, and expresses preferences whereas the computer-based system processes information in support of those human activities. One purpose of deliberately providing decisional guidance may be to provide greater support than just that of a powerful information-processing assistant. A DSS can help guide decision makers as they control the system, choosing among its various functional capabilities and options. It can help guide decision makers as they form judgments, such as assessing probabilities or identifying causal relationships. And it can even help guide decision makers as they clarify and express their preferences – for instance, preferences for one alternative over another. Whenever decision makers are called upon to interact with the DSS – to exercise discretion – the system might provide decisional guidance that either tenders information to enlighten their behavior or offers suggestions as to how to behave. Of course, designing such decisional guidance can be quite challenging for the system builder.

### 5.1.2 Prescribing, Proscribing, Structuring, and Fostering Structured Learning

We have already identified a variety of design objectives that favor greater restrictiveness. In particular, restrictiveness is often worth considering when a DSS is intended to influence the decision-making process by prescribing some behavior or proscribing some other behavior. Similarly, designers may restrict decision makers to help them structure their decision-making processes or to foster structured learning. But we have also encountered a variety of factors that discourage such restrictiveness. Too much restrictiveness can, for example, inhibit use, reduce the system's longevity, limit the environments to which it can be applied, remove the decision maker's discretion, and so forth. Decisional guidance can be a means of getting the best of both worlds. Rather than restricting decision makers, a DSS could attempt to sway or direct them via suggestive guidance. Since decision makers would not be compelled to follow the system's suggestions, this approach would likely be somewhat less effective than restrictiveness at accomplishing some of these design objectives. But it would allow for a less-restrictive system that could simultaneously accomplish objectives associated with lesser restrictiveness.

### 5.1.3 Promoting Usability

As I have noted several times already, less-restrictive systems can be difficult to learn, remember, and use. While extreme flexibility sounds good in theory, in practice too much flexibility can also be debilitating. Indeed, the restrictiveness paradox suggests that as systems become less and less restrictive in absolute terms, they become increasingly restrictive in actuality for a given decision maker. Decisional guidance — either informative or suggestive — can help reduce the effort associated with minimally restrictive systems. By providing decision makers with additional information about their options, or even suggesting how to proceed, the usability of the system can be increased. This may even help to bring actual restrictiveness more in line with absolute restrictiveness, thus resolving the restrictiveness paradox.

### 5.1.4 Avoiding Inadvertent Guidance

Designers often fail to recognize that, even if they do not intend to influence how users behave, the features they design may do so, often in subtle ways. For instance, saliency effects of menu items — such as the primacy effect, where people opt for the first items listed — can be the source of systematic biases in the choices decision makers' make with a DSS. In some sense, inadvertent guidance is the default when designers do not include deliberate guidance in a system. Avoiding the inadvertent consequences of a guidance vacuum therefore constitutes another reason for deliberately building guidance into a system.

## 5.2 How a System's Design Features Can Deliberately Guide Decision Makers

The concept of deliberately providing decisional guidance is fairly intuitive to understand, but designing the guidance mechanisms can be challenging and complex. Decisional guidance varies along several dimensions. One such dimension is the source of the substantive content of the guidance. Specific information or suggestions might be predefined by the designer and built into the system. Or the content might be created dynamically by the guidance mechanism based on the decision maker's behavior with the system. A DSS might even interact with the user to produce more tailored and sophisticated guidance. We might refer to these as the modes of guidance: predefined, dynamic, and participative. Guidance mechanisms also vary with respect to how the guidance is invoked. It might be provided automatically by the DSS or it might be offered on-demand by the decision maker.

Table 5 summarizes the various dimensions that characterize deliberate decisional guidance. Here I focus on the two dimensions that stand out as the keys to understanding decisional guidance mechanisms: the targets and the forms of the guidance. See Silver (1991a, 2006) for a more complete discussion of all the dimensions.

**Table 5.** Dimensions of deliberate decisional guidance (Silver 2006)

**Targets**
- Choosing functional capabilities
- Using functional capabilities

**Directivity**
- Suggestive guidance
- Quasi-suggestive guidance
- Informative guidance

**Modes**
- Predefined
- Dynamic
- Participative

**Invocation styles**
- Automatic
- On-demand
- Hybrid

**Timing**
- Concurrent
- Prospective
- Retrospective

### 5.2.1 Targets of Guidance: Structuring Versus Executing the Decision-Making Process

Both the structuring and the executing of decision-making processes may be amenable to decisional guidance. When using a DSS, decision makers structure their decision-making processes by choosing which functional capabilities to employ as well as which data sets, models, and visual representations to use with those functional capabilities. Decision makers are sometimes challenged to choose one of many possible functions that serve the same purpose but will likely to lead to different outcomes. For instance, when decision makers need to create forecasts from time-series data, they may find numerous forecasting methods available. Similarly, when choosing among alternatives in a multi-attribute decision-making task, they may be empowered to select from among various choice rules. In meta-choice situations such as these — where the decision maker is choosing a solution technique — the designer may want to provide guidance that either informs the decision maker of the relative merits of each approach or even suggests to the decision maker the most appropriate function given the specific circumstances. Guidance could similarly be offered for selecting among data sets, models, and visual representations.

In less-structured DSSs, the challenge may not be to choose among the solution approaches made available by the DSS but to fashion a decision-making process from the functional resources available. The decision maker may need to figure out what sequence of information-processing activities will solve the problem best. What should he or she have the DSS do first? Next? Should the most recent step be repeated? For instance, after projecting a budget that is out-of-balance, should the decision maker invoke a budget-balancing routine? Or should the decision maker revise his or her assumptions and create a new projection from scratch? Decisional guidance could help with these structural choices, as well.

While executing the decision-making process, decision makers are called upon to provide various parameters that reflect judgments or preferences. What is an acceptable return on investment? What is the relative importance of location and cost when renting a warehouse? What will the inflation rate be next year? Decisional guidance might provide additional information, perhaps even additional functional capabilities, to help decision makers arrive at these judgments and preferences. Alternatively, guidance mechanisms might suggest appropriate values to the decision maker.

### 5.2.2 Forms of Guidance: Informative Versus Suggestive

The various examples just discussed included two very different forms of deliberate decisional guidance mechanisms. Some of the guidance was purely informative, intended to enlighten decision makers so they could arrive at their own choices. When choosing a forecasting method, for instance, a decision maker might be told the mathematical properties of the method, its strengths and weaknesses, and the types of data sets and circumstances for which it is best suited. Similarly, choice rules could be described in terms of how they work, whether they are compensatory or non-compensatory, whether they require more or less effort, and so forth. Informative guidance for judgments, such as predicting future economic indicators or assessing probabilities of future events, might include historical data that could be useful as points of reference. Charts of historical trends might also be of value. Such guidance could also include judgments made by others and even a record of previous judgments made by this decision maker together with the actual results. This information might help calibrate the decision maker. Informative guidance might also include qualitative information — for instance, news stories — that shed light on the judgments being made. Informative guidance for preferential inputs might include historical information concerning the decision maker's prior preferences or descriptive statistics that provide a better understanding of the alternatives confronting the decision maker. For instance, if choosing among a large number of warehouses to rent, descriptive statistics could help the decision maker get a feel for the range of warehouses on the rental market and their attributes.

In contrast to these examples of informative guidance, a DSS might also offer suggestive guidance. For instance, the DSS could recommend which forecasting method best suits the data or the situation. It could recommend which choice rule to follow. It could propose values for the various judgmental inputs that the decision maker must provide. The substance of the various suggestions might be built into the system or the guidance mechanism might contain information-processing capabilities that generate the recommendations dynamically, perhaps with the active participation of the decision maker.

Table 6 provides examples of the various combinations of targets and forms of guidance.

**Table 6.** Examples of deliberate decisional guidance

| | | **Form of guidance** | |
|---|---|---|---|
| | | **Suggestive guidance** | **Informative guidance** |
| **Target of guidance** | **Structuring the process (choosing functions)** | Recommended operator<br>Set of recommended operators<br>Ordered list of recommended operators<br>Set of operators not recommended | Description/analysis of operators<br>Comparison of operators<br>Map of relationships among operators<br>Record of behavior in similar contexts<br>History of activity this session |
| | **Executing the process (using functions)** | Recommended values<br>Set of recommended values<br>Ordered set of recommended values<br>Set of values not recommended | Definition of required input values<br>Descriptions of how inputs will be used<br>Tables, graphs, or analyses of data<br>Record of behavior in similar contexts<br>History of activity this session |

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## 6 Design Objectives and Philosophies of Change

One of the themes of this chapter has been that a system's restrictiveness and decisional guidance need to reflect its design objectives. That is, designers need to set these design variables in a way that will produce consequences consistent with the design goals. Any given system will have its own unique set of specific objectives, but overall a system's objectives generally fit into one of two broad categories reflecting the philosophy of change underlying the development project. Some systems subscribe to a philosophy of directed change, where the DSS is intended to move decision makers from their current decision-making behavior in a specific direction, toward preferred behavior. Other systems adopt a non-directed philosophy which views the DSS as providing a set of information-processing tools that can enable change whose direction is determined by the decision maker through use of the system. These approaches to change have a differential impact on the choice of system restrictiveness and decisional guidance.

In the case of directed change, one might assume that designers should build highly restrictive systems. This approach is certainly worth considering, since the restrictions can be used to prescribe or proscribe decision-making behavior. But, as we have seen, excessive restrictiveness runs the risk of creating a DSS that inhibits use or that fails to achieve other objectives associated with lesser restrictiveness. Another design possibility, therefore, would be to combine some restrictiveness with some suggestive decisional guidance to direct the change. These technical features might be complemented with such other features as training and coaching to help produce the desired effects.

In the case of non-directed change, designing a minimally restrictive system seems to be in order. But this approach can also be problematic, because such DSSs can suffer from usability problems due to the large number of functions and options they provide. In this case, combining minimal restrictiveness with either informative or suggestive guidance specifically aimed at increasing usability and helping decision makers cope with the lack of restrictions might be valuable.

A more-extensive discussion of change philosophies, system restrictiveness, and decisional guidance can be found in Silver (1990).

## 7 Conclusion

This chapter focused on the substantive design of decision support systems, arguing that DSSs must be seen not just as information-processing assistants but as interventions into the processes through which decision are made. The chapter also asserted that ultimately designers are — or need to be — concerned not with system features but with system consequences. The challenge for DSS designers is to design a set of system features that are likely to achieve the design objectives — that is, the desired consequences — without producing undesirable side-effects.

System restrictiveness and decisional guidance are two multifaceted system features that play essential roles in how a DSS functions as an intervention, and in the consequences that follow from that DSS intervention. Carefully setting these two design variables is a vital but often overlooked element of DSS design, which too often focuses on creating individual functional capabilities. Whether designers think about it or not, their designs will restrict. And whether they think about it or not, their designs will guide. Successful design therefore requires thinking about it — paying careful design attention to system restrictiveness, decisional guidance, and their relationship each with the other.

With the great popularity of personal computing and, increasingly, browser-based applications, many people today interact with computer-based systems that afford discretionary opportunities. Some of these systems — for instance, recommender agents for e-commerce — can easily be seen as instances of DSSs. Others — e-mail, for example — cannot. While the design issues raised here may be richer for those applications that deal more explicitly with decision making, system restrictiveness and decisional guidance can play a valuable role in designing any of these interactive systems.

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# CHAPTER 50
# DSS Systems Analysis and Design: The Role of the Analyst as Change Agent

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We explore the critical role played by decision support system (DSS) developers (also called systems analysts or DSS designers) as they enact the role of the change agent. In DSS development, systems analysts actively strive to change the decision maker directly through the DSS application and its presentation. We suggest that the role of change advocate serves DSS development the best, chiefly because decision makers' enhanced interest in emerging information technologies has made it possible for decision makers to accept new Web-based DSS technologies. We also briefly explore some of the issues in the development of decision support systems over time and the importance they will play in the future. We illustrate what a systems analyst should take into consideration in designing a DSS display today, using a dashboard as an example. We then describe new tools used for DSS development such as widgets, gadgets, and mashups that once again may change the way decision makers solve problems. We see a promising future for changing decision makers as they interact with the analyst as a change agent and can visualize decision makers evolving through their DSS interactions, thereby improving decision quality, and creating a strong, contributory role for analysts to play in DSS development.

**Keywords:** Systems analysis; Systems design; Systems analyst; Change agent; Decision support system; Individual differences; Individual preferences; Decentralized DSS; Dashboards; Programmable Web; Web 2.0; Widgets; Gadgets; Mashups; DSS design

## 1 Introduction

In this chapter, we explore the critical role played by the DSS developer (also called the systems analyst or DSS designer) as they enact the role of the change agent during the process of DSS development. Throughout this process, systems analysts act as change agents to change the decision maker directly through the application and interaction created. This is a departure from other change-agent roles that analysts might pursue, which are oriented to changing a culture, rather than an individual. Analysts working as change agents for decision makers strive to provide them with a fresh perspective on their problem, a new approach to generating alternatives, a wider array of creative solutions, or a combination of support for intelligence gathering, solution generation, choosing among alternatives, and communicating decisions to relevant audiences.

The next part of the chapter is devoted to exploring a unique role for the DSS designer as an agent of change who is advocating the shaping of the decision maker via the developmental process and ultimately through interaction with the new DSS. We also set forth the personal characteristics and skills of the systems analyst that are essential when enacting the role of the change advocate agent. We discuss some actions that change agents can take to overcome resistance to change. We then proceed to discuss the evolution of DSSs from the change agent's viewpoint. In the next section of the paper we explore the DSS development process with the help of a dashboard example. We then explore the future of DSS development on Web 2.0, including innovative Web-based approaches such as widgets, gadgets, and mashups. We cover five key caveats for developers creating mashups for DSSs in the organization. The chapter concludes with our suggestions for new directions in DSS development and our contribution.

## 2 Roles of the Systems Analyst

Systems analysts who develop decision support systems can follow numerous methodologies, using many tools, favoring many practices, several of which are known to be fruitful. Since its inception in the mid to late 1970s, DSS development has been accomplished in ways that are strikingly similar to the development of other types of information systems such as transaction processing systems (TPS), management information systems (MIS), and executive support systems (ESS). Analysts who create DSSs are often skilled at creating other types of systems as well. Their education in systems analysis and design is typically identical to that of those who design other systems. However there are a few notable departures in the process of analysis and design for decision support.

Often the difference occurs in the methodology that the analyst adopts. Rather than a structured methodology, or an object-oriented methodology, the DSS developer may select a prototyping approach, serving to make the design process highly iterative and interactive. At other times, the analyst developing a DSS may focus on creating a high-quality, interactive experience for the decision maker who will ultimately interact with the DSS, so that the emphasis shifts to perfecting the completed DSS rather than the developmental process at hand.

In the development of information systems, analysts can play a wide variety of roles (Kendall et al. 1992). The analyst can take on the role of a consultant, a supporting expert, or that of a change agent, which encompasses both of the other roles. The consultant role is typically played by an outside consultant who is called into the organization specifically to address information systems issues within a business. While outside consultants bring fresh perspectives, they are at a disadvantage because of their lack of knowledge about the specific organizational culture and particular business itself. Analysts hired as outside consultants must rely heavily on users to provide a full picture of the business and its culture. On the plus side, they often do not face the credibility issues (Markus and

Benjamin 1996) that hobble many internal information technology (IT) specialists in the company.

A second role for systems analysts developing information systems is that of the supporting expert. In this role, analysts who already work for an organization are called upon to provide expertise concerning computer hardware and software, as well as specific applications for the particular business. This is a customary role, and often the analyst provides insight or commentary on an ongoing project, without managing the entire project.

A third role that encompasses both of the foregoing ones is that of the change agent. In systems development, the analyst is viewed as an agent of change whether they are internal or external to a business, whenever they perform activities related to the system development life cycle, and are present in the organization for a period lasting two weeks or more. In this role the analyst is a catalyst for change, developing a plan for change, and working with others to facilitate it. Analysts gradually develop an awareness that their presence in the organization changes it, and they work with users to facilitate changes in quality of work life, IT infrastructure, and applications.

In the early 1990s there was a great deal of interest in agents of change in the organizational development literature. Bennis (1993) suggest four different competencies necessary if change agents are to be successful in their work of improving organizational effectiveness: (1) a broad knowledge of the intelligence from the behavioral sciences and theories and methods of change, (2) operational and relational skills, such as the ability to listen, observe, identify, and report, and to form relationships based on trust, (3) sensitivity and maturity, including self-recognition of motivators and the perceptions that others have of these motivators, and (4) authenticity in living and acting according to humanistic values (as quoted in Kendra and Kaplin 2004).

Markus and Benjamin (1996 and 1997) examined the practice of information system (IS) implementation in light of the organizational development literature, joined with their own experience and practice. Their analysis of interviews and review of the literature led them to identify three roles: the traditional IT specialist role who helps implement technological changes and provides technical expertise; the IT change facilitator who is similar to an organizational development (OD) practitioner whose emphasis is on people, rather than IT; and the change advocate.

The person playing the advocate role is bent on changing the people with whom they come into contact through any tactics that work, including cajoling them out of their complacency, inspiring them to be better decision makers, manipulating them into changing, or even serving as something of a missionary to convert people to adopt the changes they are proposing. Markus and Benjamin assert that the advocate and facilitator roles for the IT specialist differ on some important qualities. They comment that "…the advocate thinks of people more as targets of the advocate's interventions than as clients with purposes of their own" (p. 397). In a further elaboration, they explain that "the most effective advocates pursue changes that serve the organizations' best interests, even when their personal or professional interests conflict" (p. 398).

They were prescient in their reading of the proverbial writing on the wall in terms of outsourcing of technical matters. They have also proved to be, a dozen years on, accurate about predicting the locus of power and reward for IS change agents, predicting (and championing the idea) that it would reside with those change agents who could demonstrate effectiveness with people in accomplishing change involving new technologies.

In the intervening years, much has been written about change agents, IS specialists, IT project managers, and the roles of chief information officers (CIOs) who serve in change capacities. Winston (1999), in her field study of 25 organizational cases, was able to confirm the existence of the three change-agent models: traditional IT specialist, facilitator, and advocate. She also found that a significant number of consultants who participated strongly preferred to work in a particular role. She also hinted that those consultants who are willing to be flexible in their implementations will reap higher rewards. Winston points to evidence from her study that the advocate role is most effective when analysts are confronted with resistance to change, whether that resistance is politically or socially determined. Winston also asserts that change-agent flexibility may enhance the delivery of IS services.

Researchers (Markus and Benjamin 1996, 1997,Winston 1999) further suggest that there are benefits to be reaped by IS change agents who are able to switch among the three change-agent roles discussed, depending on the situation at hand. Other researchers build on this work (Dologite et al. 2004) to suggest a meta-category for IT change agent which they label the adaptor. This new category encompasses all three roles previously identified and it is designed to highlight the complexity of the change-agent role (especially in settings where analysts are installing packaged software). Burns and Nielsen's findings (2006) remind us of the need for conceptualizing organizational change as grounded in the cumulative nature of change events. Kendra and Taplin (2004) recommend that, in order to improve the odds of IT project success, IT project managers must develop and master the change-agent knowledge and skills associated with both the social sciences of organizational development and the management sciences of project management, thereby transcending traditional roles to become change agents.

## 2.1 DSS Developers as Change Agents

As we can see from the foregoing discussion, there are many roles possible for the analyst as they go about implementing technology improvements, changing the IT infrastructure, and changing the organizational culture. We believe that adoption of the change-agent role described as the advocate is highly desirable for DSS systems designers, and it is one that we champion. The advocacy role is compatible with a DSS developmental perspective which has the following goals:

1. changing the decision maker via the developmental process
2. changing the decision maker through their interaction with the DSS
3. providing novel perspectives through constantly updated and refreshed material.

The third goal may be achieved through new database views, new data sources, and continual updating of models.

## 2.2 Qualities of DSS Designers Serving as Change Agents

There are many qualities and values of the DSS designer that enhance their ability to serve as effective agents of change. Chief among these are excellent IT skills coupled with outstanding communication skills, including listening and presenting. The successful DSS designer represents a formidable combination of personality characteristics, skills, and education that create a person capable of changing decisions makers they encounter. The ability to change among the three models of change agentry is an overarching capability. As noted earlier, researchers point to the potential for this type of flexibility to improve the possibility of success in making an effective change in the organizational implementation of IT. Garg and Singh (2005) also highlight the importance of flexibility in successful change-management approaches involving IT. We propose that it can also help in changing the decision maker during the DSS development process.

In a related sphere, the qualities of change agents are also discussed in research on CIOs, and some of those ideas resonate deeply with the characteristics we are examining for the DSS designer who is an agent of change. For instance, Hugos (2005) magnifies the importance of listening for a CIO who is acting as a change agent. He also encourages empathy, advocating that the change agent try walking a mile in the shoes of those they hope to lead. Walter (2006) points to his survey of CIOs and change agents that identifies leadership, passion, and intellect as critical success factors in the ability to change an enterprise. Koch (2007) points to the survey-based information gathered from 400 CIOs that discusses four valuable skill sets represented by four archetypes for the CIO. Included in these is the innovation agent, who is described as technically excellent, and someone who is welcomed as an innovative force.

Summarizing the results of their research on change agents who were instrumental in the adoption of Internet technology for very small English businesses (consisting of 10 people or fewer), de Berranger et al. (2001) note the characteristics of change agents that were positively singled out by the business owners. These qualities included: the personal touch; willingness to get involved with the community; possessing a high level of enthusiasm for the project; agents' high levels of understanding of the creative businesses they were changing; along with an informal yet professional attitude. The personal qualities and values,

**Table 1.** Personal qualities, values, and skills of DSS designers serving as change agents

| Personality qualities and values | Skills |
|---|---|
| • Problem solver<br>• Faces challenges head on<br>• Likes working closely with decision makers on solutions<br>• Possesses strong personal and professional ethics<br>• Self-disciplined<br>• Self motivated<br>• Intelligent, passionate, and courageous | • Systematically tackles problems through skillful application of tools, techniques, and experience<br>• Leadership<br>• Good communicator who relates meaningfully to decision makers and programmers<br>• Possesses understanding of computer capabilities and logic<br>• Able to write quality code<br>• Able to document code and write necessary manuals<br>• Understands the latest techniques and Web-based interfaces |

along with the required skills for DSS designers serving as advocates are summarized in Table 1.

Markus and Benjamin (1997) summarize the distinctive characteristics of the change agent as IT advocate by stating: "They use whatever tactics seem likely to work to change people's mind about the goals, the means, and the outcome of their everyday actions. They shock them with outrageous behavior, convince them through constant repetition, persuade them, and use all the rewards and sanctions within their legitimate organizational authority" (p. 64).

We believe that the systems analyst who is designing decision support systems will be most effective as a change agent by adopting the change model of IT advocate. The first priority of the DSS designer is changing the decision maker during the highly interactive development process, and subsequently they will seek to change the decision maker as he or she interacts with the DSS. The new DSS will feature novel decision-making models and displays that serve to dramatically reframe the decision maker's thinking: changing the way they identify problems, generate alternatives, support and make a decision, and communicate its priority to others in the organization.

## 3 The Change Agent and Early DSSs

In the early days of decision support, systems analysts were content with changing the presentation of data to enable decision makers to see the information differently. The output was almost always a printed report. Approaches to supporting the decision maker could be as simple as changing the way they viewed a table. In other instances, a systems analyst would provide graphical output so that the decision maker could more easily compare the sales of retail outlets or notice trends over a period of time. The systems analyst as a change agent took this calling seriously and tried to give the decision maker new ideas for solving problems. Researchers summarized the early findings on information format and extended it into the domain of graphical displays (Jarvenpaa 1989).

In 1983, Huber asserted that, "(1) the study of cognitive style as a basis for deriving operational guidelines for MIS and DSS designs has not been fruitful and (2) such study is likely not to prove fruitful" (1983, p. 576). Robey (1983) agreed with Huber's assessment, but also suggested that designers should not throw the baby out with the bath water, suggesting that knowledge of cognitive style should be used as part of the design *process* and that when researchers attempted to "assess its impact in that context," then its value to DSS design could be more adequately assessed (p. 582). Even though Robey articulated reasons for continuing these inquiries, research on individual differences in cognitive style and their relationship to DSS design was dormant for many years (Eom 1999).

Other researchers took a different tack and suggested that the answer resided in focusing on cognitive processes (Ramaprasad 1987) as a way to provide operational guidelines for MIS and DSS design. His research posed such questions for DSS researchers as "how does a manager formulate a complex (mathematical, statistical, or logical) relationship between two parameters rather than a simple (additive, correlational, or cause-effect) relationship?" (p. 146). Ramaprasad goes on to conclude that "a MIS/DSS can help reduce the chance of … errors. It can facilitate the manager's search through his/her repertoire of LMSs [logico-mathematical-structures] to check for the availability of an LMS which can be attributed. It can force the manager to study alternative LMSs before choosing one. It can help the manager test whether the LMS is appropriate…" (p. 146.)

Although research into assessing decision makers' individual cognitive styles stalled, the systems analyst as a change agent did not cease trying to improve designs. Systems analysts still tried to incorporate different forms of presentation in their systems. Rather than look at individual cognitive style, researchers successfully related acceptance and use of decision support systems to the existence of organizational subcultures (Kendall et al. 1987, 1989).

Analysts also took their role as change agents seriously and even looked at possible restructuring of organizations or changing business practices to support sound decision making better. The logic was that if decision makers could get the information about what their peers were doing, they may change their own habits and improve their decision-making performance. Blood administrators were given information in the form of reports about peer hospitals (reflecting decisions made by their administrative peers) that eventually dramatically reduced the wastage of human blood (Kendall 1980). Sprague and Carlson (1982) also discuss the merits of decentralized DSSs.

It was also demonstrated that school administrators could improve decisions if a DSS was introduced to support decentralized decision making. Decentralization is further discussed in the successful implementation of two decision support systems for the drug and criminal investigative units of the Nebraska State Patrol (Kendall and Schuldt 1993, Schuldt and Kendall 1993). Recently, researchers (Gachet and Haettenschwile 2003) have contributed to revitalizing the decentralized approach.

How a systems analyst should best introduce a decision support system is a valid question. The traditional system development life cycle (SDLC) approach may not be the best way. A prototyping approach (Kendall and Schniederjans 1991) may provide a different path to DSS introduction and eventual adoption. The prototyping approach has since evolved into the value-based agile approach (Kendall et al. 2006). Through short releases, analysts can develop DSSs very rapidly. They are then able to get quick feedback and communicate more easily with decision makers.

Other studies have suggested that it is not the development approach per se, but the underlying metaphors, that are critical to the successful adoption of decision support systems. Kendall and Kendall (1994) conclude that successful adoption of a DSS occurs if metaphors such as family, society, or organism are present in the organization. These metaphors allow for the systematic and interactive processes of identifying and weighing alternatives, the recognition of various goals and objectives, and a sense of balance and fairness. Order, rather than chaos, is emphasized. On the other hand, they conclude that success is less likely to occur if the chaotic war or journey metaphors are present. In addition to this work, Akin and Palmer (2000) provide and discuss six change-agent metaphors useful for intervening in organizations.

Some researchers, who work closely with practitioners (toolbox.com 2007), characterize the foregoing type of change activity as overcoming resistance to change. Analysts who believe they will be faced with resistance should take actions to motivate users to become involved at the outset of the DSS analysis and design project. In addition, resistance to change can be thwarted by engaging users in an early characterization of problems and subsequently in the solution of those problems.

Further, those proposing solutions should be responsible for implementing them, thereby increasing their control and limiting resistance to any changes formulated jointly with the analyst. Timing of the analysts' efforts also needs to be weighed in resistance to change. Developing a DSS may engender a major organizational change, since the ultimate goal is to change the decision maker, so analysts must be attentive to the appropriate timing of any change efforts to minimize resistance and maximize acceptance and use.

The next section uses the example of dashboard design to illustrate the DSS development process. Well-designed dashboards can anticipate and capitalize on best practices regarding decision-maker support, creating displays of measurements and a context to ensure their meaningfulness.

# 4 Designing a DSS from a Systems Analyst's Point of View – A Dashboard Example

As can be gathered from the previous section, analysts have historically possessed a choice of what development approach to take, as well as what displays to design to support decision makers best. Many of their choices are research based; however much of what has been designed has been created in an ad hoc way, through trial and error, where the analyst and decision maker finally hit on what works. When analysts seek to change decision makers, and help them evolve in their decision making, they may also seek to alter the approaches, methods, and tools that they use.

One approach to designing for decision support is to array all of the relevant information and measurements a decision maker needs directly in front of them. From the system analysts' viewpoint, the philosophy behind this approach is that, if the decision maker is provided all relevant data, both detailed and broad, expressed in a visual exhibit that makes organized displays of useful information, the decision maker can observe and monitor progress. What the user is shown in this context will in all likelihood alter their decisions and enable them to evolve as decision makers.

This approach to present decision data on a single page or screen became known as the information dashboard (Eckerson 2005, Few 2006). With its highly visual information, the dashboard approach allows decision makers to identify potential problems or opportunities, take action if one of the sensors calls for a decision, and then monitor the effect of the action. This cycle then begins anew, and the decision maker continues surveillance until a sensor identifies a problem or opportunity once again.

Rather than rely solely on bells or other alarms, dashboards encourage the use of dials and graphs. In this way, the decision maker can identify trends as well as view a measurement or snapshot of a particular point in time. Many DSS designers hold the work of Edward Tufte (1983, 1990, 1997) in high regard. Good systems developers use their creativity and knowledge of human-computer interaction (HCI) in the design of computer dashboards.

A dashboard, similar to the dashboard located in front of the driver of an automobile, can sport a variety of different gauges. Each gauge can display a graph (similar to the speed in kilometers or miles per hour); a light (similar to an indicator light warning that the automatic braking system is not functioning) that signifies an exception to normalcy; numbers (like an odometer, which simply counts the distance traveled), or even a text message describing a problem in narrative form.

Dashboards communicate information by displaying measurements to the decision maker. The systems analyst needs to develop the right type of display so that information is indeed communicated to the decision maker. A systems analyst must understand, for example, the effect of color on the decision maker. On a traffic light, red means stop, green means go, and yellow stands for caution. The analyst can adopt these colors using red for a problem, green to show the system is normal, and yellow for caution. Besides these obvious color codes, care needs to be taken with colors for readability. Yellow on a black background stands out, but yellow on a white background disappears. Bright colors are acceptable only when the analyst needs to highlight something important. At the same time, the designer might need to consider supplemental forms of alerts in the form of icons or text that help mitigate any user disabilities including color vision deficiency.

Layout is another key factor in design. The system analyst needs to design a logical, uncluttered screen to make it easily comprehensible for the decision maker. The analyst needs to limit the variety and number of graph, chart, and table styles so information can be communicated quickly and accurately. It is also very important to group associated items together (performance measures are almost always associated with other similar performance measures). Nonessential items such as photographs, ornate logos, themes, or audio can distract from the data itself.

The systems analyst also needs to consider the type of graph, chart, or table. While a pie chart may be an excellent graph to persuade others external to the organization (for instance, showing the percentage of IT expenditures compared with other capital investments), it may not be a good way for an executive to monitor the performance of regional offices in comparison to each other and to overall sales expectations.

Although there are many design consideration guidelines and heuristics that a DSS designer can follow, knowing how to meaningfully display numbers for a decision maker is still closer to art than science. Choosing to show that last month's sales were $121K is usually preferred to showing the actual sales of $120,974.34. A number also needs to appear in context. Is it higher or lower than last month's sales figure? Higher or lower than last year's or three years ago? Is the trend up or down?

Analysts must be keenly aware that they shoulder the responsibility for displaying information fairly. If bias is introduced into a dashboard, it will hinder rather than support good decisions. Throughout the development and design process and delivery of decision support, the credibility of the DSS designer as change agent is at stake. If bias is revealed, the opportunity to serve as an effective change agent for the current project or even future ones might well be compromised.

Analysts need to permit (and maybe even welcome) flexibility. As customization of desktops, database queries, and reports becomes commonplace, designers are increasingly asked to meet or exceed those expectations for users of DSS. If during the development process it becomes clear that a decision maker prefers a particular graph or table, even if the analyst does not immediately see its value, they need to accommodate the executive so that the desired table or graph can be substituted for something else on the dashboard. Since executives will undoubtedly prevail in getting the information they want one way or another, they are better served if the useful items are all together on a single page of the display screen.

# 5 The Future of DSSs and the Programmable Web

The systems analyst has gained a number of tools and techniques made possible because of the Web and the programmable Web, also known as Web 2.0. In this section we examine how the change agent can use these tools to provide unique decision-making environments for decision makers. We discuss how data are gathered and presented and also discuss the potential for decision makers to begin creating their own DSSs from parts of the programmable Web.

## 5.1 Widgets and Gadgets

Recently more tools, known as widgets or gadgets, have become available to the systems analyst for designing desktops and dashboards. This set of tools promises to provide more of the flexibly that a decision maker desires.

Widgets and gadgets depart from other design tools in that they require no particular expertise to use, and as such they provide a way for even the most casual of personal computer users to customize their desktops. These items are small programs, usually written in JavaScript or VBScript, and they reside in a special layer on the desktop itself. They provide the user a graphical user interface (GUI) between the desktop and the application, allowing the user to perform specified functions by clicking on the widget or gadget (Olsen 1998, Davidson and Dornfest 2004). Other kinds of widgets or gadgets display information on the desktop or dashboard without necessitating any user action.

Widgets, as they are called by their originator Konfabulator (Joyce 2005) and Yahoo! (2007), or dashboard widgets, as they are called by Apple Computer (2007), and gadgets as they are labeled by Google (2007) and Microsoft, can be any type of program that may be useful or even playful. Presently the widget library is a repository full of clocks, calculators, sticky notes, bookmark helpers, translators, search engines, weather forecasters, quick launch panels, and simple utilities. The user can also add leisure activities like games, music podcasts, and hobbies to their desktop display.

Executives may want to have easy access to widgets such as stock tickers, weather reports, and RSS feeds that broadcast news events, product updates, or industry news. Middle managers may want to install gadgets allowing users to track express packages and check airline, train, or other transportation schedules. Widgets and gadgets can empower users to take part in design of their own desktop, and designers who are observant can learn a lot about what users prefer when they study user-designed desktops. However, widgets and gadgets can also distract people from system-supported tasks (after all, that pop-up Sudoko might be too tempting for game enthusiasts to resist).

DSS designers must work with decision makers to support them in achieving a balance. Creating more-user-specific performance measures that are helpful to decision makers are an essential part of the designer's task. Gadgets and widgets should be tailored to gather and display information within the company. Only then will they be truly useful and perform as an integral part of a decision support system.

## 5.2 Mashups

A new approach to designing systems is to find preprogrammed Web-based applications and join them together to create a Web-based application for users. When one Web-based application program interface (API) is added to another API, the result is usually called a mashup. We suggest that mashups present enormous potential for supporting decision makers when integrated into a DSS.

The concept and practice of taking parts of programs or stand-alone programs, and reusing them is not new. One of the trends in systems development is to take COTS (commercial off-the-shelf software), and build systems using a modular approach. Many firms then hire systems analysts to customize software, thereby seeking to maximize the functionality of the application, as well as to ensure its integration into the organization. Mashups are similar to COTS in that they complete APIs that are taken from websites and are already stand alone applications serving a purpose. However, when APIs are combined with other APIs in a new way, they can fulfill another, completely different purpose than originally intended.

APIs provides all the necessary building blocks for DSS developers to rapidly develop an application (Wenz 2006). Using a specific API basically guarantees that all programs using that API will have a similar interface. Therefore, one wWebsite that uses Google Maps will look and feel very similar to another Web-based application (Gibson and Erle 2006). One benefit of this development tact is that decision makers who are familiar with the interface will easily adjust to the new application.

A mashup can be considered a new application, even though it is composed of parts consisting of APIs and other components such as really simple syndication (RSS) feeds (a news feed that is pushed to the user of an application or website) or JavaScript. An analyst can even take public data and merge private corporate data together to form a mashup. These are dubbed enterprise or corporate mashups (King 2006). Although mashups began with Google maps, they do not all need to include maps. A tutorial for constructing mashups is posted at IBM (2006).

As this article is being written, approximately 2.7 public domain mashups are being created every day (programmableweb 2007). It is widely expected that this number will soon rise to at least 10 per day. These mashups are created by enthusiasts or hobbyists who either want to contribute to the public domain on a volunteer basis (Business Week 2005) or who want to create a website and find a business model that will eventually turn a profit. The full potential of private mashups has not yet been fully realized.

Some mashups are indeed valuable. The Bogozo Real Estate (2007) website, for example, combines CraigsList (2007) real estate data with Google Maps

(2007). It adds value, because it allows a user to see a property on a map, view important items like neighborhood schools, and in the case of New York City, overlays a New York City subway map to help the user solve transportation problems as well. Streeteasy (2007) is another example of a comprehensive mashup of New York City real estate that includes statistics and trends, detailed information on neighbors and neighborhoods, and also displays photos.

Another novel real-estate application can be found at Homethinking (2007). This mashup combines real-estate transactions, with data about each agent as well as customer reviews. The point of this mashup is to help a user who is contemplating selling or buying a home to locate an agent who is active in the area, is a top performer, and who has earned positive reviews from satisfied customers.

Some mashups attempt to help consumers locate the lowest price for a product. Hawkee Social Price Comparison (2007) combines Amazon, Commission Junction, and eBay APIs to create an application that also allows customers to review products while being scrutinized and reviewed themselves by other customers. Another online shopping service called mpire (2007) groups the most popular online stores onto one website so that customers can determine the true market value for products they intend to buy. The application analyzes over 50 trillion historical sales to obtain the results. A third shopping site, called Baebo (2007), combines APIs from Amazon A9 openSearch, Amazon e-commerce, eBay, Flickr, Google Search, Technorati, Yahoo! Audio Search, Yahoo! Image Search, Yahoo! Shopping, and YouTube to create a unique shopping experience that can be directed to desktops via RSS feeds or via wireless markup language (WML) to handheld devices such as Blackberry.

People hunting for parking spaces have a number of websites to support their search. One site featuring airport parking offers even more features. Aboutairportparking.com (2007) combines a number of APIs to determine the delay status of the airport, the average wait in security lines, and directs users to official sites to look up particular information. Parking utilizes an API from Google Maps. Private parking lots are rated, daily costs are displayed, and directions to the parking lot can be obtained after a few clicks.

Government planners and business people who require census data would find Census Dashboard (2007) to be a good example of a dashboard-style combination of APIs. The site uses two Strikeiron APIs, ZIP code information, along with population demographics, and combines them with Yahoo! Maps to yield detailed information by ZIP code. Another useful application from Global Incident Map (2007) combines Google Maps with sources of information about terrorism, threats, and terrorism incidents around the world.

Mashups can also be used for political reasons. Health Care That Works (2007) has set up a website of hospital closures over the past 20 years and combined them with Google Maps, and racial and income data for New York City. The site uses the information to further its cause that low income communities or communities of color are disadvantaged by recent decisions regarding health care provision. Another example of mashups and political causes is On NY Turf (2007) that combines APIs to produce a color-coded map, called NYC No-Freedom Zones, to show which city council members have spoken out clearly against the police making rules that restrict the first amendment rights of U.S. citizens.

While there is much about mashups that is intuitively appealing and eminently doable, they should be viewed by designers with a certain amount of skepticism. Several caveats are worth reflecting on, even as the DSS designer is busily planning their next mashup. These qualifications are familiar to any designer accustomed to working with emerging information technologies, where the freshness of innovative features can sometimes cloud one's judgment about the ultimate suitability of a new application in a corporate setting. Even a non-exhaustive list of caveats associated with mashups includes five key areas: (1) reliability, (2) legal concerns, (3) the dynamic nature of the Web, (4) user support, and (5) systematic versus spontaneous development (MarketWatch: Technology 2007a, 2007b, Gerber 2006).

Reliability refers to whether users will be able to access mashups in a problem-free and seamless way. If not, developers risk losing their sterling reputations for reliability, and users risk losing valuable access when they need it most. Legal concerns are another consideration for use of mashups in DSS enterprise applications. Legal experts (Gerber 2006) caution that, since mashups by their very nature involve combining someone else's information or data into a new information service or innovative application, a plethora of legal issues must be considered before too much development time is devoted to their creation.

Some sites (for example, Google) only permit use of their website for non-commercial uses, or restrict supposedly free APIs in many other ways. Legal issues of concern touch on contract law, copyright, patent law, trademarks law, unfair competition/false advertising, obscenity, and the rights of privacy and publicity, as well as warranty disclaimers. Although it is not the place of this chapter to examine the topic of legal issues and mashups even cursorily, it is a topic worthy of further serious examination, and researchers will be working hard to keep abreast of all of the developments.

The third caveat involves the dynamic nature of the Web itself and the reality that what appears on the Web today may not be there tomorrow. While this caveat is intertwined with reliability, it serves to highlight the question of whether DSS developers who create mashups will ever be able to vouch for the mashups they create in the same way they guarantee other applications. User support is the fourth key caveat related to the use of mashups for DSS development. Once again, this caveat is intertwined with the issues of reliability and the nature of the Web; however, it subtly shifts the emphasis to examining what happens when users experience problems with mashups. How can they be supported, and is that support possible given the nature of mashups?

A fifth and final important caveat for developers creating DSSs with mashups involves the larger questions of systematic versus spontaneous development. When mashups are developed on the fly with little planning, documentation, or corporate awareness, how does that affect the systematic process of analysis, design, development, implementation, and evaluation developers have worked so hard to inculcate in users participating in systems projects over the years? Perhaps it is wise to view the development of DSSs with mashups as one methodological approach, but not the only one. Improving decision-maker flexibility and productivity must be balanced against spinning out of control on a mashup application where spontaneity becomes paramount to functionality. Although many of the mashups discussed earlier have business applications, the next logical progression is the emergence of companies that assist other organizations and individuals in creating mashups. One such company is Blipstar (2007). Their service allows businesses to create a utility for helping a customer find a store near their home using APIs such as Google Maps. Once a company uploads information about retail stores, Blipstar geocodes them, then allows the company to customize the application so it fits the look and feel of other applications they are using. The company then links this locator to its own website. Customers would interactively enter their address or ZIP code and the mashup would display the location of the nearest retail stores and detailed directions to the stores if necessary. A DSS designer can draw on these examples and learn to customize mashups for a decision maker, being sure to include the user's personalized priorities.

# 6 Conclusion

This chapter has explored the possible roles of the systems analyst in developing decision support systems. We suggest that the role of the change agent as advocate is the most appropriate role in the development of decision support systems. Analysts' roles have been characterized in a variety of ways, including those of external consultant, internal supporting expert, and change agent (who may be either internal or external to the organization undergoing change).

Change agents are also conceptualized as following models of change labeled as the: (1) IT specialist, (2) the facilitator, and (3) the advocate (Markus and Benjamin 1996, 1997). These characterizations are still the subject of controversy, as many in IS still cling to the old-fashioned notion that the only proper domain of expertise for information technology people is one that focuses solely on technical expertise. However, the centrality of the idea of change to the work of the analyst and to the continued existence of the organization has propelled many researchers, DSS designers, and decision makers into heralding the analyst as a change agent.

The goal of the DSS designer should be to change the decision maker and the decision process. Recent research (Brousseau et al. 2006) supports the idea that executives' thinking evolves over time, moving from day-to-day monitoring to systems thinking for cross-functional decision making. A decision maker's thinking evolves and matures; if it does not, the person may not advance in the organization. Our own research and experience with DSS designers underscores the importance of helping decision makers to evolve in their thinking as they interact with the DSS.

Early efforts in DSS design from the systems analyst's point of view focused on accommodating individual differences in cognitive style; the influence on adoption and use of DSSs by organizational subcultures; and the use of a variety of displays, graphs, tables, and narratives to support decision makers in making more accurate, timely, and effective decisions via improved decision processes. Interestingly, recent researchers are pointing to the usefulness of individual differences in cognitive style for designing decision applications for m-commerce on mobile phones and PDAs (Lee et al. 2007). Future DSS designers might be able to capitalize on individual preferences and mobile technology to create decision support uniquely tailored to decision makers.

The addition of the concept of the advocate change agent has reframed the prescribed behavior for both analysts and decision makers during the DSS development process, leading to a wider array of possibilities for interaction between the designer and the decision maker, and subsequently the interaction between the user and the DSS. Researchers (Sauter and Free 2005) are opening new possibilities for DSS uses, including the organization of the qualitative, nebulous data needed to make strategic decisions, as well as emphasizing the need for flexibility in the design of DSSs.

Several new tools can help analysts alter decision processes and the perspectives of decision makers. Included in these are dashboards that array all relevant information directly in front of the decision maker in a meaningful display of graphs, charts, and other performance measurements and indicators. DSS designers also possess new tools like widgets and gadgets, as well as new Web applications that combine one or more APIs called mashups. The potential use for corporate mashups has yet to be fully realized, but it is well within the capabilities of most DSS designers to incorporate this as a highly useful approach in their role as change agent. Five caveats for designers using mashups include questions of reliability, legal concerns, the dynamic nature of the Web, user support, and systematic versus spontaneous development.

Our contribution here has been to heighten awareness of the critical role of the DSS designer as a change agent. We believe that the primary goal of the analyst should be to change the decision maker; first, through their interactions during development, and subsequently as the decision maker interacts with the DSS. Future decision support systems may not focus on individual differences, but may in fact focus on individual preferences. There is an important distinction in the terminology. New technology and the programmable Web make this more than just a possibility, and DSS designers must anticipate this trend and embrace change themselves.

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# CHAPTER 51
# Evaluation of Decision Support Systems

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While the importance of evaluation in DSS is widely accepted, it has been rarely discussed due to the disparity between the interests of scholars and of practitioners. In this chapter, evaluation tools are schematized from a practitioners' point of view. That is, practitioners might be able to choose appropriate evaluating methods for their own purposes and circumstances using the following guidelines.

**Keywords:** Evaluation; Decision support system

## 1 Introduction

Scholars and practitioners have different goals for evaluating decision support systems (DSSs). The objectives of system evaluation aim to assess whether the user's needs are properly met, the system is suitable for tasks, and users perform better with the new system (Kirakowski et al. 1990). From a scholars' perspective, however, their ultimate goal of studying the evaluation of DSSs would be to let scholars and practitioners know about the study so they could gain insight for later use. From a practitioners' point of view, on the other hand, the ultimate goal of evaluation would be to improve DSS by enhancing decision quality and improving the performance of the decision-making process. The difference between the interests of the two parties has resulted in a great deal of evaluation efforts in the industrial sectors, but few studies have been conducted in academic circles. Consequently, the void between industry and academia has hampered the development of DSSs.

This chapter focuses primarily on the practitioners' perspective. It outlines a method to evaluate DSSs efficiently and presents problems that could occur during this evaluation in given circumstances. However, it refrains from empirically examining the general effectiveness of DSSs. In order to achieve this goal, three types of approaches for evaluation are introduced: the three-faceted approach, the sequential approach to DSS evaluation, and the general model of DSS evaluation.

# 2 The Three-Faceted Approach to DSS Evaluation

## 2.1 Pitfalls of Evaluating DSSs

Skeptical scholars may say there are inherent fallacies in evaluating DSSs. In fact, it is highly probable that the evaluation of DSSs contains irrational pitfalls for the following reasons.

First and foremost, it is possible that one could blindly perform a subjective evaluation. This is true especially for a condition involving user-involved system development. The system could be designed to meet the potential users' requests, and thus, the result would always be positive when the users evaluate the system. In such circumstances, it would be unnecessary to perform an elaborate and time-consuming evaluation procedure. This would be even more redundant if the potential user and the sponsor were one and the same person. However, it must be noted that a positive evaluation by potential users does not necessarily imply that the developed system is good and sound. Successful systems can be secured only when all the associated parties cooperate during all the steps of the process, from design to implementation. Thus, a sort of consensus guideline containing the opinions of all the concerned parties would be necessary, and the resultant evaluation criteria could play a guiding role throughout the whole development process. When the evaluation criteria are identified, active participation of the interested parties is essential to determine the quality of DSSs.

Secondly, it would be paradoxical to evaluate whether a solution by a DSS is correct or incorrect (Khazanchi 1991). DSSs by definition deal with unstructured or semi-structured problems (otherwise, the term support would not be needed) and solutions for the unstructured or semi-structured problems are judged only as good, bad, or reasonable, instead of right or wrong (Mason et al. 1973). Thus, for all practical purposes, one cannot assess a decision as right or wrong. Such an assessment may be, at best, the experts' preference. This explains why there are few studies on the evaluation of the decision quality with the aid of DSSs. Instead, a technical evaluation, such as how sound the algorithms within the system are, can be performed to measure the decision quality indirectly.

One could easily make the mistake of neglecting the confounding effect that better performance of decision makers may be due to an alternative cause, rather than DSSs. For example, an association between DSSs and user performance may be rendered insignificant after considering variables such as top management championship, learning through repeated training, and the possibility of forgetting the effect of performing tasks without the aid of DSSs. Barr et al. (1997) claimed that the improvements in decision quality in the presence of DSSs can be due to reliance. Alavi et al. (1992) argued that cognitive style, personality, demographics, and user-situational variables affect DSS implementation success, thus implying that various factors other than the presence of DSSs could influence the result of evaluation.

## 2.2 Three-Faceted Evaluation Methods

The evaluation of DSSs is vulnerable to errors, as discussed above. Thus, finding appropriate evaluation methods is critical in order to minimize the errors. Some evaluation techniques may be appropriate for measuring effectiveness and some techniques may be appropriate for assessing usability. Different needs require different evaluation modes (Maynard et al. 2001). According to the characteristics of those needs, the evaluation methods of DSSs can be divided into three categories: technical, empirical, and subjective evaluation (Adelman 1992).

First and foremost, technical evaluation assesses the system's logic, algorithm, and data flow. It is a domain-specific approach and usually developers are not familiar with domain-specific knowledge. This emphasizes the importance of a technical evaluation. A technical evaluation is a matter of taxonomy because developers are not supposed to develop logic or algorithms. Suppose that there is a black box containing terminals to be connected to electrical cables. Labeling meaning by taxonomy would then be a critical guideline for connecting the cables, and the verification procedure would be indispensable. More specifically, appropriateness of the analytical models such as logic and algorithms, the flow of data, costs analysis for developing the system, and technical tests of the developing system are critical items to be evaluated (Adelman 1992).

There are various tools that aid evaluation such as matrices, tablets, and models. However, these tools merely help people to judge technical aspects of the developing system. Experts are usually involved in judging such technical aspects, and participation of technical personals and potential users is needed.

Secondly, empirical evaluation focuses on performance with the aid of DSSs. There are several studies on the effectiveness of DSSs. These studies have attempted to investigate the improvements in decision quality with the aid of DSSs (Al-Khaldi 1991, Barr et al. 1997, Kottemann et al. 1994, Montazemi et al. 1996, Sharda et al. 1988, Todd et al. 1992). From a managerial standpoint, however, empirical evaluation is necessary not only to verify the effectiveness of the designated DSS but also to improve the system. That is, while scholars evaluate a system to verify its effect, the interested parties involved in the DSS implementation evaluate the system to improve it as well as verify its effect. If the interested parties in charge of DSS implementation decide to implement ready-made DSSs, they would need to verify the effectiveness of the readymade DSS. However, if they decide to develop a customized DSS, they would need an empirical evaluation to improve the developed system further.

The effectiveness of DSSs is usually measured using experimental methods combined with a surveying technique. Experimental methods are generally vulnerable to validity and therefore careful design is necessary. In addition to experimental methods, case studies and time series are also found in the academic literature. However, case studies are less appropriate for the improvement of DSSs system. Conversely, academic studies of cases would be encouraged.

Third, subjective evaluation views how effectively DSSs affect the interrelationship among the DSSs, users, organization, and environment. Aldelman (1992) claims that the DSS process needs to be monitored from three interface perspectives: the interface between the user and the DSS, the decision-making organizations and the DSS (with users), and the decision-making organization and the outer environment. A user's perception towards user interface such as ease of use, understandability, and clarity would be an ideal example of subjective evaluation while exploring the relation between the DSS and the user. Another example would be the relation between decision-making organizations and DSSs, when approached by assessing time, reliability, and political acceptability among members.

Khazanchi (1991) proposed an evaluation framework, to which the three-faceted view has been adapted in Figure 1. He views evaluation criteria as a continuum from objective to subjective. Each aspect contains relevant evaluation objects. Based on this framework, proper evaluation methods corresponding to each row and column are used.

The three-faceted view of the evaluation methods is a very useful approach, especially when seeking proper evaluation for specific needs. One merit of this view is that each facet of the evaluation method deals with totally different problem categories, and interested parties involved in system evaluation can narrow the methods search for use accordingly.

What is Being Evaluated? (Evaluation Objects)

| Objectivity of Criteria | Technical Aspects | Empirical Aspects | Subjective Aspects |
|---|---|---|---|
| Objective | • Data flow<br>• Application control | • Cost/Benefit Analysis<br>• Utilization Information Economics | |
| | | • Decision makers' confidence<br>•Time taken | |
| Subjective | | | • Ease of use<br>• User interface<br>• Understanding |

**Figure 1.** The evaluation framework for criteria and evaluation objects (adapted from Hamilton et al. 1981, Khazanchi 1991, Adelman 1992)

# 3 The Sequential Approach to DSS Evaluation

## 3.1 Understanding the DSS Evaluation Process

With the exclusion of scholars' empirical studies, most issues about the evaluation of DSSs are raised when an organization develops a DSS or decides to purchase it. If it is taken into account that even ready-made DSSs require most of the development process, we can easily establish the association between system evaluation and development.

In many cases, DSS development requires repeated evaluations over the whole process. However, the three-faceted view is not effective when evaluation methods are considered as a part of the system development process.

The idea of an integral DSS evaluation process can be borrowed from the system reuse/re-engineering process or prototyping process literature. In a broad sense, system reuse/re-engineering and prototyping processes are all about evaluation equipped with steps. The requirements for the evaluation measurements in DSS development may be also needed for reuse/re-engineering and prototyping design.

### 3.1.1 A Prototyping Design for DSSs

Andriole (1989) proposed a prototyping design for DSSs as nine testing steps: requirements analysis, functional modeling, method selection, software selection and design, hardware selection and design, system packaging, system transfer, system evaluation, and feedback.

The requirements-analysis step defines what the DSS will contain and whether the DSS development is feasible in spite of given constraints such as manageable funds and time. This step is very important and the analysis results are used throughout the whole development guideline. Such a guideline will have the role of criteria of evaluation.

The second step, the functional model, refers to narratives, flowcharts, taxonomies, storyboards, and so on. Like the first step, users as well as technical personnel are involved and will identify the criteria used for technical evaluation.

The third step, model selection, is needed to examine whether the existing analytical models, algorithms, and logic, which will be inserted as an engine of the system, are consistent with the requirements of the functional models.

In the fourth step, the development team decides whether to use a ready-made system or develop a new customized system. The team also considers the tasks of users, ensuring that a developed or chosen system is adequate for the organization's need. In doing so, various evaluation methods can be used. For example, a usability test from a subjective-faceted evaluation will determine the simplicity of the system for use.

The fifth step, hardware selection and configuration, refers to a compatibility test and is needed for prototyping the design.

The sixth step, system packaging, includes documentation and support, such as training. Although this step is comparably less related to the evaluation of a system, training is a critical factor affecting the performance and satisfaction. Kanungo et al. (2001) proposed a quasi-experimental design called Solomon's four-group design, and found that training significantly affects the effectiveness of DSSs. Alavi et al. (1992) also stressed the influence of training.

The seventh step, system transfer, is less related to the evaluation of a system. However, in subjective evaluation, interdependence among the available system, users, and organization are very important for a successful system implementation. With the aid of this step, the system can be smoothly implemented.

Lastly, evaluation and feedback steps are performed for the purpose of sum up and closure.

### 3.1.2 The System Re-engineering Life Cycle

Meanwhile, Tahvildari et al. (2003) proposed a software re-engineering life cycle as follows: requirements analysis, model analysis, source code analysis, remediation phase, transformation phase, and evaluation phase.

The first step, requirements analysis, is performed by identifying re-engineering goals. These goals are set by interested parties and form the criteria used for evaluation throughout the whole re-engineering process. Several methods are used to conduct the requirements analysis. These include the conventional approach (waterfall model, structured English, flowchart, and structured analysis technique), prototyping approach (throwaway, cornerstone, evolutionary, and operational prototyping), and object-oriented approach [Coad and Yourdon's method, the object-modeling technique (OMT) method, Shlaer and Mellor's analysis method, and Booch's method, Prieto-Diaz et al. 1994].

The second step is model analysis, which is the same as in prototyping design, along with requirements analysis. The model analysis focuses on the understanding of the functionality of the legacy system. Although analytical models inherent in DSSs are not considered due to the feature of general system differentiation from DSSs, it is necessary to capture the data flow, structure, and rationale behind the system design.

The third and fourth steps, source-code analysis and remediation, are straightforward. These steps are only associated with re-engineering and have nothing to do with the evaluation of DSSs.

The fifth step, transformation, refers to system implementation in re-engineering and thus a re-engineering team will keep testing the system to see if it can be implemented smoothly. Technical personnel will be in charge of evaluating the remedied system.

Once a system is implemented, like all other systems, an evaluation step follows. This plays a summative role.

### 3.1.3 Formative and Summative Evaluation

Although the evaluation of DSSs occurs after the prototyping design and the system reuse/re-engineering, it needs to be tailored. The first step of tailoring would be to provide an adequate framework for the evaluation of DSSs. In doing so, there are important terms which must be noted, including formative and summative evaluation. Usually a formative evaluation is performed during the development process as a time horizon. More specifically, a formative evaluation is iteratively performed until the weak points are eliminated and the desired objectives are reached to achieve improvement. On the other hand, a summative evaluation is performed when the development is complete and after the system is newly used (Power 2003). A summative evaluation is performed to determine the system's efficacy, defined as an ability to do what it was designed to do (Gediga et al. 1999, Kirakowski et al. 1990).

Going back to the prototyping design for DSSs by Andriole, methods that might be used in each step can be categorized into three components: identification of evaluation criteria, formative evaluation, and summative evaluation. Similarly, certain methods in each step of the system reuse/re-engineering life cycle should be used and they would belong to one out of three components.

### 3.1.4 The DSS Development Life Cycle

Chaudhry et al. (1996) defined the DSS development life cycle as an iterative process based on project assessment, problem analysis, design, development testing, implementation, and maintenance.

The first step includes the identification of problems and the determination of system development feasibility. The system development feasibility is addressed by examining system requirements and by analyzing technical, operational, and economic circumstances. Thus, this step is about setting the scope (guidelines) rather than evaluation.

The second step, problem analysis, includes the selection of a problem-solving paradigm such as a model, logic, and algorithms. In this step, the system requirements are also determined. Along the lines of the first step, the selected problem-solving prototype will play a guiding role throughout the whole development process.

The third step, design, includes logical, database, model base, and user-interface design. The model base and logical design is different from general information systems.

The fourth step is development, testing, and documentation. Akin to other systems, in this step, applications and databases are developed and tested. Thus, subjective evaluation is usually performed. Technical evaluation methods can also be used at this point.

The final step is implementation, followed by maintenance, as in other information systems. User training and summative evaluations are performed in this step.

### 3.1.5 The Human Decision-Making Process

The evaluation process as an integral part of DSS development can help us to gain insight into the human decision-making process. Forgionne (1999) viewed human decision making as a series of processes and stated that intelligence, design, choice, and implementation are involved in the process, based on previous literature. Although system-related tasks are excluded from the process, observing the human decision-making process may help us to view evaluation as a process.

In the first phase, intelligence, the decision maker is required to collect relevant information in an attempt to identify problems associated with organizational situation and environment. This phase is similar to the first two steps of the DSS development life cycle, project assessment and problem analysis. Problems identified in this phase could be solved by the following steps in the second to fourth phases. That is, the identified problems in this phase will lead the whole process.

The second phase involves design. During the design phase, the decision maker uses a model that can be used for solving the identified problems. The model can be decision alternatives, objective criteria that he can refer to, numerical relationships or functions, or a combination of these. During this phase, the decision maker might want to verify and examine whether he is using an appropriate model and whether he has committed an error or not. If this phase is embodied in a system like a DSS, such wishes may be amplified. During this phase, corresponding to the DSS development process, various technical evaluation methods can be used and experts can be involved in the evaluation. Assuring objectivity in this phase lends confidence to the output of the system.

The third phase is choice. The decision maker will choose among the options that he has created. There is no parallel step for this in the DSS development process because choice is the stage that a human does. Instead, Karim et al. (1998) developed a cost-benefit framework for evaluating the design decision for various scenarios. That is, it provides a method to judge an efficient output information matrix.

The fourth step is implementation. In this phase, the decision maker scrutinizes his decision and makes a final decision. This phase is almost the same as a summative evaluation.

Figure 2 provides a broad framework for the DSS evaluation process based on the findings of the human decision-making process, DSS development process, prototyping design process, and system reengineering process.

Once the evaluation criteria has been identified, the DSS is repeatedly evaluated using formative evaluation methods in each of steps of the DSS development life cycle, and summative evaluation is performed after the development is complete. Although evaluation criteria can be altered through the development of the DSS, such minor arbitrary changes will be neglected in the discussion to avoid confusion and complexity. Through the DSS evaluation framework explained in this section, associations among the human decision-making process, DSS development process, system reengineering process, prototyping process, and DSS evaluation process have been discussed. Since evaluation is a part of the system-

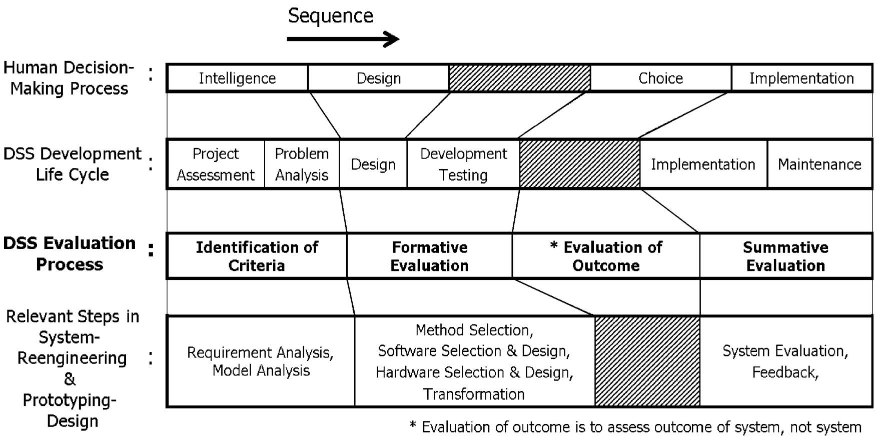


**Figure 2.** The DSS evaluation process

development process, it should be addressed from a sequential perspective. Interestingly, the human decision-making process requires at each phase the identification of evaluation criteria, formative evaluation, and summative evaluation. These three components were proposed as the DSS evaluation process in this section. This perspective will cover relevant processes such as the system reengineering process and the prototyping process, while following the human decision-making process.

## 3.2 The Importance of Identifying Evaluation Criteria

A decision support system is evaluated on the basis of criteria using a specific evaluation method. Without criteria, there is no basis for the evaluation. An evaluation criterion refers to a objective list that adds value to a system and should be achieved by a system (Adelman 1992). On the other hand, evaluation methods refer to how to measure the extent to which the system fits the criteria. Criteria and methods are combined according to circumstances and different evaluation methods are used for different criteria (Adelman 1992). For instance, the methods used to test the soundness of the optimization of algorithms and the methods used to test the decision quality should be different (the soundness of optimization algorithms and decision quality here are examples of criteria).

The identification of evaluation criteria is expected to serve as a guide throughout the whole development project, and thus, its importance cannot be overstated. While identifying the pitfalls of evaluating DSSs, we discussed how the consensus guidelines, derived from all the interested parties' opinions, are necessary to avoid the error of blind evaluation while performing subjective evaluation. Interested parties include users, designers, programmers, evaluators, and sponsors. It would be a fallacy to assume that, if the requirements of one party are met, so too are those of other groups. Preferably, all interested parties are encouraged to participate in the evaluations. At the same time, all interested parties must participate in the identification of evaluation criteria.

# 4 The General Model of DSS Evaluation

## 4.1 Domain-Specific DSSs and Technology-Specific DSSs

Kuwata et al. (2002) claim that disaster information systems, one specific type of DSSs, are different from usual DSSs because they require real-time responses and performance; they need more-efficient user interfaces and are difficult to evaluate in a realistic environment. Emergency response systems based on with DSSs are demanding systems that require considerable efficient evaluation, but few studies provide an evaluation framework for this purpose.

Like disaster information systems, the domain of DSSs ranges over most industries. Adam et al. (1998) classify DSS usage across organizations based on the complexity of tasks and the extent to which the use of a DSS spreads within an organization (the spread score). As a result, the data show that the complexity level is proportional to the spread score, which implies that the volume of use and the level of dependence on the DSS will increases across industries or domains.

Meanwhile, with the further development of the information technology (IT) sector, more-specific systems such as online analytical processing (OLAP), group decision support systems (GDSSs), knowledge-based DSSs, and geographic information systems (GIS)-based DSSs have extended their own territories while adapting to each other. Acknowledging that the ultimate goals of these systems are identical, an evaluation framework could provide a common guide.

A domain-technology-specific DSS is a trend. In the next section, we will provide a model that attempts to meet the demands of domain-technology-specific DSSs.

## 4.2 The General Model of DSS Evaluation

### 4.2.1 System Restrictiveness

The task, the user, and the organizational context are three important elements that can affect DSS design by adding or subtracting functionalities (Parikh et al. 2001). Since tasks, users, and the contexts of organizations with one another can vary, DSS designs can also vary for different organizations. Thus, DSS design cannot satisfy all the conditions of various organizations in terms of tasks, users, and organizational context. System restrictiveness is defined as the way in which a DSS limits its users' decision-making processes (Silver 1991). A very restrictive system refers to a system that supports only a small subset of all possible decision-making processes (Parikh et al. 2001).

System restrictiveness is not always the condition that should be removed. Reducing the system's restrictiveness by adding functionalities generally increases the decision quality, but also results in complexity, and a high cost of development and training. Thus, system functionality should be balanced and reach a moderate level.

Perceived restrictiveness negatively affects system evaluation. Perceived restrictiveness is believed to be larger than system restrictiveness (Parikh et al. 2001). Although users feel that satisfaction is part of the evaluation, bias can occur in evaluating the decision quality of objective evaluations.

### 4.2.2 Decisional Guidance Versus Evaluation Criteria

Montazemi et al. (1996) stress the importance of decisional guidance for the effectiveness of DSSs. Decisional guidance refers to the manner in which a DSS leads users to structure and execute their decision-making process (Silver 1991). Silver (1991) classifies decisional guidance into four dimensions: targets (structuring and execution), forms (informative and suggestive), modes (predefined, dynamic, and participative), and scopes (short- and long-ranged). Montazemi et al. (1996) claimed that decisional guidance reduces the system restrictiveness while minimizing users' confusion.

Interestingly, decisional guidance is very similar to the evaluation criteria that are usually identified in the early stage of DSS development. In fact, the evaluation criteria can be formalized into decisional guidance. Since a DSS is developed on the basis of the evaluation criteria, it is natural that high performance with decisional guidance is expected.

### 4.2.3 Decision-Making Effectiveness

Decision-making effectiveness examines the relationship between what should be done and what has already been done (Evans et al. 1989). In other words, if the expected results in the DSS criteria are ensured, the system can be deemed effective.

Based on the discussion about the domain-technology-specific trend, it should be noted that domain-technology-specific DSSs can be or are being guided by decisional guidance. This implies that there exist certain criteria according to which domain-technology-specific DSSs can be evaluated. What matters is not the efficacy of decisional guidance, but the need and capability for evaluation of the domain-technology-specific DSS using a decisional guidance. Thus, the use of target, form, mode, and scope for decisional guidance and the suggestion that they maximize decision-making effectiveness is out of the question.

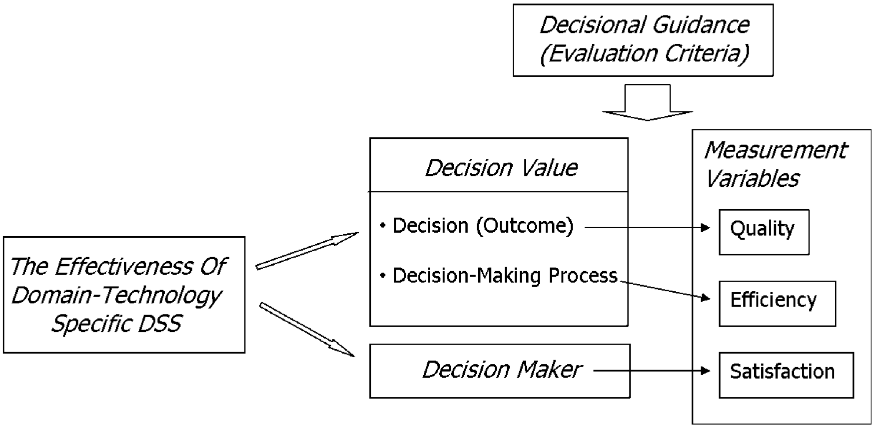


**Figure 3.** The general model of DSS evaluation

Forgionne (1999) divides the decision value into process and outcome. Evaluation of the process and the outcome for domain-technology-specific DSSs is also performed by measuring the process and the outcome.

Meanwhile, decisional guidance eliminates users' perceived restrictiveness. Unlike system restrictiveness, perceived restrictiveness is confined to the users' bounded rationality. Since decisional guidance originates from evaluation criteria, a users' bounded rationality cannot be relieved by the decisional guidance. When evaluators evaluate the outcome of domain-technology-specific DSSs, decisional guidance prevents evaluators from becoming too subjective.

Figure 3 represents the general model of DSS evaluation. It is adapted from findings described in this section and the research model, as well as the effects of decisional guidance on decision making by Parikh et al. (2001).

This model can be widely used over various types of DSSs for a range of combinations of domain and technology. This approach focuses on three aspects: decision quality, efficiency of decision-making process, and decision-maker's satisfaction. Also, these aspects are measured based on the decisional guidance. This approach helps the interested parties who are involved in evaluation to draw a big picture associated with the evaluation of their own domain-technology-specific DSS.

# 5 Conclusion

The three-faceted approach, the sequential approach, and the general approach to DSS evaluation have been discussed. The three-faceted approach focuses on how to evaluate three discrete aspects and categorizes all possible evaluation methods into technical, empirical, and subjective methods. This approach is called on when one wishes to identify appropriate evaluation methods for specific needs. The evaluation of DSSs is vulnerable to errors, and this approach addresses this inherent vulnerability as there are no constraints in the selection of methods. However, it is not organized and not easy to implement, especially during the development process.

The sequential approach to DSS evaluation focuses on the sequence of evaluation. It categorizes the DSS evaluation process into three sequential components: identification of evaluation criteria, formative evaluation, and summative evaluation, which investigates the human decision-making process. Hints from the DSS prototyping and the system-re-engineering processes indicate what should be evaluated, because these processes are themselves all about evaluation. While this approach is useful for understanding the fundamental evaluation process and provides a guideline for evaluation, it is not clear how to implement such an evaluation process. Thus, this approach can function only from the standpoint of evaluators.

The general approach to DSS evaluation focuses on what to evaluate. As measurement variables, it proposes decision (outcome) quality, the efficiency of the decision-making process, and the decision-maker's satisfaction, while stressing the need for decisional guidance. Currently, more-specific DSSs combined with technology or analytical models are being developed to meet the specific needs of certain industries. This trend towards specialization leads to the need for a framework for a general evaluation scheme that can be applied to more-specific DSSs.

These three approaches are not exclusive. They can be combined to fit into each organization's environment. The purpose of evaluation is to improve DSSs, and this chapter provides some insight into how to design an efficient evaluation process.

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# CHAPTER 52
# Planning a Portfolio of Decision Support Systems

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The planning of a portfolio of decision support systems takes place within the broader information systems planning process. The process can be viewed as being comprised of five phases with each having multiple activities. The objective of the process is not only to create the portfolio, but also to increase the likelihood of its implementation and to raise the value delivered by its decision support and other systems. Understanding the challenges of the planning process helps to explain the rationale behind the process itself.

**Keywords**: Information systems planning; Decision support systems; Information technology (IT) strategy

## 1 Introduction

Planning is the act of formulating a program for a definite course of action, usually to fulfill goals or objectives that are defined either before or during the formulating of the program. Planners seek to produce a program – or plan – that is better than the alternatives. One underlying presumption is that planners have the ability to evaluate alternative plans in terms of their anticipated benefits and costs in the presence of uncertainty about the future. Another is that the plan can and will be implemented over some predetermined period, which is referred to as the planning horizon. The planning process itself is costly in terms of the required time and effort, but faith in the presumptions motivates planners to proceed with the process.

Information systems planning has been defined as "the process of identifying a portfolio of computer-based applications that will assist an organization in executing its business plans and realizing its business goals" (Lederer and Sethi 1988, p. 446). The portfolio specifies the decision support systems, transaction processing systems, and any other conceivable type of information system. Decision support systems play such a significant role in the management of an organization that they are probably the most important type of information system that might be identified. Because transaction-processing systems typically provide data input to decision support systems, they can likewise be of great importance.

Information systems planning includes not only identifying the portfolio of decision support and other information systems, but also the specification of changes to the infrastructure of databases, software, hardware, and telecommunications to support the portfolio. It can encompass technical training planning, end-user computing planning, standards and procedures planning, facilities planning, and systems control planning in addition to software planning, hardware planning, network communications planning, data security planning, disaster recovery planning, and personnel planning. It can include the identification of the required new skills and positions necessary for the planning process, the implementation process, and the ongoing business processes supported by the systems. It can include the development of a variety of documents, such as task lists and schedules, to improve the quality of the portfolio and to increase the chances of successful implementation of the systems. The purpose of information systems planning can thus include not only producing the portfolio and foundation for its implementation, but also laying the groundwork for the longer-term management of information systems in the organization.

The complete output of information systems planning is often referred to as the information technology (IT) strategy. It typically includes much more than the portfolio. It includes the infrastructure changes, new skills and positions, task lists and schedules, and the delineation of other changes to improve the long-term management of information systems in the organization.

The purpose of this chapter is to explain the process of creating a portfolio of decision support systems. The chapter does so within the context of information systems planning with an emphasis on decision support systems. An understanding of the objectives of such planning is essential in order to comprehend the process; therefore the next section elucidates the objectives of that planning process. The subsequent section describes the process. A section about the challenges of information systems planning follows because the challenges help the reader better understand the rationale for the activities in the process.

## 2 The Objectives of Information Systems Planning

Although tangible measures for successful information systems planning such as improved profit, return on investment, or net present value would be preferable to subjective evaluations, such measures have proven problematic not only in information systems planning research but in planning research in general (King 1988, King and Grover 1991, Segars and Grover 1998). Because the success of such planning is believed to be best measured in terms of the fulfillment of its key objectives (Venkatraman and Ramanujam 1987), the assessment of the extent of fulfillment of key objectives has typically been employed for such judgment.

One study developed a set of ten questions, and used it to discover the practices that predict successful planning (Lederer and Sethi 1996). Table 1 adapts those questions to decision support systems for illustration in the current chapter (although the original paper considered information systems in general). The table identifies objectives closely related to information systems in particular (e. g., identify strategic decision support systems) plus objectives related to the longer-term management of information systems (e. g., increase the visibility of decision support systems in the organization). It thus succinctly shows some objectives planners seek to accomplish in the planning process.

Table 2 shows a set of 30 questions from an article that reported the rigorous development and validation of a research instrument using them (Segars and Grover 1998). The researchers later applied the instrument to develop planning profiles and to understand various planning dimensions (Segars and Grover 1999, Segars et al. 1998). Unlike the unidimensional instrument above, this one measured objectives classified into four major dimensions of planning: alignment, analysis, cooperation, and improvement in planning capabilities. Alignment referred to the benefits of the improving linkage of the information system (IS) strategy and business strategy. Analysis referred to the benefits of studying the internal operations of the organization. Cooperation referred to the benefits of agreeing about development priorities, implementation schedules, and managerial responsibilities. Improvement in capabilities referred to the bettering of the planning process itself. The research thus demonstrated the potential multidimensionality of planning objectives, while revealing numerous individual objectives.

**Table 1.** Information systems planning success in terms of objectives specific to decision support systems

| How well did the planning process: |
|---|
| identify strategic decision support systems? |
| identify new and higher payback decision support applications? |
| gain a competitive advantage from decision support systems? |
| align decision support systems with business needs? |
| improve communication about decision support systems with users? |
| increase the visibility of decision support systems in the organization? |
| allocate information technology resources among proposed decision support systems? |
| develop an information architecture? |
| increase top management commitment to decision support systems? |
| forecast decision support systems resource requirements? |

**Table 2.** Information systems planning success in terms of general information systems objectives

| **How well did your organization fulfill each of these objectives of alignment, analysis, and cooperation from its strategic information systems planning (SISP) efforts?** |
|---|
| **Alignment** |
| Understanding the strategic priorities of top management |
| Aligning IS strategies with the strategic plan of the organization |
| Adapting the goals/objectives of IS to the changing goals/objectives of the organization |
| Maintaining a mutual understanding with top management on the role of IS in supporting strategy |
| Identifying IT-related opportunities to support the strategic direction of the firm |
| Educating top management on the importance of IT |
| Adapting technology to strategic change |
| Assessing the strategic importance of emerging technologies |
| **Analysis** |
| Understanding the information needs of organizational subunits |
| Identifying opportunities for internal improvement in business processes through IT |
| Improved understanding of how the organization actually operates |
| Development of a blueprint which structures organizational processes |
| Monitoring of internal business needs and the capability of IS to meet those needs |
| Maintaining an understanding of changing organizational processes and procedures |
| Generating new ideas to reengineer business processes through IT |
| Understanding the dispersion of data, applications, and other technologies throughout the firm |
| **Cooperation** |
| Avoiding the overlapping development of major systems |
| Achieving a general level of agreement regarding the risks/tradeoffs among system projects |
| Establishing a uniform basis for prioritizing projects |
| Maintaining open lines of communication with other departments |
| Coordinating the development efforts of various organizational subunits |
| Identifying and resolving potential sources of resistance to IS plans |
| Developing clear guidelines of managerial responsibility for plan implementation |
| |
| **How well have these planning capabilities improved over time within the firm?** |
| **Improvement in capabilities** |
| Ability to identify key problem areas |
| Ability to identify new business opportunities |
| Ability to align IS strategy with organizational strategy |
| Ability to anticipate surprises and crises |
| Ability to understand the business and its information needs |
| Flexibility to adapt to unanticipated changes |
| Ability to gain cooperation among user groups for IS plans |

**Table 3.** Information systems planning success in terms of general information systems objectives

| How well did the information systems planning |
|---|
| predict future organizational trends? |
| improve short-term IS performance? |
| improve long-term IS performance? |
| improve decision making? |
| avoid problem areas? |
| increase user satisfaction? |
| improve systems integration? |
| improved resource allocation? |
| enhance management development? |

Table 3 shows a set of nine questions meticulously developed and validated to serve as an instrument for future researchers (Raghunathan and Raghunathan 1994). This shorter, unidimensional instrument to measure the success of information systems planning illustrates additional questions more specifically related to information systems (e. g., information systems performance improvement and increased user satisfaction) and others specifically related to the broader perspective (e. g., enhance management development). In combination, the three sets of questions demonstrate the breadth of objectives of information systems planning. They also set the foundation for a discussion of the process itself.

## 3 The Planning Process

McLean and Soden (1977) provided perhaps the first comprehensive description of the information systems planning process. They characterized it as having multiple steps. During the first step, planners set the mission of information systems within the organization. Next they assess the information systems department's and the organization's environment. They set objectives for the department, develop strategies for it, and define its policies.

According to the authors, they next prepare a conceptual, long-range IS plan to define an architecture for meeting the organization's future needs. Using the long-range plan, they develop a medium-range plan with a portfolio of ranked information systems, and in the final step, they compose short-range plans with annual expenses and manpower budgets, timetables, and individual information system schedules.

**Table 4.** IS planning phases and their activities

| Phases | Activities |
|---|---|
| Strategic awareness | Determining key planning issues<br>Defining planning objectives<br>Organizing the planning team(s)<br>Obtaining top management commitment |
| Situational analysis | Analyzing current business systems<br>Analyzing current organizational systems<br>Analyzing current information systems<br>Analyzing the current external business environment<br>Analyzing the current external IT environment |
| Strategy conception | Identifying major IT objectives<br>Identifying opportunities for improvement<br>Evaluating opportunities for improvement<br>Identifying high-level IT strategies |
| Strategy selection | Identifying new business processes<br>Identifying new IT architectures<br>Identifying specific new projects<br>Identifying priorities for new projects |
| Strategy implementation planning | Defining change-management approaches<br>Defining action plans<br>Evaluating action plans<br>Defining follow-up and control procedures |

Planners and researchers have learned a great deal in the past three decades about planning, and much has changed. However, the fundamental notion of setting broad objectives, assessing the environment, setting specific goals, and establishing more-flexible longer-range and detailed shorter-range plans remains.

Mentzas (1997) more recently described planning as a set of five phases of multiple activities, as shown in Table 4. His characterization illustrates the fundamentals as well as some of the issues in the evolution of the process. His approach has been applied in information systems research (Newkirk and Lederer 2003, Mirchandani and Lederer forthcoming).

The purpose of the *strategic awareness* activities is to generate top management understanding of the planning process and top management commitment to its success. The determining of key planning issues gives planners an opportunity to understand the potential problems they face before the process actually begins. The defining of the planning objectives focuses the planners on realizing the opportunities for the organization from the beginning of the process and onward throughout that process. Understanding the issues and objectives also enables planners to communicate better with top management and others throughout the organization.

The forming of the planning teams defines the appropriate skills and backgrounds of the planners. Business skills and background are typically much more relevant than technical ones. Top management participation in the teams is essential.

Top management commitment is typically obtained by demonstrating to top management the potential value of the planning process and the potential deleterious effects of the failure to plan. The failure to obtain top management commitment during past planning projects has resulted in the early termination of the projects or, even worse, the failure to implement the systems recommended by it, thus rendering all of the planning effort useless. Obtaining top management commitment is therefore probably the most critical activity in the phase.

The *situational analysis* activities represent the most-detailed and tedious effort in the planning process. Their purpose is to understand the current external competitive forces (i. e., industry competitors, customers, vendors, government regulations) and technology environments, and the firm's current response via its business, organizational, and information systems. Understanding these environments helps at anticipating changes in them that must be considered in proposing new systems. Understanding the organization's current response helps planners avoid proposing systems that already exist. Although not explicitly mentioned in Table , a pervasive activity of paramount importance underlying the activities in this phase is to understand the organization's business strategy, not only via the firm's response to the external competitive forces, but also in terms of any documented strategy.

***Strategy conception*** seeks first to identify major information systems objectives defined in terms of how the systems should contribute to helping the organization realize its business strategy. The phase identifies more-specific opportunities for improvement based on those objectives, and begins the process of evaluating the opportunities. Can, for example, new systems provide value to the market area? Can they provide it to the production area? To which area can they provide greater value? Planners use what they have learned both about the organization's objectives in the context of the current and anticipated competitive environment and about the success of the organization's current response to that environment in order to create new systems strategies, that is, general designs for using new systems for improvement in particular areas of the organization.

***Strategy selection*** translates the high-level systems strategies from the previous phase into the detailed business processes of the future. It identifies the specific new projects that will appear in the portfolio as well as the architecture in which they will exist. It prioritizes them based on an analysis of their anticipated benefits and costs.

***Strategy implementation planning*** is aimed at increasing the likelihood that the organization will implement the recommendations of the planning process. Because user resistance is deemed a major source of the failure to implementation, planners define change-management approaches to anticipate and prevent such resistance. Training is perhaps the most important change management approach, but detailing how the new system will help users perform their jobs better is also critical. Analyzing reasons for potential resistance suggests other change management approaches.

Planners also define and evaluate the details of the implementation of the initial projects to be implemented. Typically they give the highest priority to low-risk, high-return projects with fast implementation. They do this to confirm the value of the planning activity and to inspire continued management support for the remaining projects in the plan. They define the follow-up and control procedures to help them implement projects on time, within budget, and at good quality. These procedures can (and should) include audits of completed projects.

# 4 The Challenges of Planning

An understanding of the process of information systems planning is incomplete without a discussion of its challenges. The challenges elucidate the process by underscoring the dilemmas planners face as they create the portfolio. Ten such challenges follow.

## 4.1 The Methodology Challenge

Planners refer to the set of tasks within the planning procedure as a methodology. Sometimes they employ consultants to provide and lead them through the methodology, and sometimes they design their own in-house methodology. The tasks themselves are fairly well defined, but regardless of whether planners choose the consultant or in-house methodology, they must decide the approach and relative emphasis to place on each of the various tasks. For example, how much attention should they devote to predicting the anticipated cost of each proposed information system accurately? How much attention should they devote to accurately predicting the anticipated benefits of each information system? How much autonomy should a corporate parent grant its subsidiary (Mirchandani and Lederer 2004)?

Six key characteristics of the planning process (and thus its tasks) are comprehensiveness, formalization, focus, flow, participation, and consistency (Segars and Grover 1999), and planners need to decide how they will handle each. Comprehensiveness refers to the thoroughness of the planning, in terms, say, of determining objectives, considering alternatives, weighing the consequences of the alternatives, and providing detail in the plan. Formalization refers to the management structures, techniques, written procedures, and policies guiding the process. Focus refers to the balance between creativity and control in the planning process. Flow can be top-down (as characterized by greater top management initiation and direction) or bottom-up (as characterized by greater functional area management initiation and direction). Participation refers to the parties actually involved in the planning itself rather than initiating it or giving it direction. Finally, consistency refers to the frequency of the planning cycles and the revision of the existing plans.

Specific questions can illustrate the challenges posed by the characteristics. For example, how much detail should planners provide in their plans? How closely should they rely on written procedures to guide the planning? How creative should they be in selecting information systems? How much top-down direction should they seek? How much involvement should they obtain from users throughout the organization? How frequently should they revise the plan? All of these questions illustrate that both too much and too little planning can be detrimental.

One study showed that both too much and too little comprehensiveness in planning the implementation of the proposed portfolio reduce the success of the planning itself (Newkirk et al. 2003). Another study similarly showed that as organizational commitment (i. e., participation) increases, information system planning success increases until it reaches a maximum; as organizational commitment continues to increase, success decreases (Basu et al. 2002). The same relationship did not hold true for top management commitment (i. e., focus). These studies thus suggest the existence of an optimum level of some of the characteristics, and the planners' challenge is to find that level.

## 4.2 The Alignment Challenge

The alignment of the information systems plan with the corporate plan is the most important challenge facing IT executives (Luftman and McLean 2004). Alignment means that the contents of the information systems plan reflect the contents of the corporate plan and vice versa. The information systems plan thus provides decision support and other systems that are intended to help the organization carry out its business strategies to realize its business objectives and compete more effectively (Chan et al. 1997, Kearns and Lederer 2003).

IT executives seek alignment because they believe that systems that complement business strategies will generally provide greater organizational value than those that do not. They believe that top management in particular and the rest of the organization too will more likely support the implementation of such systems. On the contrary, if the systems do not complement business strategies, top management will more likely lose interest in them and focus instead on those that do.

Alignment challenges planners for several reasons. In some organizations, the business objectives and strategy are not easily accessible to information systems planners. They might, for example, not be in written form. In other words, the organization might not have well-defined objectives or a strategy. Top management might, especially in privately owned firms, keep its objectives confidential. Even if the objectives and strategy are accessible, they might be so general as to be difficult to translate into information systems. And in some organizations today, top management might still be reluctant to recognize the possibility that systems can support the strategy leaving them unwilling to clarify or elucidate as necessary to permit alignment. Mutual understanding between chief executives and chief information officers may be the key to overcoming this challenge, but achieving this may itself be difficult (Reich and Benbasat 2000).

## 4.3 The Environment Challenge

Competitors, customers, vendors, government, information technology vendors, and users are components of a rapidly changing business environment (Lederer and Mendelow 1990). Competitors, for example, adopt new strategies to gain market share via new products, production methods, and marketing approaches. Customers adopt new strategies and tactics to reduce the costs and increase the quality of the products they purchase. Vendors adopt new strategies to increase selling prices and reduce the production costs of what they sell. Such environmental changes represent a substantial concern for planners and researchers (Sabherwal and King 1992, Teo and King 1991).

Information systems planners attempt to anticipate both business and information systems changes by competitors so that competitors cannot use their own systems to gain an advantage. Sometimes planners attempt to choose new systems to implement them before their competitors do so and thus gain an advantage, and sometimes they prefer to implement in order to trail competitors closely and learn from competitors' mistakes. Information systems planners attempt to anticipate changes by customers and vendors to increase their leverage over customers and vendors, and thus prevent customers and vendors from increasing their own leverage over them. The lack of availability of information about competitors, customers, and vendors can complicate the task of learning about them. In fact, research has shown that changes by competitors, customers, and vendors can prevent systems planning from helping organizations achieve their planning objectives (Newkirk and Lederer 2006).

Government legislation frequently demands changes in systems. The Health Insurance Portability and Accountability Act (HIPAA) of 1996, the Basel Accord of 2001 (Basel II), and the Sarbanes-Oxley Act of 2002 are examples of recent legislation with major effects on such systems, but legislation has affected them in virtually all industries and all functional areas. Planners do not want to propose and construct new systems for which government legislation would demand potentially anticipatable changes. They do not want to propose new systems that government legislation might soon render obsolete. The need to anticipate government legislation can be complicated by the lack of available information about potential legislative changes. Hence, organizations expend considerable effort tracking, anticipating, and even attempting to influence potential new legislation so as, at least in part, to control the costs of information systems and improve their information systems planning.

Information technology vendors compete aggressively with each other (Benamati and Lederer 2000). Some oversell the capabilities of new products, and rush them to market with insufficient testing, poor support, and inadequate documentation, yet still pressure organizations to adopt them. New products can thus be of poor quality and cause unexplainable errors after adoption. They can be incompatible with existing products and demand bridges between them be created. They can require unforeseeable training in order for users to become proficient in their use. At the same time, organizations are pressed to adopt the latest new technology to gain the benefits; data warehousing via real-time decision support systems for business intelligence has perhaps emerged as an example of a new technology with great potential yet demanding careful IS planning (Watson et al. 2006).

Choosing obsolete information technology products can enable competitors to gain an advantage whereas choosing untested and unstable ones can cost the organization greatly. The plethora of new products with the aforementioned problems can create difficulty for planners in their efforts to choose the most appropriate ones. Sometimes vendors make information about their planned products available, but often they do not. As a result, planners may expend great effort developing strategies to work with vendors to understand their emerging products, yet still may make choices they regret (Benamati and Lederer 2001).

Users change. They develop new needs, desires, and preferences. They learn about the potential of information systems and about the usage of them by others both within their organization and in other organizations. Planners study them to anticipate their needs, desires, and preferences, and to do the best job of satisfying them in planned information systems.

## 4.4 The Cost Estimation Challenge

In most cases, when the cost of a proposed system is not negligible, top management wants to know that cost before approving the expenditure and including that system in the portfolio. Estimating the new hardware requirements of proposed systems tends to be somewhat challenging, but estimating the cost of new software is typically much more difficult. The estimation process is complicated by uncertainty about the user's precise needs or preferences as well as uncertainty about the features and capabilities of any new information technology that will be used to construct the new information system (Lederer and Prasad 2000). Whether the foundation of a new system is a commercially available package or an in-house product using the latest programming language or other software tool, development overruns are typical and can be substantial. In either case, the eventual core questions for estimating costs are these: how many new programs are required, and how many hours will be required to design, write, and test each one?

While the costs of new information systems are generally difficult to estimate, estimating those of decision support systems is much more difficult than those of transaction processing and other systems. Operational functions are more-easily understandable than are human decisions, and hence easier to design support for and to cost estimate.

Planners are well aware of this cost estimation challenge. Even thought they may inform management that their initial estimation is much more approximate than later estimations (after further analysis and design), they know that their first estimate may never be forgotten. Planners may even be reluctant to predict costs. However, top management typically wants to know the costs before approving the information system and including it in the portfolio.

## 4.5 The Benefits Estimation Challenge

In most cases, when the cost of a proposed information system is not negligible, top management wants to know the benefits that the proposed system will deliver before approving the expenditure and including that system in the portfolio. For most managers, and especially for the chief financial officers who must approve large-scale expenditures, quantifiable benefits are much more convincing than intangible ones. Describing anticipated benefits as better information or improved decision making will less likely motivate managers to approve the proposed information system than will benefits quantified in terms of increased revenue or decreased costs. Decreased costs in terms of a reduced workforce are particularly appealing to management.

Predicting quantifiable benefits is challenging for any new information system due to the uncertainty about how users will work with the information system. However, it's especially challenging for decision support systems where, in many cases, anticipating specific benefits and especially quantifying them may be quite unreasonable. For example, proposers of a data-mining system may have little tangible idea about what the organization might learn from the information system, but great conviction that the data can yield useful information. However, top management typically wants to know the benefits – as specifically and quantifiably as possible – before approving the information system and including it in the portfolio.

## 4.6 The Justification Challenge

Combining the predicted costs and benefits into a convincing statement to justify each proposed information system is another challenge. Conceivably neither the cost estimate nor the anticipated benefits are particularly convincing to a top management that would prefer a numerical indication, such as a return on investment or net present value, for each proposed information system. The challenge is to overcome top management's reluctance to take the risk on less quantifiable proposals or its reluctance to share the planners' vision about the potential of those projects to contribute.

## 4.7 The Security and Disaster Challenge

Planning for security and especially for disaster can require the inclusion of information systems in the portfolio or even infrastructure changes. Unlike other systems, security and disaster systems prevent potential losses that may never occur, but this may not generally be seen as return value on the investment in them. Of course, when a natural disaster or a security breach does occur, it can be extremely costly, but the systems do not necessarily help organizations compete.

With management often so heavily focused on enhancing competitiveness, the justification for their inclusion in the portfolio can be difficult.

## 4.8 The Resource Allocation Challenge: New Versus Maintenance

The initial suggestion to implement a new information system to solve a problem always raises the question of whether or not an existing system can solve the problem. Typically, existing systems are inadequate. The justification for the inclusion of the new information system in the portfolio hinges on the additional benefits and marginal costs the existing information system entails. The existing system can dampen enthusiasm for substantial improvement, and thus prevent the inclusion of a desirable information system in the portfolio.

## 4.9 The Flexibility Challenge

Although the objective of planning is to produce a portfolio of information systems to implement over a specified time horizon, unexpected changes will still occur over that period despite the effort to anticipate competitor, customer, vendor, technology, legislative, and user changes. The longer the period, the more likely and prevalent such changes will be, especially later on.

Changing the plan can be costly because it can mean changes to information systems that have developed in part or have even been completed in full. Planners attempt to minimize such changes, but realize that the plan will most likely need to be adjusted. They need to maintain more detail in the earlier information systems in the horizon and less in the later ones. They need to revisit the plan over the horizon and be prepared to change it if necessary. Maintaining flexibility in the planning process is thus a challenge to them.

## 4.10 The Implementation Challenge

The greatest challenge of information systems planning is not the creation of the portfolio itself but the implementation of the information systems in the portfolio (Gottschalk 1999, Hartono et al. 2003, Lederer and Sethi 1988). Sometimes, the entire plan is ignored. Sometimes, only a few of the proposed information systems are implemented, and most of the information systems implemented over the horizon were those proposed outside the plan.

A variety of reasons can explain this problem (Lederer and Mendelow 1993). For example, despite the effort put into the planning process, many managers do not take it seriously. They believe, although they may not say it, that the actual decision to implement a new system is made not in the planning process but rather when management begins to assign resources to the actual development of the system. Many managers believe that they can bypass the planning process and effect the decision to implement their proposed system later on.

The simplest way to bypass the process is probably to create a crisis. The basis of the crisis can be environmental change. The claim would be made that planners could never have foreseen a change in competitors, customers, vendors, government legislation, information technology, or users (the longer the horizon, the easier it is to make this claim). The crisis would demand a new information system and thus a change in the priorities of the information systems plan. Advocates of systems that would be delayed or dropped would protest, and the costs and benefits issues of the delayed or dropped systems would be raised anew. Of course, unanticipated changes in competitors, customers, vendors, government legislation, information technology, or users can genuinely foil an information systems plan.

Manager and user resistance to information systems already in the portfolio can also cause those planned systems to be dropped. Managers and users may perceive proposed information systems as threatening. No need to question them existed during planning because their priority may change without questioning, so they might begin their questioning when development resources are about to be assigned. Of course, poor-quality information systems can genuinely foil an information systems plan too. The questioning is not necessarily a disingenuous move.

## 5 Conclusion: Success and Failure

The ideal information systems planning process would produce a portfolio of decision support and other information systems, from which many (especially those planned for implementation in the early days of the horizon) would be implemented. As time passes and the environment changes, some might reasonably be dropped from the portfolio and others might be added.

The failed information systems planning process would produce a portfolio of decision support and other information systems from which none or very few would be implemented. Management would question the value of the time and effort invested in the planning process. Planners might eventually defend the process by claiming that the most valuable outcome from the planning process was that they, the planners, learned a great deal about their organization, although this may not sit well with management.

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# CHAPTER 53
# Decision Support System Evolution: Predicting, Facilitating, and Managing Knowledge Evolution

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Decision support systems (DSSs) need to evolve over time for many reasons, including changing user needs, technologies, and problem understanding. This chapter investigates what constitutes DSS evolution, taking the view that DSS evolution means that changes occur in all aspects of those systems, including hardware, databases, user interface, applications, and knowledge. This chapter summarizes and extends some of the literature on evolution and it also summarizes some approaches designed to help manage DSS evolution, including both the prediction and facilitation of evolution.

**Keywords**: Decision support system; Evolution

## 1 Introduction

Apparently, Courbon et al. (1978) were the first to use the notion of evolution in decision support systems (DSSs). Soon after that, Keen (1980) elaborated on key aspects related to evolution in DSSs. That research was mostly concerned with the notion that DSSs evolve over time, that the development methodology of DSSs is evolutionary. In a closely related set of developments, Lehman et al. (1983) appear to have been the first to use the term ***evolution*** in conjunction with generic computer software. In particular, Lehman (1998) labeled software development and maintenance as software evolution. He described software change and enhancement as unending, suggesting that evolution is also unending.

### 1.1 Scope

DSSs as a bundle of hardware, data and knowledge, user interface, and software application change and evolve over time. The purpose of this chapter is to investigate the notion of DSS evolution and DSS characteristics and component evolution. Previous literature has primarily been concerned with notions that DSSs evolve and that methodologies of DSS development consider this evolution. In addition, there has been some concern as to why DSSs evolve. However, there has been limited research into how DSSs actually change and evolve over time.

Accordingly, we review the previous literature on DSS evolution, according to its individual components, and clarify the process of DSS evolution for its components over time. In addition, we extend the notion of evolution to a more-proactive perspective aimed at management of evolution, where we try to predict and facilitate evolution as part of DSS management, rather than just passive evolution.

The scope of this chapter is to investigate the evolution of DSSs in general as well as in its components. For some DSS components there is an extensive evolution literature, for example, for database schema. However, for others there is a more-limited literature, for example, the evolution of different knowledge representations. Because of the extensive nature of this topic, we provide an additional discussion on knowledge evolution, including knowledge artifacts, such as taxonomies.

## 1.2 Structure of the Chapter

This chapter proceeds as follows. Section 2 discusses key issues associated with evolution and how it relates to DSSs, including such issues as the nature of DSS evolution, some sources of evolution, and the extent to which backward compatibility is an important issue in DSS evolution. Section 3 provides a review of some of the previous literature that deals with DSS evolution, analyzing each of the major components of a DSS. Section 4 focuses on knowledge evolution, while Section 5 drills down on how to manage knowledge evolution by facilitating and predicting knowledge evolution. Section 6 provides a brief summary.

# 2 DSS Evolution

This section lays out the key issues in DSS evolution, including defining what we mean by DSS evolution.

## 2.1 What is Evolution?

Before we talk about DSS evolution, what do we mean by evolution? Typically, definitions suggest a gradual change in whatever is evolving, generally as it moves to a different state. For example, definitions include,

- "A process in which something passes by degrees to a different stage (especially a more advanced or mature stage)," or
- "A gradual process in which something changes into a different and usually more complex or better form" (http://www.thefreedictionary.com/evolution).

## 2.2 What is DSS Evolution?

In terms of DSSs, what does this mean? DSS evolution relates to

- changing DSS features or components over time
- changing technology on which the system is used
- development of more-efficient algorithms over time
- evolving knowledge in the system over time
- changing users and user preferences over time

If DSSs evolve, this raises additional questions. For example,

- Is evolution a formal process or is evolution something that just happens?
- How can we tell if evolution has occurred?
- How do we measure the extent of evolution?
- Can we predict aspects of evolution?
- Can we facilitate evolution, perhaps increasing the speed of evolution?

## 2.3 Evolution Versus Revolution

In general, it will be assumed that evolution is different from revolution. Revolution is a more-dramatic change than the change associated with evolution. For example, revolution has been defined as "a sudden or momentous change in a situation" (http://www.thefreedictionary.com/revolution).

As an example of revolution, in the 1980s there was a rapid growth of so-called expert systems, knowledge-based systems, or rule-based systems. Although expert systems were often aimed at supporting decisions, rule-based knowledge historically was not generally viewed as part of decision support systems. Expert systems and their rule bases provided an alternative way to capture decision supporting activity.

However, over time, the revolution in expert systems and other technologies has become an evolution point for DSSs, rather than a revolution. Rule-based systems have become integrated with other technologies and problem-solving approaches. A review of papers published in the journal ***Decision Support Systems*** yields many papers that employ rule- or knowledge-based approaches. Now DSSs that employ rule-based technologies are often referred to as intelligent DSSs if they have to be distinguished from other DSSs. They are also increasingly just referred to as DSSs, because intelligence is integrated into the system.

## 2.4 Why Evolution?

Why do DSSs evolve? Although Lehman (1998) refers to development and maintenance, this provides limited insight into why DSSs evolve. The purpose of this section is to summarize some of those rationales for why DSSs need to evolve.

There are a number of reasons for the evolution of a DSS over time. First, user preferences may change gradually over time. Accordingly, the DSS must respond to those changes by allowing the user either to make preference changes or by monitoring system use and facilitating those changes.

Second, specific user needs may change, driven by a number of rationales for change. It is well known that the requirements for a system have a tendency to change as the user(s) sees the system and better understands how it is going to work. As they better understand the system, users have better understanding of how it can meet their needs.

Third, the specific user may change. As users are promoted or assigned other job activities within an organization, the actual system users may change (Arnott 2004). Different users are likely to have different requirements.

Fourth, the set of users for which the system is designed may change. When so-called executive information systems (EIS) emerged, they were aimed at executives. However, this led to a setting where executives and non-executives had differential information and support. Further, those that worked for the executives were affected by the use of the systems. As a result, the non-executives wanted access to the system. In addition, by spreading the costs over a larger base of users, firms could drive down the cost per user. Accordingly, it was not long before a larger base of users was granted EIS access with different users having different capabilities. As the user set changed, the system capabilities needed to change (King and O'Leary 1996).

Fifth, there may be errors in the system that need to be fixed as part of the normal maintenance process. As errors are fixed the system will change, and the user's view of the system will change, likely precipitating additional evolution. This link is often overlooked in evolutionary analysis.

Sixth, available technology may change. Technology is constantly changing and these changes can have a substantial impact on the delivery of a DSS. For example, before the Internet and the Web browser, developing a user interface was a large portion of any DSS task. Now, developers simply build the systems to employ a browser interface. As another example, Erwin and Snelling (2001) explore the evolution toward a grid computing environment. Although we are unaware of any grid computing DSSs, it does illustrate the change in computing environments over time. Keen (1980) felt that this was a key cause of evolution.

Seventh, understanding of the problem may change. A DSS can be built to solve one problem, but as the problem becomes better understood, the scope of the problem may change. For example, the problem may start out as a warehouse location problem, but turn into a broader problem, more oriented towards the entire supply chain. This has been referred to as a cognitive change (e. g., Arnott 2004).

Eighth, as noted by Keen (1980), the problem being solved tends to move from a simple one to a complex one. As these complexities are introduced, the system will need to change to address them as part of the application.

Ninth, decisions may evolve from being decisions made by an isolated individual to a group decision. Shakun (1991) suggested that the same evolutionary methodology suggested by Keen (1980) be used to facilitate development of group DSSs.

Tenth, as noted by Arnott (2004), the internal organization structure may change. For example, there may be downsizing, outsourcing, division restructuring, and other changes.

Eleventh, ideally the DSS is designed in concert with an organization's strategy in order to create value for the organization. As a result, if that strategy changes, then the DSS will also need to change. As organizations and strategies change and evolve, supporting systems will need to do the same.

Twelfth, the world in which the decision is being made may change. A new competitor or a change in resource availability can have major effects on the DSS model and the decisions that need to be made. Angehrn and Jelassi (1994) indicated that environmental changes were a major cause of the need for DSSs to evolve. Arnott (2004) noted that external events such as changes to industry structure and government regulations can also lead to the need for evolution.

Accordingly, there are a large number of reasons for how and why a DSS is likely to change and evolve. Evolution is not limited to one such factor, but may include multiple factors. Further, as with much of evolution, time plays an important role, allowing evolution to take place in a dynamic environment.

## 2.5 Is Evolution Backward Compatible?

In general, evolution does not mean that previous inputs will continue to be processed in the same manner, i. e., backward compatibility. DSS artifacts, such as taxonomies and knowledge bases, are not in general backward compatible; they evolve to solve the problem as the user, problem and capabilities change. Further, as noted above, users may change, so that even users are not backward compatible. As a result, typically, a problem of interest at time $t$ is not necessarily of interest at time $t+1$, and not necessarily solvable with the same DSS, to derive the same solution.

## 2.6 Predicting Versus Facilitating Evolution

There are at least two distinct features associated with DSS evolution beyond knowing that it will occur: the prediction of what the system will evolve to, and the facilitation of that evolution. Predicting evolution has to do with trying to understand what future state or states the current system will evolve towards. Facilitation has to do with trying to understand how to best push or change the system to a new future state. As a result, facilitation may include the identification of a particular future state for the system to evolve to. In any case, both prediction and facilitation are critical to the overall management of the DSS. Both play an important role in managing change in the DSS and managing the DSS. These topics are discussed later in the chapter.

## 2.7 Is Evolution a Formal Process?

In machines we can formally plan for the evolution of the overall system and particular aspects of the system. As a result, in that setting, evolution is a formal process, typically with particular observable end states or intermediary states. Generally, the formal aspect of evolution is associated with the formal evolution of individual components, e. g., database evolution, target end states.

However, evolution is not necessarily a formal process. In classic DSS evolution (e. g., Keen 1980) there is an air of informal evolution. In that setting evolution can result from informal or unplanned changes that occur over time. Using either approach, evolution can take on emergent properties.

## 2.8 Emergent Properties

Emergent system properties are those that result from using the system and from system components interacting with each other. Individual components would not exhibit the behavior; instead it is with the interaction of the components that the behavior arises. In general, emergent properties are not always predictable. Instead, they are a function of the interaction and evolution of the components. Emergent properties are likely to be less predictable, and possibly less visible, than other system properties (e. g., O'Leary 2001).

## 2.9 How Can We Tell If Evolution Has Occurred?

If evolution is an informal process, determining the extent of evolution may become an important issue. Evolution can occur in the systems or its users and the processes that they use. In many ways, the key question is simply: Is the system different than it used to be? However, the extent and type of evolution will vary by DSS component, whether it happens to be knowledge used in the system, solution approaches used by the system, or even technology. Further, emergent properties may be more difficult to find and measure and predict, a priori. So-called network effects are a classic emergent property of integrating multiple computers on the same network.

The extent to which a DSS has changed might be assessed by using a standard set of inputs. In a deterministic system, a related set of standard outputs would be associated to this standard inputs. Unfortunately, this approach assumes that there is backward compatibility in the evolution of the DSS.

Further, additional system output decision comparisons may provide limited basis of comparison. The existence of similar or different particular decisions does not provide substantial input as to whether or how much a system has changed over time.

As a result, determination of the extent of evolution will typically depend on change in DSS artifacts. Those artifacts can either be an explicit part of the system or ancillary to the system. Artifacts embedded in the DSS may include database schema or taxonomies. Comparing artifacts at particular points in time allows us to gauge the extent of evolution. Since the analysis is based on particular artifacts, much of the analysis is likely to be artifact specific. Ramesh and Sengupta (1995) discussed one such ancillary artifact. They suggest using multimedia to capture historical information about a system's evolution. Using multimedia, a history of system usage could be used to provide snapshots of evolution. For example, a video of a design session could be used to understand how and why a system has evolved.

## 2.10 Scope of Evolution

The term evolution has received many different uses over time in the decision support literature. In particular, have found many uses that are not directly related to DSS evolution. Accordingly, an important issue is what types of evolution are not considered in this chapter:

- industry evolution (Schuler 2001), where a DSS is used to analyze the evolution of a particular industry.
- managing software evolution (Berzins 1998), where a DSS is used to provide support for software prototypes.
- product evolution (e. g., Tiwana and Ramesh 2001, Kojo et al. 2003), where the DSS is designed to facilitate the evolution of a product.
- specific problem evolution (e. g., Balbo and Pinson 2005), where knowledge about how a problem can evolve and how to respond to it is addressed as a DSS. However, the problem that a DSS solves may well evolve and change as needs change.
- evolution of strategic customer relationship management practices (Pan et al. 2006). However, ultimately, the DSS may change to reflect changes in best practices that occur over time.
- using a DSS as a basis and tool to predict the evolution of other topics, e. g., predicting new patients (Riano and Prado 2001). Instead the focus is on the DSS and using tools (which could include a DSS) to predict and facilitate change in the DSS, in general.

Accordingly, the focus of this chapter is on DSS evolution, and the evolution of what are historically taken to be some of its components.

# 3 Previous Research: Evolution of DSSs

There has been a limited amount of research on the evolution of DSSs, mostly aimed at individual characteristics or components of DSSs. These components include the technology on which the DSS is based, database, user interface, application, and knowledge built into the system. Further, this research has really focused on changing systems but not understanding the process or predicting or facilitating DSS evolution. The research is summarized in Table 1.

**Table 1.** Summary of research

| | |
|---|---|
| DSS evolve | Courbon et al. (1978) and Keen (1980) |
| DSS development methodology | Keen (1980) |
| Technologies evolution | Gibson and Nolan (1974) |
| Database evolution | Banerjee (1987), Chen et al. (1995) |
| User interface evolution | Integrated into operating systems |
| Application | Rao and Turoff (2000) |
| Processes knowledge | Zhuge (2005) |
| Taxonomy knowledge | O'Leary (2004, 2007) |
| Ontology knowledge | Haase and Stojanovic (2005) |
| Association rules | Golani and Etizion (1999) |
| Discovered knowledge | Yoon and Kerschberg (1993) |

## 3.1 DSS Development Methodology: A Historical Perspective

The fact that DSSs evolve and the inclusion of that evolution in the development methodology associated with DSSs has been apparent from their beginning. Historically, Keen (1980) was most concerned with the notion that systems evolved, and what seemed to cause that evolution. Evolution was built into the notion of how DSSs developed over time. When Keen (1980) discussed the concept of evolution, he directly indicated that the final system can be developed only through a process of learning and evolution and that the DSS evolves in response to learning. Keen (1980) felt that evolution occurred only because of interaction between user and designer, learning, personalized use, or the evolution of new functions. He also indicated that the system evolved in response to evolving needs. Keen indicated that program structures and programming methods need to facilitate evolution. Keen indicated that evolution means adding new commands, which would probably be translated as adding new capabilities, but did not provide further guidance as to how to actually evolve DSSs. Keen did suggest that there was a need to study the evolution of data and data structures and that data-based DSSs do not evolve as easily as model-based DSS. Keen also saw evolution as technology based, since he noted that evolution can be blocked by the inability to obtain additional technology. Finally, he noted that complex systems evolve from simple systems.

As a result, historically, the focus of evolution has been on the fact that DSSs evolve, and not on what particular aspects of DSS evolve or how that evolution should be managed or predicted. A brief history of some DSS evolution issues is provided by Arnott (2004). For example, Keen and Gambino (1983) suggested that DSS adaptation occurs at the sub-task level. This view focuses on the decision problem rather than other factors. Stabell (1983) indicated that DSS evolution should occur with the tension between the descriptive and prescriptive views of the decision. However, this ignores evolution due to factors other than the model of the decision. Sage (1991) developed a seven-stage requirements analysis approach for DSSs, and indicated that requirements determination is likely to be a driver for evolution. Accordingly, this approach focuses on the roles of the requirements and the decision. Silver (1991) also focused on the importance of the decision in evolution, considering how DSSs affect decision-making processes, and the role of the DSS in guiding system use. Accordingly, Silver focused more on the user, rather than other aspects of the DSS.

## 3.2 DSS Technology Evolution

DSS technology has also undergone substantial evolution over the years and will continue to do so. This evolution has not gone unnoticed, although it may not have been referred to as evolution.

In particular, there has been some research focus on how information technology (IT) systems have changed. In an era before package software, enterprise software, and even before formal notions of DSSs, Gibson and Nolan (1974) suggested that computer-based applications follow a common growth cycle over time. Although it is arguable as to the specific applicability of the discussion in that paper, the overall notion was one (although this terminology was not used) where application type evolved over time, starting with cost-cutting accounting applications, moving to functional applications and a focus on control, to database applications where the user could query the database.

This type of evolution could be expanded and generalized to DSS evolution over time and a number of models be developed. For example, a focus on decisions is likely to be concerned first with what has happened and structuring the problem. This may take any of several forms, including a database query, where the user tries to understand what the problem and its source are. As they begin to understand the nature of the problem, the system and what they do is likely to change. Once there is a strong concept of what the problem is and what data is necessary to understand it, a second step is likely to focus on monitoring the particular problem area. Reports may be created as part of managing the problem area. Finally, in the third step, rather than just monitoring and reacting to problems, users are likely to want to anticipate problems, forecasting data to facilitate

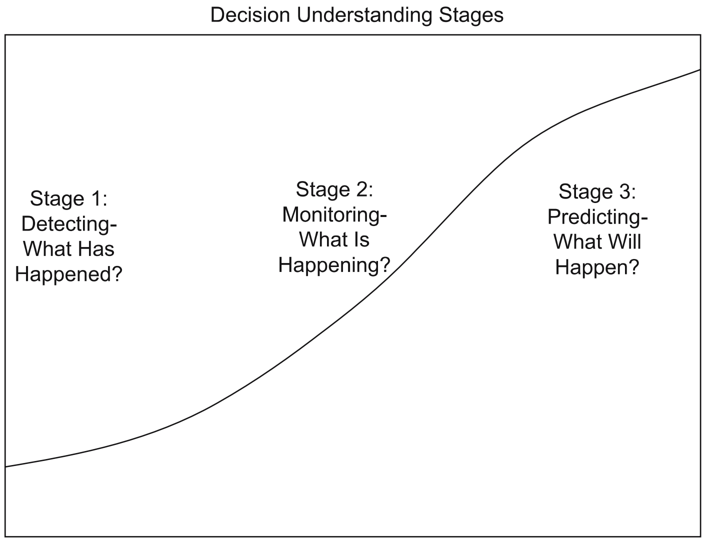


**Figure 1.** Decision understanding stages

that prediction process. This approach is summarized in Figure 1, as part of decision understanding.

Furthermore, the technology associated with DSS systems has gone from dumb terminals linked to mainframes, to stand-alone workstations and personal computers, to locally networked computers, to computers networked across the

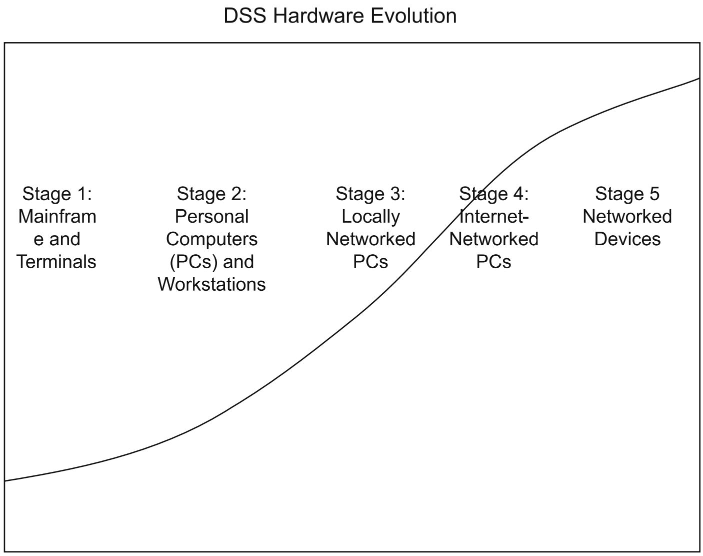


**Figure 2.** DSS hardware evolution

Internet. Figure 2 generalizes and extends the Nolan (1993) view of the three eras of IT organizational learning, by expanding the networked stage to local and Internet-networked PCs. As emerging technologies, such as grid computing (Erwin and Schelling 2001) increase in importance, they may be integrated into our view of DSSs. Further, this view can be extended beyond PCs to alternative technologies, such as mobile computing devices, including mobile phones. Stage six is likely to be an environment of wearable and embedded computing.

Recently, McAfee (2006) continued research into these stages by investigating the three emerging worlds of information technology. The evolutionary flow associated with information technology moved from function to network to enterprise, with a corresponding focus on discrete tasks, tasks that interact, and business-process-based information technology, respectively.

DSSs can be a part of any of these stages. Perhaps DSSs fit best as functional information technology, because they often assist with the execution of particular tasks. DSSs may also fit well with network IT, particularly if multiple users have access to it, say over the Internet. For example, emerging technologies such as Wikis may fit into this view of DSSs. Enterprise IT specifies business processes. Emerging technologies such as business-process management connect DSSs and so-called enterprise IT.

The focus of this chapter is on evolution, so a complete analysis of all of the technologies influencing DSSs is outside of its scope and probably impossible anyway. However, the technologies that already have an impact on DSSs are many and wide ranging, including mobile technologies such as PDAs and telephones. In addition, other technologies, such as data warehouses and artificial intelligence have also had a substantial impact.

## 3.3 Database Evolution

One of the key components of a DSS is likely to be a database. In the same sense that a DSS evolves, a database needs to evolve. If decision-making needs change then the data supporting those needs also is likely to change. Accordingly, DSS databases need to evolve (e. g., Banerjee et al. 1987). Two key concepts associated with database evolution are database schema and metadata.

There is a substantial literature on database schema evolution (e. g., Roddick 1995 and Liu et al. 1994) and in the context of enterprises (Chen et al. 1995). Loosely, schema evolution refers to the ability of a database schema to change without losing information. Schema evolution has been necessary in those settings where there is a need to retain data under schema definitions that have been changed. Research has been done relating to both relational and object-oriented data.

In general, schema evolution is guided by a database administrator. Furthermore, ideally schema evolutions are closely related to the previous schema so that data under the previous schema can be viewed under the current schema. In addition, evolution should be reversible so that erroneous changes can be reversed.

However, database evolution does not imply complete historical support for a particular schema.

Unlike database evolution, DSS evolution may not allow even partial support for previous capabilities. Evolution in DSSs is much more similar to evolution in biology. For example, DSS evolution may push the DSS to supporting entirely new questions, at the expense of supporting previous questions. Furthermore, evolution to new technologies may not be fully backward compatible.

Sen (2004) traces the history of metadata as the evolution of the concept of metadata. However, only recently has there been limited research on the evolution of metadata per se, particularly the prediction and facilitation of metadata. One such case study (Loasby 2006) traces metadata evolution at the British Broadcasting Corporation (BBC). Much of the recent focus on metadata occurs because of the focus on so-called service-oriented architectures (Gabriel 2005). Because DSSs can be developed as stand-alone applications, they may evolve their own metadata, which could cause substantial difficulties for integration with enterprise data interfaces or other data sources.

## 3.4 User Interface

DSS user interfaces have evolved over time. Early DSS spent substantial development time and resources on the user interface. However, general user-interface work at Xerox Parc translated into generally applicable user interfaces. For example, as the Windows operating system and software evolved from DOS (disk operating system), to Windows 3.1, to Windows 95, to Windows 98, to Windows 2000, and to Windows XP or even Windows Vista, the user interface is increasingly built into the operating system capabilities and basic software capabilities. As another example, Microsoft Excel provides the ability to generate pie charts, bar charts, and many other capabilities. Furthermore, even enterprise software companies like SAP are integrating their software with Microsoft Office applications (Ferguson 2006) in order to make it easier for users and to leverage user-interface capabilities more fully. Accordingly, fewer special user-interface capabilities are needed for DSSs developed for those environments.

As DSSs migrate to mobile computing environments, user interfaces will continue to evolve. For example, mobile computing environments such as phones or other devices provide smaller screens and have different keyboards and other human-computer interfaces.

## 3.5 Application Evolution

DSS evolution includes the particular application and software for which the system is designed. One of the few and best examples of application evolution in the literature is Rao and Turoff's (2000) analysis of the evolution of medical decision-making DSSs. An extensive analysis of the problem domain for which the DSS was constructed is presented. Through the analysis of a number of systems, the authors trace the evolution of a number of key system medical support characteristics, including:

- Nature of support (clinical versus diagnosis)
- Information nature (detailed and complex versus not detailed and not complex)
- Information currency and stability (highly current versus highly noncurrent, and dynamic versus static)
- Reasoning (abstraction versus causal)
- Medical group interaction (high versus low)
- Nature of tools (qualitative versus quantitative)

In addition, the systems are analyzed according to collaborating multiple-decision-making features and supporting group DSS features. For example,

| | |
|---|---|
| Temporal representation | Customizable temporal markers |
| Prior research/ factual reference | Supports hypertext |
| Knowledge base interaction | Supports rule-based knowledge |
| Multiple-criteria decision making (MCDM) | Supports MCDM tools |
| Individual decision making styles | Encourage individual participation (e. g., pen names, conference areas) |

# 4 Knowledge Evolution

Increasingly, DSSs have knowledge embedded within them and use knowledge-based artifacts. As a result, as DSSs evolve, the underlying intelligence on which they are based and these knowledge artifacts also need to change, and knowledge evolution is a critical part of DSS evolution. The remainder of this section focuses on that knowledge evolution.

Decision support systems are likely to use many different kinds of knowledge, each with their own unique characteristics. Because there are many forms of knowledge representation, we cannot discuss each of the different kinds of knowledge. However, we will discuss a few types of knowledge to illustrate some of the evolutionary issues associated with knowledge evolution, including process knowledge, taxonomy knowledge, ontology knowledge, associative knowledge, and general discovered knowledge.

## 4.1 Process Knowledge

There has been some interest in the evolution of process knowledge. For example, Pan et al. (2006) discuss the evolution of customer-relationship-management process knowledge. Further, Zhuge (2005) discusses the evolution of the flow of knowledge through an enterprise. Formalization of process knowledge in computer-based systems can take many forms. One example of a formalization of process information is that of RosettaNet and their partner interface processes. RosettaNet partner interface processes (PIPs) are specialized system-to-system extensible markup language (XML)-based dialogs that define business processes between trading partners. Each PIP specification includes a business document with the vocabulary, and a business process with the choreography of the message dialog (http://xml.coverpages.org/rosettaNet.html). PIPs are organized into seven clusters, or groups, of core business processes that represent the backbone of the trading network. Each cluster is broken down into segments – cross-enterprise processes involving more than one type of trading partner. Within each segment are individual PIPs (http://xml.coverpages.org/rosettaNet.html).

PIPs are formally categorized in a life cycle with a number of different potential states that enable us to ascertain formally where they are in their evolution:

- On hold
- In production
- Waiting validation
- In validation
- Obsolete
- Versioned

In addition, the PIPs are each attributed a version number, e. g., V01.00.00, so that evolution and change of the knowledge over time can be captured and versions controlled. As corporate processes change over time, PIPs can also change. Furthermore, PIPs can move from one state and back to another. A PIP that is versioned can still become obsolete and be replaced.

Similar models of knowledge versions can be used with other types of knowledge. Still other forms of process knowledge might be captured, indexed, and stored using taxonomies.

## 4.2 Taxonomy Knowledge

Another frequently used form of knowledge representation is the taxonomy. For example, the APQC (1996) and the Arthur Andersen taxonomy are used to capture, index, and store knowledge about processes. Apparently based on the taxonomy framework, information about business process is categorized to a number of different levels within the taxonomy. Within each of the categories, knowledge such as case studies and key performance indicators are stored for users. O'Leary (2004 and 2007) documents empirically the evolution of the APQC taxonomy into different artifact versions available over time from different sources.

### 4.3 Ontology Knowledge

Recently, ontologies have attracted substantial attention, perhaps more than any other knowledge representation. Ontologies also provide a key basis on which to index, capture, and search knowledge. The evolutionary change of knowledge has been categorized as an impediment to ontologies by O'Leary (1997). As a result, it is not surprising that ontologies evolve over time. There is a growing literature concerned with evolving ontologies (e. g., Haase and Stojanovic 2005) and ensuring that those ontologies are consistent (e. g., Haase et al. 2005) even in environments where the ontology is shared (Xuan et al. 2006).

Although ontologies are closely related to database schema, Noy and Klein (2004) argue that there are important differences. However, they use previous research on schema evolution to provide insight into ontology evolution. Ultimately, the set of change operations that they develop is different than database schema evolution.

### 4.4 Association Rules and Evolution in Time

Association rules provide relationships between different objects in an available database, e. g., height and weight, or smoking and illnesses. Golani and Etizion (1999) and Koundourakis and Theodoulidis (2002) explore how such rules can evolve over time. For example, changes in tax law will lead to evolution from the old to the new rules. Similarly, as individuals age, rules will need to change to reflect the changes associated with getting older. To understand and capture this evolution requires periodically refitting of the rules to data gathered over time. Issues related to the association rules, such as the confidence level, can be tracked as part of the evolution process of the association rules.

### 4.5 Discovered Knowledge

Since the early 1990s, knowledge discovery has been an important research area. Discovered data is dependent on the particular data analyzed. Discovered knowledge changes over time, as more or different data is analyzed. As a result, discovered data is not necessarily backward compatible. Instead, as the data on which knowledge is based changes, the knowledge is also likely to change. This is not unexpected. As an example of research in this area, Yoon and Kerschberg (1993) present a framework for evolving knowledge as the data in the database evolves.

## 5 Predicting and Facilitating Knowledge Evolution

Given that evolution will occur, one concern of this chapter is to try to predict and facilitate that evolution to manage the DSS. The same issues of prediction and facilitating technology evolution occur with every aspect of DSSs. For example, we would like to be able to predict and facilitate the technology or knowledge evolution of DSSs. As a result, some of the same approaches used here can also be applied to other components.

## 5.1 Predicting Knowledge Evolution: An Empirical Approach

We see that knowledge and other DSS components evolve, which raises the question: can we predict evolution or the effects of evolution? One of the primary assumptions made by O'Leary (2004 and 2006) is that we can predict how taxonomy knowledge will evolve. As a result, O'Leary (2004 and 2006) focused on knowledge in the form of taxonomies and thus with taxonomy evolution. A number of different approaches were employed to try to analyze taxonomy evolution change empirically, with the goal of predicting its evolution.

O'Leary (2006) gathered various kinds of quantitative information about the taxonomy changes associated with different taxonomy artifacts. A number of empirical approaches were used to analyze that data. For example, entropy was used to measure complexity, and it was found that, as the taxonomy evolved, entropy increased. As a result, taxonomy changes would be expected to result in greater entropy. Accordingly, using various empirical relationships, such as this, future states of the taxonomy might be predicted from past relationships.

## 5.2 Predicting and Facilitating Knowledge Evolution Using Genetic Algorithms

Rather than taking an indirect approach of predicting evolution, based on its past evolution, perhaps it is possible to directly predict and facilitate evolution. Genetic algorithms (GAs) mimic the evolutionary approach of natural selection in nature. As a result, conceptually we could use GAs to mimic DSS evolution across its different components or even treat the components as a whole for evolution.

GAs keep a set of solutions, typically as strings, that can be used to create new solutions. Based on those strings, GAs use a number of operators as a basis of simulating evolutionary factors, including mutation and crossover (also called recombination). The resulting children can then become a part of the population used to create new solutions that evolve toward different system configurations.

How might this be done with respect to knowledge embedded in a DSS? One approach is to focus on a particular form of knowledge representation. O'Leary (2007) found that entropy captured taxonomy change information. As a result, entropy might be used to measure the quality or fitness of different proposed solutions. Further, O'Leary (2007) also found that taxonomy categories experienced a number of different operations over time as taxonomies evolved. Taxonomy categories were

- aggregated
- disaggregated from other categories
- eliminated
- added

These taxonomy category operations could be embedded within the context of a genetic algorithm approach to evolving taxonomies. There a number of ways of capturing these category operations. An example approach could be as follows. Let a two-level taxonomy, with one primary level (*I*) and three sub-items (*A*, *B*, and *C*), be represented by a sequence ($x_1$ $x_2$ $x_3$ $x_4$ $x_5$ $x_6$ $x_7$ ) where ($x_1$ $x_2$ $x_3$ $x_4$ ) = (1,1,1,1,0,0,0) means that the primary item and the three sub-items are included. ($x_5$ $x_6$ $x_7$ ) could then refer to the aggregations *I-A* and *I-B*, *I-B* and *I-C*, and *I-A* and *I-C*. The original taxonomy would then be (1,1,1,1,0,0,0). Elimination of item *I-C* would result in the replacement of the 1 with a 0, (1,1,1,0,0,0,0). Aggregation of *I-A* and *I-B* would yield (1,0,0,1,1,0,0). Given these sequences we could use a genetic algorithm approach to creating and choosing new sequences.

Koza (1997) provides a generic approach that could be used to facilitate evolution in the following three steps:

1. Generate an initial population of taxonomy elements, for example, two taxonomies

$x_1\, x_2\, x_3\, x_4\, x_5\, x_6\, x_7$

$y_1\, y_2\, y_3\, y_4\, y_5\, y_6\, y_7$

2. Iteratively perform sub-steps using the following rules:

Reproduction (maintain the same strings)

$x_1\, x_2\, x_3\, x_4\, x_5\, x_6\, x_7$

$y_1\, y_2\, y_3\, y_4\, y_5\, y_6\, y_7$

Crossover (create new strings)

$x_1\, x_2\, x_3\, x_4\, x_5 \mid y_6\, y_7$

$y_1\, y_2\, y_3\, y_4\, y_5 \mid x_6\, x_7$

Mutation (change an item with small probability)

$x_1\, x_2\, x_3\, y_4\, x_5\, x_6\, x_7$

3. Using some approach to determine which constructed strings are most appropriate, choose and continue cycling, or finish. Fitness measures such as entropy might be used to provide such a measure or it could be based on user-specified design requirements.

Although this approach clearly needs additional development and empirical testing, it does suggest that genetic algorithms could be used to predict or facilitate knowledge evolution by providing a potential evolved taxonomy or system structure.

## 5.3 Facilitating Knowledge and Preference Evolution Using Intelligent Agents

User preferences shift over time as the user better understands the problem, the system, and the two in context. Enembreck and Barthes (2003) and others have proposed using intelligent agents to facilitate a continuous adaptation to user preferences, e. g., in Web environments. In this approach, intelligent agents can monitor the use of the system to better understand user preferences. Agents can gather data about how users use or do not use knowledge, or about user preferences.

A similar approach can be used to understand the need to evolve and to facilitate DSS evolution. Agents can be used to gather information from users explicitly. For example, agents could be used periodically to query users as to whether or not the system was meeting their needs, and what changes would be helpful. This analysis could leverage specific information that the users have about the system and potential changes.

Agents could also be used implicitly to facilitate evolution. For example, agents could watch and keep track of which features and capabilities are and are not being used. If a feature or capability is being used extensively, then that can indicate that it is an area of the system that could be extended. If a feature is not being used or is only being used on occasion, then the user is not that aware of this feature or capability, this feature is not necessary, or this feature needs improvement and change. As a result, agents could be used to signal a need for evolution.

## 5.4 Predicting and Facilitating DSS Evolution Using the Delphi Method

The Delphi method is designed to try to predict the future. It does so by asking multiple experts what they think will happen in the future. As the approach is used, an understanding of the expected future is attained, and then fed back to the same experts to see if any other perceived or expected changes are found, based on the feedback. The Delphi approach can also be useful in facilitating an understanding of what is likely to change and how to facilitate that change.

The Delphi method has been used previously in conjunction with knowledge-based systems. Roth and Wood (1990) used the Delphi approach to help elicit knowledge for a knowledge base. They found that it was an important tool for generating additional knowledge over and above that available to a single expert.

Multiple experts generated many more ideas, suggesting that it was important to involve multiple experts in knowledge acquisition.

In terms of DSS evolution, the Delphi method could be used to capture expert or user assessments as to which system features or capabilities could be changed and how that revised system could look. Experts and users could be asked what knowledge they expected to be different or relevant and what knowledge was missing from the existing system. The Delphi method could also be used to anticipate which technologies could be integrated into a DSS to extend and evolve the system.

# 6 Summary and Contributions

This chapter has investigated DSS evolution and how to manage that evolution through predicting and facilitating evolution.

## 6.1 Summary

This chapter investigated notions of evolution in DSSs. We defined evolution, and the characteristics of evolution, such as backward compatibility, measuring evolution, and why we would expect DSSs to evolve. In addition, we investigated issues of backward compatibility, determining if evolution has occurred and whether evolution is always a formal process.

The previous research on DSS evolution was also investigated. Research on each component was summarized and in some cases extended. Based on an analysis of that literature, the weakest point in current studies seems to be evolutionary studies of particular application types and in the evolution of knowledge. As a result, this chapter investigates knowledge evolution as it might be construed in a DSS in more detail. The chapter also investigated issues such as the prediction of evolution, e. g., the knowledge in a DSS, and trying to facilitate evolution of a DSS, using e. g., Delphi and genetic algorithm approaches.

## 6.2 Contributions

This chapter extended the notion of evolution to DSSs as a bundle and as a set of components, and brought together and extended some of the research on DSS evolution. We also noted that evolution can occur actively or passively. In the case of active evolution, we can predict and facilitate evolution as part of the management of evolution, whereas DSS evolution happens alone in the passive case. Both types of DSS evolution will exhibit emergent behavior, but our primary means of tracking evolution will be through artifacts, because of the general lack of backward compatibility.

In some cases, there has been substantial research in the analysis of the evolution of particular components of DSS, e. g., databases, technologies, ontologies, etc. However, there has been limited research addressing how DSSs are affected by evolution.

This chapter has provided some tools and methods that can be used to predict the evolution of different components, e. g., knowledge. The Delphi method was suggested as a means to predict the evolution of all the different types of components, including the technology on which DSSs are based. Genetic algorithms were also considered as a basis to try to evolve DSSs. Intelligent agents were seen as a tool to gather data or knowledge about the user and use it as a means of understanding how the parameters in a DSS or even its components might need to change to accommodate the user.

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# PART IX

# Decision Support Cases and Applications

# CHAPTER 54
# Systems for Supporting Operations Management Decisions*

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This chapter surveys the state of the art of decision support systems (DSSs) for operations management (OM) with the intent to highlight the important role that DSSs play in facilitating decision processes in OM. Organized along the temporal dimension of OM decisions, our discussion starts with DSSs for long-term OM decisions including operations strategy, capacity planning, location planning, product/process design and design/manufacturing integration. This is followed by a discussion on DSSs for medium- and short-term OM decisions on production planning and control that includes systems such as communication-oriented production information and control systems, material requirements planning, manufacturing resources planning, distribution requirements planning, enterprise resources planning, and operations/project scheduling. After a brief discussion on DSSs for service operations, we conclude our book chapter by providing some perspectives on future development in DSSs for OM.

**Keywords:** Computer integrated manufacturing; Enterprise resource planning; Material requirements planning; Material resources planning; Operations management; Production; Scheduling; Service operations

## 1 Introduction

Operations management (OM) deals with the effective and efficient production of goods and services that involves making intricate decisions in the design, operation, and improvement of various production activities. Technological aids in the form of decision support systems (DSSs) are crucial in tackling the interdependent and complex nature of these OM decisions. This chapter surveys the state of the art of DSSs for OM and discusses the design and implementation issues of these systems. It also provides some perspectives on the future development of such systems.

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* This chapter is adapted from Chung (2003), Encyclopedia of Information Systems, volume 3, pp. 391-402.

## 1.1 Operations Management Defined

Operations management is concerned with the economical use of inputs (human resources, capital, materials, and so forth) in a transformation process whose outputs are goods or services. Thus, OM involves decision making on how to best design and operate an operations system, generally referred to as production system. The term *production system* includes organizations that manufacture (tangible) products or provide (intangible) services. Examples of the latter are hospitals, banks, entertainment industries, government agencies, charity organizations, and restaurants.

## 1.2 Key Decisions in Operations Management

Figure 1 outlines key decisions in OM and the roles played by DSSs in providing aids to these decision-making processes. It should be noted that the OM system depicted in Figure 1 is applicable to both manufacturing and service contexts. Furthermore, all these OM decisions will also be encountered in global operations settings. The categorization of decisions into long, medium, and short terms is simply for the convenience of discussion. Although these decisions correspond to the strategic planning, tactical planning, and operational control activities in a firm, the time horizons for long, medium, and short terms are usually defined in a relative sense. Naturally, all temporal decisions in the OM system will have impacts on other decisions within or across time horizons.

Figure 1 shows that DSSs can play an important role in facilitating decision processes for all categories of OM decisions. While all planning activities require past data as well as forecasts of future events (e.g., demand forecasts), knowledge-based DSSs are essential to provide decision and planning aids.

The long-term decisions in the OM system basically deal with operations strategy, product planning, and the design of facilities and processes. Issues to be addressed include what to produce (product planning), how to produce (process planning), how much can be produced (capacity planning), and where to produce (location and layout planning). The medium- and short-term decisions are concerned with planning and control of production activities.

In the following sections, our discussion is organized according to these temporal decisions. After addressing the issues associated with the DSSs for operations strategy, we discuss decision support for the design of facilities and processes, followed by discussion of operations planning and control systems. We then briefly address the issues in decision support for service operations. Finally, we conclude by providing perspectives on future development in DSSs for operations management.

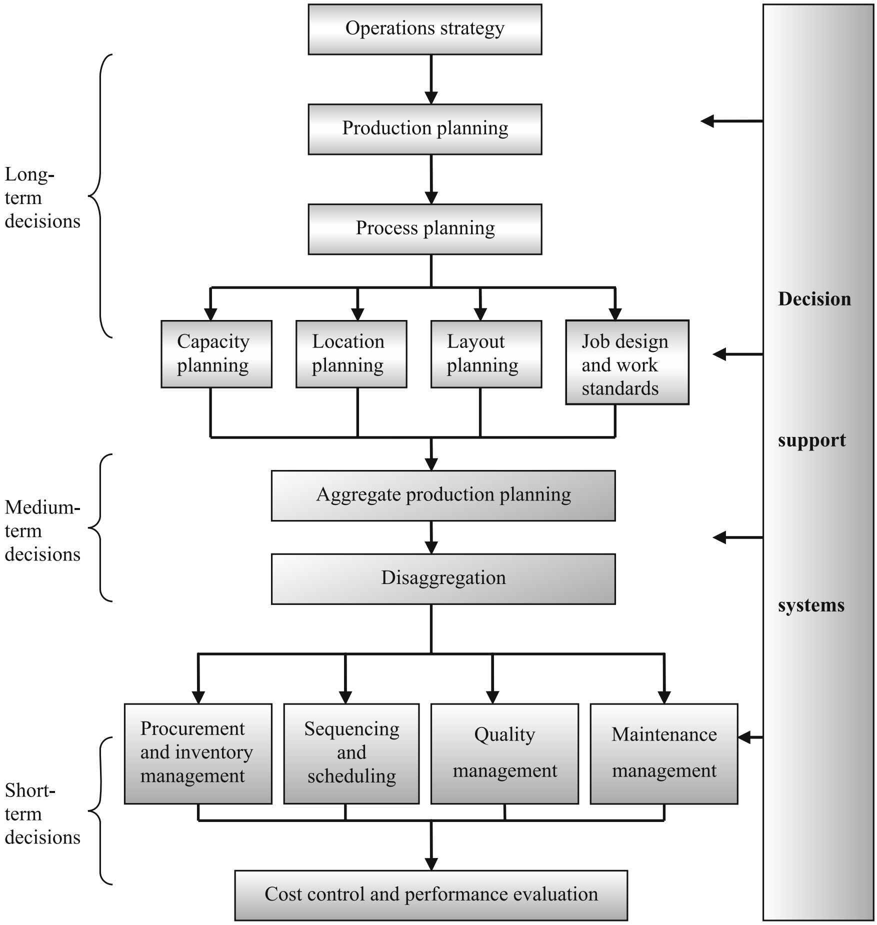


**Figure 1.** The operations management system

## 2 Decision Support Systems for Long-Term OM Decisions

As shown in Figure 1, in addition to operations strategy, long-term OM decisions include product and process planning. Process planning can be further broken down into capacity planning, location planning, layout planning, job design, and the establishment of work standards. Generally speaking, these decisions are not independent of each other. However, there has been no DSS developed for addressing these decisions simultaneously. Our discussion, while identifying the need for integrating these decisions, focuses on DSSs for individual problem areas.

## 2.1 Decision Support for Operations Strategy

Operations strategy is concerned with setting the long-term direction of a firm's operations function to best support its overall corporate strategy. This does not mean that operations strategy should always assume a subordinate, reactive role in the corporate strategy. On the contrary, operations strategy quite often dictates a firm's corporate strategy. Either way, a firm's operations strategy needs to be integrated with its corporate strategy.

Skinner (1969) first introduced the concept of manufacturing strategy and suggested that the manufacturing function can provide a firm with formidable competitive potential. A similar conclusion is equally applicable to the service sector. Stalk et al. (1992) point out that competition is a war of movement in which success depends on anticipation of market trends and quick response to changing customer needs. Successful competitors move quickly in and out of products, markets and sometimes, businesses – a process more akin to an interactive video game than chess. In such an environment, firms are actually competing on the basis of information. To compete successfully one must gather information about market and competitive conditions quickly, rapidly analyze and make decisions based on available information, and deploy resources to implement corporate strategy in a timely manner. Indeed, the importance of providing information and decision support to the development and implementation of corporate/operations strategy can never be over-emphasized.

There are two (not necessarily mutually exclusive) types of operations strategy. The first type involves decisions that relate to the design of a process and the infrastructure needed to support the process. Process design decisions involve the selection of technology, the capacity of the process, the location and layout of the process, and so forth. The infrastructure decisions include the development of the planning and control systems, quality management systems, the organization of the OM functions, and so on. The other type of operations strategy refers to the firm's competitive strategy in which operations will play a key role. For example, the so-called activities-based strategy, capabilities-based strategy, and time-based competition (TBC) are considered operations strategies.

Although strategic decision support systems (SDSSs) have received substantial attention in the literature, very few SDSSs are specifically designed based on a particular competitive strategy (Keefer et al. 2004, Eom et al. 1998). While a general SDSS may have the advantage of being flexible, a support system that is developed based on a particular competitive strategy will better facilitate the implementation of that strategy. Cook et al. (1998) incorporate a TBC model called CCP – change, causation, and possibility – in an SDSS. The CCP model is a cycle of three-stage tasks. The environmental scanning model of the SDSS is to constantly monitor the changes in both the firm's external and internal environments. Diagnostic problem-solving systems or expert systems perform causal analysis on the relevant and significant changes detected in the first stage. Based on the results of causal analyses, creativity facilitation systems and scenario planning systems will then search for meaningful changes and the associated possible scenarios. Scenario-driven planning (SDP) process paves the way for implementation of (TBC-based) operations strategy.

Recently a pharmaceuticals manufacturer in Europe adopted a Web-based knowledge management system called the collaborative manufacturing strategy system (Co-MASS) to assist its strategy formulation decisions involving 15 managers from dispersed locations (Karacapilidis et al. 2006). The system has four basic modules: a generic strategic reference module, a problem-specific argumentation module, a dialogue management module, and an alternatives evaluation module. The generic strategic reference module supports the strategy-making process by providing a methodology such as a strategy map to move the process forward. The problem-specific argumentation module provides a mechanism (e. g., a common language among participants) to share meaning, promote understanding, and integrate individuals' knowledge domains. The dialogue management module manages the interaction between the system and the participants. The alternatives evaluation module employs a specific evaluation algorithm that converges divergent opinions into agreeable action items. After using Co-MASS for a year, the company credits the system's collaborative strategy-making support to sustaining its rapid growth in the highly competitive pharmaceuticals market.

## 2.2 Decision Support for Capacity Planning

The planning and management of capacity in a firm can occur at various levels. The long-term capacity decision basically deals with planning the capacity of facilities, while the medium- and short-term capacity decisions deal with planning the availability of human resources. Certainly, the distinctions among long, medium, and short terms can be arbitrary and debatable. Also, these temporal decisions are not independent of each other.

The long-term decisions concerning capacities of facilities are often treated as capital investment or capital budgeting problems. Returns on investment, payback periods, and so on are the major concerns. On the other hand, the long-term capacity decisions and the relevant DSSs are inseparable from the firm's strategic planning process (Hammesfahr et al. 1993).

The capacity decisions are also inseparable from the firm's product mix decisions and other operational considerations. For example, Berman and Hood (1999) report a capacity optimization planning system (CAPS) for semiconductor manufacturing. The system consists of detailed discrete-event simulation models which can help decision makers understand the interactions between line throughput, product mix, tool utilization and classes of production (e. g., standard versus expedited jobs). Such simulation capabilities can help decision makers set tool utilization and buffer targets and understand the relative value of dedicated tools and reserve capacity.

## 2.3 Decision Support for Location Planning

Location decisions are important for both manufacturing and service industries in both the public and private sectors. For reviews of issues and research in location planning, see Brandeau and Chiu (1989), Revelle and Laporte (1996), and Schilling et al. (1993).

Many solution methods reported in the literature can be incorporated into DSSs for location decisions. For example, Narasimhan et al. (2005) present a DSS for service location design for an agency in the state of Michigan. The DSS incorporates a number of factors such as branch office efficiencies based on multiple measures, budget restrictions, capacity limitations for processing transactions, and demand requirements. Both data envelopment analysis (DEA) and mixed-integer programming (MIP) models are employed in the system.

## 2.4 Decision Support for the Design of Facilities and Processes

The design of facilities and processes actually starts with product planning. Product and process engineering are usually inseparable. This is particularly true when the so-called concurrent engineering (CE) approach is used. Rather than a simple serial process in which the design project proceeds from one phase to another, CE emphasizes cross-functional integration and concurrent development of a product and its associated processes. Facility and process design sets the stage for making job-design and work-standard decisions that include questions such as: What is the job description? Who does the job? Where is the job done? Should the job be automated? How long does it take to do the job? These decisions have significant impacts on an organization's productivity, quality of work life, and other strategic goals.

## 2.5 From Product/Process Design to Computer-Integrated Manufacturing

There are many software programs available for facilitating the product/process design activities. For example, quality function deployment (QFD) and value analysis/engineering (VA/VE) software helps design engineers identify customer requirements, technical characteristics, ways to eliminate unnecessary costs, and so forth. On the other hand, computer-aided design (CAD) is an approach to product and process design that utilizes the power of the computers. Computer-aided engineering (CAE) is the process that helps the evaluation of the engineering characteristics. Computer-aided manufacturing (CAM) applies computers and microprocessors to direct manufacturing activities. Computer-aided process planning (CAPP) is used to design the computer part programs that serve as instructions to computer-controlled machine tools, and to design the programs used to sequence parts through the machine centers and other processes needed to complete the parts. CAPP bridges the gap between CAD and CAM. Basically, CAPP determines how to convert a product design into the final form of the manufacturing product. Different volume representations and decompositions entail variations in such factors as cutting paths, machine tools, setup, and machining costs. Thus, the actual manufacturing activities and related tool requirements are greatly affected by CAPP. All of these automated technologies, and other hardware systems such as computer numerically controlled (CNC) machines, automated materials-handling (AMH) system, automated storage and retrieval systems (AS/RS), automated guided-vehicle (AGV) systems, and flexible manufacturing systems (FMS) are brought together under the notion of computer-integrated manufacturing (CIM).

An important issue in planning production processes is the layout of production facilities. The early programs developed to facilitate layout planning include CRAFT (Buffa et al. 1964) and CORELAP (Lee and Moore 1967). These are programs for optimizing layouts. They were developed well before the DSS concept was born. Over the past two decades, there have been sporadic reports on DSSs for facilities layout planning. Arinze and Cheickna (1989) proposed a methodology for knowledge-based decision support for layout planning. The methodology aims at facilitating the selection of an appropriate layout planning model from the knowledge base. Lee et al. (1996) report a DSS for work station arrangement in a single-vehicle closed-loop AGV system. Such a DSS helps in the determination of optimal workstation sequences. Foulds (1997) proposed a microcomputer-based DSS, called LayoutManager, for facilities layout design. The DSS is developed to aid layout planners in the mechanical assembly area of a manufacturer of printed circuit boards. Although the LayoutManager contains various DSS features, it is not readily transferable to other layout planning settings, such as the cross-docking operations. Tam et al. (2002) proposed a nonstructural fuzzy DSS for site layout planning in construction projects. Again, this is a DSS for a specific layout planning setting, rather than a DSS for layout planning in general.

As the operating environment and parameters change, layouts need to be improved to accommodate changes. This is the so-called dynamic layout planning problem. It can also be extended to the concept of agile facility design in the context of agile manufacturing (Ashley 1997, Emigh 1999). DSSs for layout planning should provide firms with a mechanism to experiment easily with different layouts so as to achieve improvements. Winarchick and Caldwell (1997) present an interactive simulation tool that can be used to try out different layouts. Azadivar and Wang (2000) develop a layout optimization procedure using both simulation and genetic algorithms. Genetic algorithms have proven to be quite effective and popular for supporting design facility layout decisions (e. g., Islier 1998, Rajasekharan et al. 1998, Suresh et al. 1995). They are particularly powerful when incorporated into simulation models. Hauser and Chung (2006) also incorporated genetic algorithms into experimenting with facility layouts for improving cross-docking operations. Hauser et al. (2006) report a DSS that combines genetic algorithms with simulation for the above layout improvement in the cross-docking environment.

There are two basic types of layout planning problems: product versus process layouts. The layout planning problems and the support systems reviewed above are so-called process-layout planning problems. A typical example is facility-layout planning in job shops. Line balancing is another type of layout-planning problem known as product-layout design. While there is rich academic research literature on the dynamic line-balancing problem (Ghosh and Gagnon 1989), support systems for designing and rebalancing assembly lines mostly come from commercial products (e. g., SIMUL8, FlexLink, Proplanner).

### 2.6 Virtual Factory

Although known as integrated, CIM is usually a collection of various automated technologies. A truly integrated system places more emphasis on the interfaces among technologies, functions, and programs. This is particularly crucial for the case of the virtual factory. The term virtual factory refers to manufacturing activities carried out not in one central plant, but rather in multiple locations by suppliers and partner firms as part of a strategic alliance. In this setting, it is essential for the virtual manufacturer to have a deep understanding of the manufacturing capabilities of all parties in the production network. An integrated information system becomes crucial to the success of carrying out the difficult task of coordination. The virtual factory concept also paves the way for the development of supply chains management concepts.

## 3 Decision Support Systems for Planning and Control of Operations

The medium- and short-term decisions in an OM system (Figure 1) deal with a firm's production planning and operational control activities. In this section, we discuss the evolution of DSSs for such activities – from the early communication-oriented production information and control system (COPICS) by IBM to the most recent developments in enterprise resource planning (ERP) systems.

### 3.1 Communications-Oriented Production Information and Control System

In the early 1970s, IBM developed the COPICS integrated computer-based manufacturing system. COPICS is oriented to production and related applications. It also provides data to other functional areas such as sales, finance, personnel, design, research, and quality assurance. COPICS is built around a database creation and maintenance system that permits easy file reorganization when system changes occur. Data can be reorganized without incurring the significant expense of modifying existing programs that will have to use the new files. Data duplication is thus significantly reduced. This also leads to reduction in data storage and maintenance costs as well as computer processing time. Real-time processing is another essential feature of COPICS. Data are transmitted online, that is, by means of terminals linked directly to the computer. Records are updated immediately after a transaction occurs. Consequently, the system is in position to respond (if a response is required) without the usual delay inherent in periodic batch processing.

The applications covered by COPICS range from engineering and production data control to cost planning and control. Because COPICS was developed before the maturation of DSS concepts, it basically aimed at providing timely information (rather than supporting decisions) for planning and controlling manufacturing activities. Because COPICS involves substantial data processing, it needs to be run on mainframe computers. This was a technological constraint in the 1970s. The rapid advances of computer and information technologies during the past two decades resulted in shifting most applications away from mainframe computers. Although COPICS offers information rather than decision support, its basic principles provide the foundation for later developments in material requirements planning (MRP), manufacturing resources planning (MRP II), and ERP. Growing emphasis on decision support is found in these later developments.

## 3.2 Material Requirements Planning

A material requirements planning (MRP) system is a massive information system that performs detailed planning for the timing and sizing of material (e.g., components and parts) requirements. Its objective is to provide the right part at the right time to meet the schedules for completed products. An MRP system generates the production and/or procurement plans for each part number, including raw materials, components, and finished goods. Based on a time-phased (i.e., stated on a period-by-period basis) master production schedule (MPS), an MRP constructs a time-phased requirement record for any part number. The data can also be used as input to the detailed capacity planning models. The MRP logic is based on the basic accounting procedures for calculating inventory balances. For any single item (part number), the gross requirements (i.e., the anticipated future usage of or demand for the item) in a period is subtracted from the sum of beginning inventory and scheduled receipts. The result is the projected available balance for the item at the end of that period. If this projected on-hand balance shows a quantity insufficient to satisfy gross requirements (i.e., a negative quantity), acquisition of additional material must be planned. This is done by creating a planned order release in time to keep the projected available balance from becoming negative. The planned order release is created by a procedure called lead-time offset, which calculates the planned order release date by subtracting the lead time from the projected shortage date (Orlicky 1975).

This basic MRP logic provides the correct information on each part in the system. Linking these single-part records together is essential in managing all the parts needed for a complex product or customer order. MRP uses a gross-to-net explosion procedure to translate product requirements into component part requirements. Explosion is the process of determining, for any part number, the quantities of all components needed to satisfy its requirements and continuing this process for every part number until all purchased and/or raw material requirements are exactly calculated.

As mentioned earlier, an MRP system is a massive information system. Vollmann et al. (1998) point out that "the enormity of the overall data base even for small firms is awesome." In addition to basic files such as the item master file, the bill-of-material file, the location file, the calendar file, and open order files, an MRP system also needs to link to other data files in related areas such as forecasting, capacity planning, production scheduling, cost accounting, budgeting, order entry, shop floor control, distribution invoicing, payroll, job standards, and engineering. Indeed, an MRP system cannot be run in an isolated fashion.

## 3.3 Manufacturing Resources Planning

A stand-alone MRP system is usually insufficient for effective planning of production activities. Additional supporting functions are needed. An MRP system with augmented front and back ends is called a manufacturing resources planning (MRP II) system or a manufacturing planning and control (MPC) system (Wight 1984). The front end includes demand management, aggregate planning, and master production scheduling. The back end includes implementation of procurement and inventory management, priority management [e. g., sequencing and (re)scheduling, dispatching], and short-term capacity management. A general framework for an MRP II system with an extension to decisions in an automated manufacturing system (AMS) environment is depicted in Figure 2.

The right half of Figure 2 consists of the traditional MPC or MRP II system. Aggregate planning (AP) and master production scheduling (MPS) comprise the front end of most production/operations planning and control systems. In aggregate production planning, management is concerned with determining the aggregate levels of production, inventory, and workforce to respond to demand fluctuations in the future. Chung and Luo (1996) present a decentralized approach for production planning in an FMS environment. An organizational decision support system (ODSS) architecture (George 1991, George et al. 1992, King and Star 1990) is used for supporting the implementation of the decentralized approach.

The aggregate plan provides an overall guideline for master production scheduling, which specifies the timing and sizing of the production of individual (end) products. The master scheduler takes the aggregate decisions as targets and tries to achieve them as much as possible. Ideally, the sum of production (inventory) quantities in the master schedule over a time period should equal the aggregate production (inventory) quantities for that time period. However, deviations may

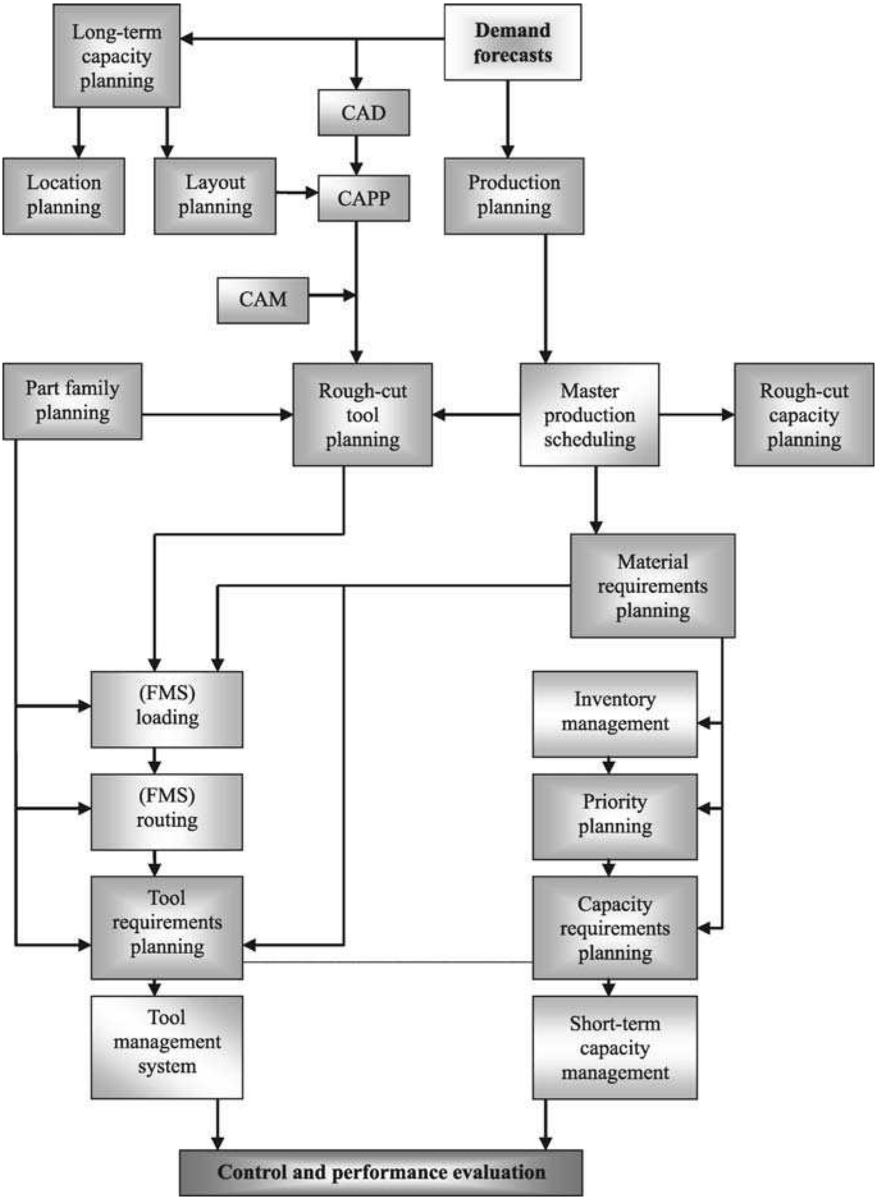


**Figure 2.** Manufacturing planning and control systems in traditional and automated manufacturing environments

occur due to considerations such as capacity limitations at critical work centers. Feedback from actual master scheduling performance provides information for modifying future aggregate plans. To be feasible and acceptable, a master production schedule should meet the resource constraints at critical work centers. This feasibility check is called resource requirements planning (RRP) or rough-cut capacity planning (RCP). If the RCP indicates potential infeasibility at some critical operations, either the master schedule is revised to accommodate these capacity limitations or a decision is made to maintain the master schedule and implement adjustments to the capacities at relevant work centers. This may also require adjustments to the long-term capacity plan or the aggregate plan.

After the feasibility check via RCP, the feasible and acceptable master schedule becomes an authorized master schedule and can be further broken down into detailed schedules with the use of lower-level planning and scheduling systems such as MRP. An MRP system determines the timing and size of the production of components and parts. It also serves as the basis for detailed inventory management (e. g., procurement and materials control), priority planning (e. g., sequencing and scheduling), and capacity planning. In RCP, the estimation of capacity requirements is based on the MPS information. The capacity requirements planning (CRP) activity, on the other hand, utilizes the information generated by the MRP system, including open orders and planned order releases. CRP also takes into consideration the current status of all work-in-process inventories in the shop. Thus, CRP provides a more-accurate account of the capacity requirements than does RCP.

The left half of Figure 2 deals with important decisions in an AMS environment. Earlier, in Section 2.5, we discussed CIM-related tools or software such as CAD, CAM, and CAPP. Quite often, it is desirable to pool operations with common tool requirements in AMS. Parts family grouping (PFG) is desirable for the purpose of loading flexible manufacturing systems (FMS) and planning tool requirements (Chung 1991). This practice is consistent with the group technology (GT) philosophy, which groups dissimilar machines into work centers (or cells) to work on products that have similar shapes and processing requirements. Lee-Post (2000) presents a novel approach to form part families by exploring the nature of similarities captured in an existing classification and coding/part specification scheme. Because the code number/specification of a part represents important descriptive knowledge of a manufacturing engineer about how the part should be designed and manufactured, part families formed based on these code numbers/ specifications can extend the manufacturer's understanding of the subtle similarities embedded in these parts. This enables the manufacturer to exploit the philosophy of GT to the fullest – covering areas of manufacturing, design and process planning.

A routing decision in an AMS environment is concerned with the order in which a part type visits a set of machines. The loading and routing decisions have direct or indirect impacts on the actual tool requirements. Rough-cut tool planning (RTP) is meant to provide a rough estimate of the tool requirements implied by MPS. Figure 2 shows that CRP is the counterpart of tool requirements planning (TRP) in the traditional MPC system. In most AMSs, the actual tool requirements are quite often dictated by the tooling policies in the tool management system (TMS). For an overview of models and DSSs for planning and scheduling in FMS, see Dhar (1991).

## 3.4 Distribution Requirements Planning

MRP logic can be applied to a firm's distribution system. Such an application is called distribution requirements planning (DRP). DRP provides the basis for tying the physical distribution system to the MPC system. Like MRP, DRP is a time-phased, backward scheduling technique that integrates the planning of distribution inventories with manufacturing planning by providing information that identifies need, replenishment, and order dates for material requirements. DRP ties warehousing operations to transportation and reconciles forecast demand with transportation capacity and inventory. Plans derived from the DRP and from the resulting shipping requirements are the basis for managing the logistics system. Thus, DRP facilitates logistic activities such as vehicle capacity planning, vehicle loading, vehicle dispatching, and warehouse receipt planning. When DRP is linked to MRP in a typical manufacturing firm, forecasts can be driven through the organization from distribution to manufacturing and onto procurement. Because the logic and record formats of DRP and MRP are compatible and all MPC modules are linked, DRP allows a firm to extend MPC visibility into the distribution system (Martin 1983).

## 3.5 Enterprise Resources Planning

In the 1990s, MRP II was further extended to deal with engineering, finance, human resources, and other activities of business enterprises. Consequently, the term enterprise resource planning (ERP) was coined. Although, ERP systems are traditionally aimed at handling transactions and producing reports, they do have decision support characteristics and offer decision support benefits (Holsapple and Sena 2001, 2003, 2005). Going forward, this will increasingly be the case as ERP software progresses.

The emergence of local area and global networks enables diverse users to share data and resources. This capability allows firms to go beyond traditional modes of developing systems for individual functional areas in a fragmented manner. Both data and processes can be integrated so that inefficiency in storing redundant data, plus entering and formatting data from one system to another, can be minimized.

ERP intends to integrate and automate various modules (i. e., software) for managing and controlling traditional back-office functions and activities such as finance, human resources, marketing, and operations. When implemented correctly, an ERP system links *all* the areas of the business. Thus, information flows quickly across the value chain. Minimizing redundant data and information processing can lead to substantial savings. Furthermore, many redundant jobs can also be eliminated. With ERP, the firm may be forced to re-engineer its processes so that the business can run more efficiently.

One of the most promising markets for ERP is supply chain management (SCM). A supply chain is the system by which an organization procures raw materials, components, and parts, then transforms them into intermediate and final products, and ultimately delivers the products and services to customers. During the past decade, SCM has rapidly become an information technology (IT) challenge that cuts across business relationships, application infrastructures, and corporate cultures, as well as the complete web of partners (e. g., company employees, suppliers, and customers).

While electronic data interchange (EDI) has been quite effective in supporting supply chain activities, more-integrated, extensive, and dynamic systems are needed as the scope of SCM expands rapidly. Some ERP vendors have recognized such needs and business opportunities. For example, SAP developed an SCM system that consists of three components: an advanced planner and optimizer (APO), business-to-business (B2B) procurement, and a logistics execution system (LES). The APO contains five major application modules:

- The *supply chain cockpit* provides a configurable graphical user interface for modeling supply networks, retrieving information, and event triggers that alert users about pending situations.
- *Demand planning* provides forecasting and planning tools that allow planners to use data warehouse (i. e., the SAP Business Information Warehouse) to develop sales forecasts.
- *Supply network planning* provides optimization and simulation techniques to coordinate activities and plan material flows along the supply chain.
- *Production planning* and detailed scheduling supports multiplant planning, material, and capacity monitoring.
- The *global available-to-promise module* provides the capability for checking multi-level component and capacity availability to match supply with demand.

The B2B procurement provides Web-enabled, real-time procurement of maintenance, repair, and operating (MRO) supplies and services. The LES extends the warehouse management and transportation capabilities of the SAP core system (i. e., R/3).

Another promising technology, which relies on wireless communication to integrate SCM activities effectively by closing information gaps in a supply chain, is radio frequency identification (RFID). A basic RFID system consists of electronic tags, antennas, and readers. A tag is a microchip containing object-identifying and descriptive information of a specific item and its environment such as temperature and location. The stored information can then be transmitted by the tag's antenna to a reader's antenna via radio waves. An in-depth technical discussion of various types of tags and readers can be found in Asif and Mandviwalla (2005).

The ability to uniquely identify and provide information about the state of an object and its environment, with revolutionary speed and without contact or line of sight, has made it possible to track and learn details about everything through every step of the value chain. As a result, RFID applications revolutionize supply chain activities in distribution, production control, warehouse management, logistics, and services. For instance:

- Wal-Mart's top 300 suppliers are using RFID tags on their products for tracking through Wal-Mart's warehouses and stores to further improve Wal-Mart's already efficient distribution system. The use of RFID enables Wal-Mart to build fewer warehouses, lower its inventory levels, and drive down store costs (Hudson 2006).
- Wells' Dairy in LeMars, IA, went beyond applying RFID tags on cases and pallets shipped to Wal-Mart's distribution centers. It implemented a RFID system in its manufacturing process. The information collected by its RFID system has been used to improve its inventory tracking, automate quality control and inventory processes, simplify data collection processes, as well as promote process changes that enhance business performance (Control Engineering 2005).
- Kitchens saved $16.7 million in labor expense and $6.9 million in error reduction by automating the receiving and check-in processes with the use of a RFID warehouse management system (Chappell et al. 2002).
- Proctor and Gamble in Australia, via its Gillette division and supply chain partners, launched a pilot RFID project with Australian academic and government organization to investigate the benefits of sharing RFID-collected data across a consumer goods supply chain. Pallets fitted with RFID tags track movements of goods and share that information among participants throughout the entire supply chain. The supply chain visibility helps reduce pallet inventory, product recalls, and inventory costs (Collins 2006).
- American Express and MasterCard are pilot testing a contact-less payment system that allows customers using RFID cards to checkout of restaurants and retailers such as McDonalds and CVS more speedily and securely (Cho 2004).

These RFID applications yield such benefits as supply chain efficiency and visibility as well as a reduction in stockouts, handling errors, and labor costs (Angeles 2005). No wonder the market for RFID systems in the manufacturing supply chain is projected to grow from $65.8 million in 2003 to $3.8 billion in 2008 (Control Engineering 2004).

## 3.6 Operations Scheduling and Project Scheduling

Gantt charts, named after their inventor Henry L. Gantt during World War I, is one of the oldest scheduling tools that has seen wide application. Gantt charts became the foundation for later development in the network approach to project management such as the critical path method (CPM), and the program evaluation and review technique (PERT).

Gantt or bar charts are also useful for operations scheduling on the shop floor. Typical practice is to use a schedule board to display jobs and their durations. However, operations scheduling is much more complicated than simply showing jobs along time lines. While an operational schedule is a plan with reference to the sequence of and time allocated for each item, or operations necessary to complete the item, many factors need to be considered to develop such a schedule: due dates, work-center resource capabilities (labor and/or machines), availability of materials, job priorities, etc. Numerous sequencing/scheduling rules have been developed. Commercial scheduling software with varying degrees of sophistication is abundant. A typical software package may take advantage of computer technologies such as windowing, graphics, and networks so as to provide easy access to information, what-if analysis, real-time evaluation, (re)scheduling, etc.

De and Lee (1998) developed a knowledge-based operations scheduling system that generates detailed operations schedules to meet user-specified objectives, which are both throughput (e. g., makespan, sum of completion time, weighted sum of completion time) and deadline oriented (e. g., sum of tardiness, maximum lateness, weighted sum of tardiness). The detailed operations schedule includes a policy of releasing jobs onto the shop floor, but also assigns time slots to perform job operations at specified workstations after jobs have entered the shop floor. In addition, the scheduling system is capable of performing exploratory analyses that can be used to examine, for instance, the impact on shop floor performance when the job mix is changed or to determine the delivery schedule for a particular customer order. Finally, the scheduling system provides decision makers with easy access to shop-floor information such as resource utilization, job status, and bottleneck workstations so that preventive maintenance of overused resources can be planned ahead of time.

# 4 Decision Support Systems for Service Operations

## 4.1 Characteristics of Services

Service production differs from manufacturing in many ways. First, services are intangible, while manufacturing has physical outputs from the process. Second, services are produced and consumed simultaneously (Fitzsimmons and Fitzsimmons 1998). Therefore, services cannot be inventoried. Unlike manufacturing, where a firm can build up inventory during slack periods for peak demand and thus maintain a relatively stable level of employment and production plan, in services, demand needs to be met when it arises. Consequently, it is important to plan for sufficient capacity to satisfy customer demand. Third, service operations often require a high degree of personalization, rapid delivery speed, and a certain degree of customer contact and/or customer involvement. Furthermore, the inherent variability of the service encounter makes it difficult to standardize services. As a result of these unique characteristics of services, it is obvious that the need for timely information to support decisions is even greater than in manufacturing.

## 4.2 Decision Support Systems for Service Operations

DSSs for service operations are usually industry dependent. For example, the systems developed for a bank will be quite different from those used in a physician's office, a hospital, or a restaurant. Here, we briefly discuss a few examples.

In the mid-1980s, American Airlines introduced a computerized online reservation system, SABRE. The system has since been not only adopted by the whole industry, but also extended to other travel-related industries. The SABRE reservation system also allows American Airlines to constantly monitor the status of its upcoming flights and competitors' flights on the same route to support pricing and allocation decision making on unsold seats. This is what is called yield management. Today, yield management is practised widely, not only in the airline industry, but also in other industries such as hotels.

Many retail giants have established private satellite networks using small-dish antennae placed on store roofs to receive and transmit masses of data. Such a communication network allows the firm to coordinate multisite operations so as to realize substantial benefits. The instant transmission of rate of sales, inventory status, and product updates provides valuable information in a timely fashion for decision making.

Wal-Mart manages not only one of the world's largest chain of retail stores, but also one of the world's largest data warehouses. It squeezes even more value from these systems with data-mining techniques that will help it replenish inventories in stores. The systems house data on point of sale, inventory, products in transit, market statistics, customer demographics, finance, product returns, and supplier performance. The data can help Wal-Mart decision makers analyze trends, manage inventory, and gain a better understanding of its customers.

Decision makers at Tesco Plc., the largest retailer in Britain, use information about its 12 million customers from a loyalty program called Clubcard to tailor promotions to individual shoppers, offer competitive low prices on items bought regularly by its price-sensitive shoppers, upgrade its product offerings to appeal to affluent shoppers, and assess its strategic initiatives such as the rollout of an ethnic food line called World Foods in towns with large South Asian or Arab populations. The data from its loyalty program helped Tesco boost its market share in groceries to 31%. As a result, its sales jumped 17% to $79 billion and its net income rose 17% to $2.96 billion at the end of February 2006 (Rohwedder 2006).

## 4.3 eService

According to Chase et al. (2000), eService is the delivery of service using new media such as the Web. The spectrum of eCommerce ranges from selling goods with little or no service content to providing (pure) services on the Web. In between, there are value-added services (e. g., online travel agents) and products sold with a high service content (e. g., ordering online customized computers); also see

Section 5.3 for a discussion of E-Ops. Advanced eServices today include online markets, auctions, and online management of customer premise equipment such as routers, media centers, and computers (Gordijn 2006). Boyer et al. (2002) point out the importance of eService as an operating strategy. In the case of an online market, for instance, the market participants interact to reach a joint decision on product disposition, delivery timing, and price; the online system functions as an organizational decision support system in which the organization being a market. In other cases, an eService system may provide information to support the individual decision making of a customer.

FedEx, a leading global shipping and delivery company, has successfully developed and employed a wide spectrum of eServices to meet its customers' needs (Song 2003). Personalized eServices are provided through My FedEx. A customer's specific information including his/her profile, preferences, up to 25 tracking numbers, and most-used services such as Track My Packages, Ship My Packages, Ship Links, and My Links can be stored in My FedEx. A Track Inbox interface provides shipping status updates each time the customer logs in or refreshes the page. A FedEx Ship Manager helps customers prepare airbills, notify recipients of delivery, email senders of successful deliveries, schedule courier pickups, review shipping history, obtain rate quotes, process customer requests such as schedule shipment/merchandise return pickups, order shipping supplies, view and print recipient's signature as proof of delivery, and review shipping invoices. In addition, general purpose eServices such as shipping information, package tracking, and rate inquiries are available to the general public with no login requirements. Finally, Global Trade Manager supports export/import for over 22 countries by identifying, locating, and obtaining documents for international shipment, as well as determining duties and taxes to be levied against a shipment. FedEx believes that these eServices are to be credited for its success in meeting customer expectations, improving customer experiences, building customer loyalty, and achieving customer retention.

# 5 Perspectives on Future Development

The trends evident in this discussion suggest that rapid advances of information technologies change not only the ways in which systems support operations management, but also the ways in which operations are managed. This trend will inevitably continue. Several issues are important to future developments in DSSs for operations management.

## 5.1 ERP for Decision Support

First of all, ERP is expected to continue to grow in both reach and range of capabilities. Undoubtedly, more business functions need to and will be integrated into these systems. We should also expect more decision support capabilities to be built into ERPs. In other words, the role of an ERP will not be limited to providing information and facilitating transactions. It will increasingly become a key DSS for operations management and for organizational management in general. That is, DSSs for operations strategy, and general SDSSs will increasingly be incorporated in ERP systems.

## 5.2 Strategic Knowledge Flows

We described the evolution of DSSs for manufacturing planning and control – from COPICS to MRP, MRP II, and then to ERP. This evolution signifies the expansion of application scope and the increase of system capabilities. Future evolution will necessarily require us to change our mindset completely. Traditionally, the concept of manufacturing management puts material flows first, while information flow plays a supportive role to the manufacturing function. Cook et al. (1995) point out that, as competition in the marketplace intensifies, managers in manufacturing firms need to think strategically. Thinking strategically requires that top priority be given to managing knowledge flows properly. The flow of materials (i. e., the manufacturing function and the coupled logistics system) becomes only part of the firm's resource deployment aimed at achieving the strategic goals derived from the knowledge flows.

## 5.3 E-Ops

Electronic commerce (EC) is another important development that will drastically change the production and delivery of goods and services. EC and its central tool, the Internet, are heavily affecting operations and every other facet of business. Indeed, decision support applications in EC are widespread, and capable of much greater development (Holsapple et al. 2000). Chase et al. (2000) coined the term E-Ops (electronic operations) to describe the application of the Internet and its attendant technologies to the field of OM. With E-Ops, the infrastructure of a modern organization is viewed as an entity consisting of three conceptual levels:

- the business model level, which defines the organization's core business and strategy
- the operational level, which defines the processes needed to implement the strategy
- the information systems (IS) architecture level, which provides computer technology support to the above two levels.

E-Ops applications can be used for the internal processes of an organization, such as back-office support and the common factory processes of ordering, scheduling, product design and development, quality monitoring, etc. E-Ops can also be used for processes that support the external linkages between a company's suppliers and customers. Boyer (2001) provides a useful guide to E-Ops.

### 5.4 Virtual Operations

Section 3.2 briefly discussed the notion of the virtual factory. It should be noted that the term factory does not necessarily imply manufacturing. In fact, virtual factories, virtual operations, and virtual corporations are conceptually equivalent. Literally, a virtual corporation can contract out all phases of the design, production, distribution, and sales of its products and/or services. Many supply chain management (SCM) or ERP software vendors claim that their products support virtual operations. Regardless of the validity of these claims, any manufacturing or service firm (if such a distinction is still necessary or meaningful) should rethink its business strategy and information architecture.

### 5.5 Globalization

Even without virtual operations, globalization is a reality and a must for many industries. Although terms like global market, global manufacturing, global sourcing, and global supply chain are not new, globalization still poses tremendous challenge for firms: to effectively design and efficiently implement both transaction/reporting systems and DSSs to support their global operations. Indeed, E-Ops, ERP, and virtual operations should all be built around the architecture of systems for global operations, and vice versa.

## 6 Conclusion

A variety of DSSs for OM have been developed and are used today to facilitate decision processes associated with both structured production planning and control activities, as well as unstructured strategic OM decisions. The importance of DSSs for OM will become even more apparent as the rapid advances in information and communication technologies change the ways in which operations are managed and supported. Consequently, next-generation DSSs for OM will be integrated, information/knowledge-driven, enabled by E-Ops/virtual operations, and global.

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# CHAPTER 55
# Systems for Supporting Marketing Decisions

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Systems to support marketing decisions may be called marketing management support systems (MMSSs), marketing decision support systems (MDSSs) or intelligent MDSSs (IMDSSs). They can assist marketing management in a range of strategic planning, tactical, and decision-making activities. This chapter provides an overview of the history of such systems and the characteristics of the problems they aim to support. It then examines different classifications of such systems, and gives some published measures of the extent of their use and the expressed levels of satisfaction with them of marketing management. The second part describes recent published research in the area. While mentioning the DSS approaches that are used, such as case-based reasoning, neural networks, analytical hierarchy process, and genetic algorithms, it summarizes the research by marketing decision areas. Many of these are classic examples such as marketing strategy, customer segmentation, product pricing, and new product development. Others incorporate the newer marketing channels such as the Internet and mobile phones, or introduce approaches such as CRM and geo-visual marketing. It has been suggested that recommender systems and customer DSSs should be an integral part of marketing management's decision support portfolio, and these are also discussed here.

**Keywords:** Marketing; Decision support systems; Management support; Marketing decisions; MMSS; MDSS

## 1 Introduction

Not long after decision support systems (DSSs) were first defined and described, a number of academics and practitioners realized there was scope for their use in the marketing arena. The first marketing models appeared in the early 1960s, since which there has been continuing interest in marketing DSSs, both in the academic literature and in marketing practice.

Given that DSSs are covered from many angles in this book, this paper will not make points about DSS in general, but will focus instead on the intersection of DSSs and marketing, the types of DSSs that can effectively impact on the marketer's decision-making process. We shall generally term these marketing decision support systems (MDSSs), although it will be seen that there are a number of subcategories for which terminology differs from author to author.

The classic requirements of marketers have existed for a long time, but have recently been modified, expanded, and intensified. Major influences have been the

Internet, particularly the World Wide Web, effects of globalization, increased customer and service focus, shorter product life cycles, and raised customer expectations. eCommerce has enabled different business models, electronic marketing, new sets of online customer data, and different possibilities of interaction and decision making. Some newer companies operate solely in the electronic space, other established bricks-and-mortar organizations have had to decide how, and how much, to add electronic commerce and marketing to their conventional operations.

The expanding and changing nature of the marketing field, the range of decisions taken by marketers at different levels, and the varied marketing support system offerings creates a major challenge for anyone wishing to categorize ongoing developments. Should they be split according to marketing functions or situations, or by type? The literature covered to date reveals wide variations in how marketers and MDSS developers perceive systems and their place in the marketing decision process. Accordingly this chapter will be subdivided into a number of marketing decision areas, not mutually exclusive or exhaustive, that are touched on in recent published papers in the MDSS field.

This chapter will start by briefly sketching the historical background of MDSSs, and give some indications of the extent of their use. Using some of the terminology of Wierenga and Van Bruggen (2000), it then discusses the demand side, commenting on the types of decisions that marketing management are asked to make, and the problem-solving modes they may use to do so. Some categorizations and classifications of MDSSs or MMSSs (the supply side) are then given, followed by a section on the use and perceived success of these systems. The second part summarizes recent published work in the area, divided into sections related to marketers' decision needs. Established marketing decision areas are: marketing planning and strategy, customer segmentation approaches, pricing, new products, product analysis and management, direct mailing and database marketing. More recent developments include: advertising through newer channels, Web-based marketing support systems (recommender systems and customer DSSs), event-driven marketing, geo-visual marketing, and customer relationship management.

## 2 Background

Lilien and Kotler (1983) note that marketing management has had four main modes of response to the challenges of marketing decision-making: experience, practice standards, data, and model building. The idea of models to describe aspects of marketing was described in the early 1960s (e. g. Bass et al. 1961, Frank et al. 1962), and Kotler (1966) introduced the concept of a marketing nerve centre, providing the marketing manager with "computer programs, which will enhance his power to make decisions". A number of well-known marketing models were developed during the next decade. These included MEDIAC (Little and Lodish

1969), SPRINTER (Urban 1970), CALLPLAN (Lodish 1971), DETAILER (Montgomery et al. 1971), and BRANDAID (Little, 1975). Based on his experiences building marketing models in a number of companies, Little (1970) complained that "the big problem with management science models is that managers practically never use them". In a follow-up paper, Little (2004, p. 1855) gave four reasons for his earlier statement: good models were hard to find, good empirical estimation of parameters was even harder, managers did not understand the models, and most models were incomplete on critical issues.

Although the earliest examples of DSSs in the marketing field appeared some years before this, the first definition of a marketing decision support system (MDSS) appears to be that of Little (1979) in his paper "Decision Support Systems for Marketing Managers". There a MDSS is defined as "a coordinated collection of data, models, analytical tools and computing power by which an organization gathers information from the environment and turns it into a basis for action."

In a survey of decision support applications from the academic literature between 1988 and 1994, Eom et al. (1998) selected articles that included descriptions of "a semi- or unstructured decision, a human-computer interface, the nature of the computer-based support for human decision-makers' intuitions and judgments, and a data-dialogue-model system". Just over half of the resulting 271 applications were in regular use, and 72% were in the corporate functional management area, split into production and operations management (41%), MIS (19%), marketing (13%), finance (10%), strategic management (6%), human resources (4%), and other areas. This reveals that, despite being in some ways a relatively nonquantitative area, marketing was not lagging behind in making use of such systems. In his study of the top 1000 US companies, Li (1995) showed that the most common MDSS applications were pricing and product related.

Wierenga and Van Bruggen (2000) list 38 marketing management support systems (MMSSs) identified in the academic literature between 1969 and 1993, from whose authors they obtained questionnaire information. These are divided into their own classifications of marketing models (13), marketing expert systems (8), marketing decision support systems (12), marketing knowledge-based systems (3), and marketing case-based reasoning systems (2). They did not include any systems from their other classifications of marketing information systems, marketing neural networks or marketing creativity systems.

Matsatsinis and Siskos (2003) list 114 intelligent marketing decision support ystems (IMDSSs), with a short description of the area each covers, and academic references (1982–2000) or website URLs. The authors note that the list cannot be considered to be complete, due to the difficulty of obtaining information on corporate IMDSSs, either operational or in design and development.

This paper does not aim to update these lists in any comprehensive manner. Instead, we examine some of the developments published in recent academic literature. These will include new approaches to some classic marketing decisions, as well as DSSs applied to some of the newer situations in which marketers find themselves, such as eCommerce.

## 3 Marketing Decision Types and Problem-Solving Modes

Daniel et al. (2003, p821) cite the “lack of a commonly accepted map of the marketing process, let alone of the potential marketing IS applications which support it.” According to Wierenga and van Bruggen (2000, p. 29): “Marketing problems are often not well defined in terms of goals, means, mechanisms and constraints, and often do not lend themselves to the procedural or logical reasoning used in conventional computer programs or knowledge-based systems.”

While certain marketing decisions are standard and will probably remain so, the breadth of activity of the marketing manager, director or VP has expanded over time. Apart from various changes of emphasis and focus (e. g., orientation from the product to the customer, and globalization effects), the last decade has seen a major addition to the potential activities of marketers: the Internet and online marketing. Previous systems have tended to aid the marketer, and improve his or her knowledge of the likely purchasing patterns and characteristics of certain categories of customer. Newer Web-based systems are bringing individual customers directly into the decision-making process. Today’s marketers have access to much wider and more detailed sources of information, and are therefore able to take different types of decisions, in new ways. As in other fields such as manufacturing and finance, the changing landscape makes classification both of decision types and systems that support these systems difficult. To assist with an overview of the area, we shall therefore give some relevant points made by authors.

Kotler et al. (1997) describe the marketing process as that of analyzing marketing opportunities, selecting target markets, developing the marketing mix, and managing the marketing effort. As with other disciplines the main marketing management functions are analysis, planning, implementation and control. From a longitudinal study Li et al. (2001) show that marketing systems in major companies have changed from being predominantly used by middle management in the early 1980s to a more even balance between top, middle, and lower levels in 1990 and 2000.

Discussing the lack of clarity in the literature on marketing strategy, El-Ansary (2006) creates a taxonomy and framework that distinguishes marketing strategy formulation from marketing strategy implementation. He defines marketing strategy as “the total sum of the integration of segmentation, targeting, differentiation and positioning strategies designed to create, communicate and deliver an offer to a target market.” (p. 268). The elements of the marketing mix, the four Ps of product, pricing, promotion and place, are considered to be marketing management, or tactics, designed to implement the marketing strategies.

There are many different requirements for marketing managers and decision-makers. Some require a precise answer, such as quantity, price or place. In other cases managers need to explore a situation creatively, look for relationships, suggest alternative options and new ideas, and share these with others as part of an ongoing process. Wierenga and Van Bruggen (1997) suggest there are four marketing problem-solving modes: optimizing, reasoning, analogizing, and creating, ordered from hard optimization with exact calculations to soft associations and creativity. This ordering also coincides with a level of structure from high to low.

- *Optimization* comes from the operations research/management science stable, where the marketing problem is modeled, and an appropriate algorithm is applied to identify the optimal values that maximize or minimize some objective function. In order to do this, certain assumptions may be made, and a local solution may sometimes be found as part of a bigger problem.
- The field of marketing is far less deterministic than, say, that of manufacturing, and so other problem-solving modes typically have to come into play. Often (Wierenga and Van Bruggen 1997) marketing managers may form a mental model of a marketing phenomenon, based on their knowledge of the variables in the area, and the relationships between them. This is typically less complete, more qualitative and subjective than the scientific models used for optimization, but it can be used for model-based *reasoning* about the marketing problem (Johnson-Laird 1989).
- Analogical reasoning or *analogizing* is used when one recalls past situations which may have similar features and uses these as a basis for a course of action, perhaps with some adaptation. Given the marketing environment of promotions, campaigns, and new product launches, and a situation where the construction of a reasonably informed mental model may be difficult, this problem-solving mode may often be the most suitable approach.
- The *creating* mode is an attempt to arrive at new ideas through divergent thinking. The situation may be such that mental models and analogies are available, but the cognitive model for this mode requires novelty of some form to be generated in the marketing management domain.

For any given marketing problem, one of these four modes may be most appropriate (Wierenga and Van Bruggen 1997), but it is possible to combine them, or to have a transition from one to another during the problem-solving process. Factors that influence the marketing problem solver's choice of mode are suggested by Wierenga and Van Bruggen (1997) as:

- Problem characteristics (degree of structured, depth of knowledge, and availability of data).
- Decision environment characteristics (time constraints, market dynamics, and organizational culture).
- Decision maker characteristics (cognitive style, experience, education, and skills).

# 4 Types of Systems to Support Marketing Management and Decision Making

There is disagreement between authors about the naming and purpose of different types of marketing DSSs, as there is with DSSs generally. Examining DSSs for marketing planning, Wilson and McDonald (2001, p. 821) prefer to define a DSS as “a system which aims to support unstructured or semi-structured tasks performed by individuals or groups, including but not limited to decision-making”. This takes into account the importance of “improved communications, insight and learning” that such systems can convey in the planning process. Although such systems may not be applied as group DSSs in the more-conventional sense, their benefits are often influential across a group. Wierenga and Van Bruggen (2000) support the idea of marketing support systems being for both management insight and decision-making, by naming the broad group as “marketing management support systems” (MMSSs), and dividing them into the eight classes shown in Table 1. An approximate date of introduction of each class is given, and their categorization into classes depends to some extent on the historical progression, the technology available at the time, and the objectives of the systems.

Other authors prefer to adopt different subdivisions of the broad set of MDSSs, as with DSSs in general. There may also well be argument about some of the definitions in Table 1. For example, the term *marketing models* is used narrowly here in the sense of historical operations research-derived optimization tools, and can alternatively be used in a broader, more-current sense, incorporating also functions such as statistical analysis and forecasting. The description of MDSSs in Table 1 is rather more focused than that (given earlier) of Little (1979) and the general DSS definition of Keen and Scott Morton (1978): “Decision support systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer-based support system for management decision makers who deal with semi-structured problems.” Turban and Aronson (2001) define an expert system as “a system that uses human knowledge captured in a computer to solve problems that ordinarily require human expertise”, noting that their application is usually in a specialized or narrow problem area. Table 1, however, divides this area into three classes, one where a best solution is sought, one where the reasoning process is the main focus, and one that is case based.

Matsatsinis and Siskos (2003) find some difficulty with the classification in Table 1, preferring to see marketing information systems as the overarching group (possibly containing a number of MDSSs), and viewing marketing expert systems, marketing knowledge-based systems, marketing case-based reasoning systems, and marketing neural networks as subcategories of intelligent marketing DSSs (IMDSSs). Li (2000) lists types of computer-based systems for developing marketing strategies as marketing information systems, decision support systems, executive information systems, expert systems, artificial neural networks (ANNs),

**Table 1.** Eight classes of marketing management support systems

| MMSS type and approximate date | Description |
|---|---|
| **Marketing models (MM 1960)** | consist of mathematical representations of marketing problems that aim to find optimal values for marketing instruments. The philosophy underlying these systems is that it is possible to find an objective best solution. |
| **Marketing information systems (MKIS 1965)** | aim at the storage, retrieval, and statistical analysis of data. By means of manipulating quantitative information, marketing information systems assist marketers in analyzing what has happened in the market and determining possible causes of events. |
| **Marketing decision support systems (MDSS 1980)** | provide marketers with the opportunity to answer what-if questions by means of making simulations. Marketing decision support systems put a large emphasis on the judgment of the decision maker, rather than on searching for the optimal solution. |
| **Marketing expert systems (MES 1985)** | capture knowledge from a marketing expert in a specific domain and make this knowledge available in a computer program to solve problems in the domain. Like marketing models, expert systems take a normative approach in searching for the best solution for a given problem. |
| **Marketing knowledge-based systems (MKBS 1990)** | describe a broader class of systems than marketing expert systems. They obtain their knowledge from any source, not just from human experts but also from textbooks, cases, and so on, and can use a wide range of knowledge representations methods. Unlike marketing expert systems, marketing knowledge-based systems do not focus on finding a best solution but emphasize the reasoning processes of decision makers. |
| **Marketing case-based reasoning systems (MCBR 1995)** | focus on the support of reasoning by analogies. Analogous thinking is a way of solving problems in which solutions to similar past problems are taken as a starting point for solving a current problem. Marketing case-based reasoning systems make cases available in a case library and provide tools for accessing them. |
| **Marketing neural networks (MNN 1995)** | are systems that model the way human beings attach meaning to a set of incoming stimuli, i. e., how people recognize patterns from signals. Based on this principle, a large supply of algorithms is available now that we can recognize patterns in data. |
| **Marketing creativity support systems (MCSS 2000)** | are computer programs that stimulate and enhance the creativity of marketing decision makers. |

[adapted from Van Bruggen and Wierenga (2000) and Wierenga and Van Bruggen (1997)]

and fuzzy logic. In this paper we shall use the terms MMSS and MDSS interchangeably, and include all of the categories mentioned above.

Van Bruggen and Wierenga (2001) hypothesized that the *supply* of system type should match the *demand* of the problem-solving mode. They asked users of 38 MMSSs to rate the appropriateness of the four problem-solving modes (optimizing, reasoning, analogizing, and creating) for the situations in which their systems were being used. Their results showed that in cases where there was a good match between the problem-solving mode and the type of MMSS used, the systems were implemented in more companies, had a higher endurance rate, had more impact on actual decisions, were implemented more successfully, and generated enjoyed higher user satisfaction than those cases with a bad match. Wierenga and Van Bruggen (1997) suggest that the choice of system type is linked to the object of support, which can be the outcome itself, the process, or process and learning. These are in turn linked to the mode of support: automate, inform, or stimulate (Zuboff 1985 in Wierenga and Van Bruggen 1997). Given these, they determine the most appropriate MMSSs to be MM or MES when *optimizing* is the marketing problem-solving mode, MKIS, MDSS, MNN or MKBS when *reasoning*, MCBR or MNN when *analogizing*, and MCEP when *creating*. Looking at the marketing decision situations faced by three different roles of media planner, fast-moving consumer goods (FMCG) product manager, and the new business manager of an IT company, Wierenga and Van Bruggen (2000) show that each tends to use a different combination of two or more of the problem-solving modes, suggesting application of more than one system type. This is supported by Li et al. (2000, p558) who note that, for marketing strategy formulation, "It is unlikely to be the case, however, that a single technique or technology will be suitable for each of the wide range of complex problems inherent in strategy formulation, or appropriate to each of the many organizations engaged in the process."

## 5 Use and Perceived Success of Marketing Support Systems

Zinkan et al. (1987) examined managers' attitudes to the use of a simulation DSS for aiding marketing decisions in retailing. Results showed that risk averseness, involvement with the DSS design and cognitive differentiation were important predictors of level of use, while managerial experience, prior experience with a DSS or age were not. Satisfaction was impacted by amount of use and age. Only 32% of the top 1000 US marketing managers were satisfied with their marketing information systems, 16% were neutral (Li, 1995), while 54% felt that the systems gave them some competitive advantage.

Of a sample of Dutch companies with 10 or more employees and a designated marketing manager (Wierenga and Oude Ophuis 1997), only 37% claimed to have a MDSS. Adoption was significantly positively influenced by support from top management and from marketing colleagues, and where people were aware of successful MDSS applications in other companies. Other positive factors were a business-to-customer versus a business-to-business focus, and the availability of marketing information. Level of use and satisfaction were however impacted by other aspects. Usage was influenced positively by personal involvement and interest in systems generally, capability for direct interaction with the system, and level of system sophistication. Satisfaction depended on participation in the implementation process, adaptability and interactivity of the MDSS, and was negatively related to general computer experience – perhaps because on average the MDSSs in the survey rated 2.28 on a sophistication scale from 0 to 4.

The Li et al. (2000) survey of computer-based support for marketing strategy development in large British manufacturing companies found that only 15% used DSSs to assist with developing marketing strategy, and 6% used expert systems. Mean ratings for the benefits that systems gave towards strategic thinking or formulation were between somewhat and moderately helpful. As far as the systems they currently used for developing marketing strategy were concerned, 8% were very dissatisfied, 47% were dissatisfied, 53% moderately satisfied, and 9% satisfied – none were very satisfied. The major reasons were limited support functionality and models for marketing strategy, and an inability to accommodate managers' judgment and intuition. There were also perceptions by many that the MDSSs did not meet managers' real needs or handle uncertainty and ambiguity. Not surprisingly, Li (1997) earlier found a much lower rate of use of marketing information systems in small companies.

Wierenga et al. (1999) concluded that there is much evidence that MMSS can improve key corporate performance measures. However this depends on how one measures success, and on the details of the specific environment of the systems being used. They propose five broad factors that should determine the level of success of an MMSS: the demand for decision support, the supply of decision support offered by the MMSS, the match between demand and supply, the design characteristics of the MMSS, and the characteristics of the implementation process of the MMSS.

The Li et al. (2001) survey found the proportion of marketing information systems software devoted to the categories of decision modeling, artificial intelligence modeling or system simulation to be relatively low, suggesting little real decision support activity amongst marketing managers. They also assert that results of marketing resource allocation may be improved through use of a well-designed MDSS, and users may be willing to move to decisions further from the base case, Lilien et al. (2004) suggest that managers using them may not perceive they are obtaining superior results.

The Verhoef et al. (2002) study of Dutch database-marketing companies indicated that relatively few of them were using the more-sophisticated decision support techniques available to them and publicized in academic literature. Those applying segmentation methods, using predictive modeling, or using more-sophisticated techniques rated their campaign performance significantly higher than those who did not apply each of these.

# 6 Recent Published Work on Marketing DSSs

## 6.1 Marketing Planning and Strategy

Marketing planning operates at different levels, strategic (and relatively unstructured) and tactical (more structured). The outcomes may vary from sharing of ideas to a marketing plan with a standard format and layout. When plans for new products or marketing campaigns are drawn up regularly, an organization may have the potential of drawing on its past experiences. The knowledge will typically be a mixture of tacit and explicit. We start by mentioning research focusing on marketing planning and strategy.

Based on action research in a number of South African companies, Wilson (2004) concluded that appropriately designed and implemented DSSs can potentially improve strategic marketing planning by (a) aiding the use of marketing tools through visual displays, calculations, quick iteration and user guidance; and (b) facilitating group planning with better focused discussions, better mutual understanding, and greater consensus on strategic choices. This would, however, only occur provided success factors are present, including a senior sponsor, a system that is intuitive and seen to be empowering rather than controlling, a team with breadth of experience and authority, and clear definitions of units of analysis.

Attempting to counter some of the difficulties mentioned earlier in the Li et al. (2000) survey, Li (2000) designed a hybrid system for developing marketing strategy. This incorporates an ANN model for forecasting market growth and market share, an interactive individual and group assessment module, a fuzzification component and fuzzy expert system model, and a graphical display module.

Li (2005) later developed a Web-enabled hybrid system for strategic marketing planning, using a Delphi approach for decision-making. This allows for geographically dispersed managers to provide input to a Web-based expert system and knowledge base containing a wide range of marketing and strategic models. A further article by Li (2006) describes an Internet-based multiagent intelligent system with separate software agents for developing marketing, global, eCommerce, competitive and IT/IS strategies, and a coordination agent. The decision makers are in control of a six-step process, and the author gives guidelines for coupling the system effectively with human judgment and creativity.

Changchien and Lin (2005) present a DSS for design of -short-term marketing plans that uses case-based reasoning. Acknowledging the dissimilar formats and organization of past plans that a company may have, they use extensible markup language (XML), with a fairly comprehensive document type definition (DTD) list of the components of such plans. The marketer enters a number of keywords that retrieve appropriate candidate past plans from the system, using an XML parser. The similarity of each component to target specifications for key components of the plan is then measured with multi-attribute decision making (MADM), and shown visually in the resultant MAGA diagram. Based on the number of attributes successfully matched, each past case is scored, and the marketer presented with a short list. They can scan through the features of each past case and then do pairwise comparisons between the cases, for each key feature. An analytical hierarchy process (AHP) (Saaty 1994) then ranks the cases, and the marketer has the opportunity of modifying the top-ranked past plan, or drawing on components of the top-ranked cases with highest attribute similarity levels.

We shall now look at some recent published work in some of the classic marketing areas such as customer segmentation, pricing and new product development, before moving to marketing DSSs making use of the Internet, newer channels and technologies.

## 6.2 Customer Segmentation Approaches

The survey of Verhoef et al. (2002) found that 70% of Dutch database marketing companies used some form of segmentation, but of these, only 64% applied it to vary treatment or timing of treatment of customers, and 27% used it to build predictive models per segment. The recency-frequency-monetary (RFM) variables are typically the most used in segmentation (Miglautsch 2000). In the Verhoef et al. (2002) survey, recency was used most by segmenters (58%), followed by frequency (48%), and monetary purchase amount (32%). Lifestyle information and sociodemographic information was used by 28% and 34%, respectively.

One way of expressing the potential benefits of relationships with individual customers is by calculating customer lifetime value (CLV). This can be done in various ways, but a frequent approach is to combine the RFM values. Liu and Shih (2005) extended this method by using the AHP to choose a set of weights for R, F, and M, based on inputs from a number of groups. Using the weighted RFM to estimate CLV, customers were then clustered into groups by the k-means method. For each cluster, association rule mining was applied to all past transactions of customers to provide product recommendations. Liu and Shih (2005) showed that their approach for the higher CLV customers was superior to one using equally weighted RFM, and one with a typical collaborative filtering (Mobasher et al. 2000) approach. They cautioned that the improvement did not hold to the same extent for less-loyal lower-CLV customers.

Self-organizing map (SOM) networks (Kohonen 1995) are nonparametric variations of neural networks that have been used as classification and dimension reduction tools. Kiang et al. (2004) extended the SOM network to cluster consumer data into segments. Applied to data from AT&T, they showed that their method generated essentially the same six segments traditionally obtained from this data. Allowing also for two to seven clusters, the within-cluster variance with the extended SOM approach was shown to be lower in each case than that obtained through the conventional factor analysis/*k*-means clustering method.

## 6.3 Pricing

Much has been written about pricing models in marketing (Lilien and Kotler 1983, Rao 1993), but comprehensive DSSs to support pricing decisions at a low level have been slow to arrive and gain acceptance. Examining the case of supermarket retailing, generally with very high numbers of stock-keeping units and stores, Montgomery (2005) asserts that the availability of data, improved computing, power and advances in academic research have made implementation and use of pricing DSSs (PDSSs) feasible. He lists a number of requirements for a PDSS, and suggests that various vendors are now offering acceptable PDSSs, using varied approaches. From an industry perspective, Valentine and Venkatraman (2005) support Montgomery's statements, note the value of Bayesian methods in providing robust and adaptive modeling, and suggest that the greatest challenge is in developing accurate forecasts with incomplete information.

In the specialized area of fashion goods, Mantrala and Rao (2001) describe a stochastic dynamic programming PDSS called MARK that takes pricing decisions on markdowns, and provides insight into relationships between order quantity and dynamic pricing decisions.

## 6.4 New Products

Describing the 25-year history of a marketing DSS for evaluating and selecting concepts for new products, Gensch (2001, p. 180) makes the point that "once people in an organization come to a collective belief that a model is a realistic and useful abstraction of a real world problem, they use the model to better understand the process being modeled". Other reasons given for this DSS's ongoing use and success were: full involvement of all players in development, leading to ownership; a structure integrating much data and incorporating uncertainty; a clearly objective decision process; a dynamic process allowing reevaluation; and empirical measures of success to validate the model.

Chen et al. (2002) give details of a prototype system for eliciting customer requirements for a new product, and for finding patterns in these that may point out marketing opportunities. The customer requirements elicitation (CRE) uses the laddering process (Rugg and McGeorge 1995) to derive a customer attributes hierarchy (CAH), and feeds this into an ART2 neural network to derive a series of output patterns for the company and its main competitor, segmented into appropriate customer groups.

Because the product line decision is *NP*-hard, Alexouda (2005) suggests an alternative approach to designing a line of substitute products, which aims to maximize either buyers' welfare for nonprofit organizations, seller's return, or market share. For small problem spaces the MDSS uses the complete enumeration method to find an exact solution, otherwise it uses evolutionary, or genetic, algorithms to arrive at a near optimal solution. The interface is easy for the marketer to use and competing scenarios can be tested with what-if analyses.

## 6.5 Product Analysis and Management

Consumers have difficulty choosing between products when they have a number of attributes that are conflicting and consumers' views of their requirements are imprecise. Mohanty and Bhasker (2003) show how consumers trying to choose between competing products on the Internet can have them classified into hierarchical preference levels through fuzzy logic and a virtual buying agent.

Sales forecasting is a key element of marketing planning. Zhong et al. (2005) extended a previous DSS for forecasting at category and brand levels, to allow for possible nonstationarity in the vector autoregressive model. The category management DSS with Bayesian vector error correction allows for interaction by a marketing analyst, and for category managers to input tactical marketing information. Test results on retail data show reduced forecast errors overall.

Market basket analysis became possible when increased computing power enabled detailed analysis of transaction-level data, with the association-rule mining introduced by Agrawal et al. (1993). This approach has recently been extended to the multiple-store environment by Chen et al. (2005). Their model allows for different product mixes over different time periods, and for products to be put on and taken off the shelves at multiple times. Simulation results show improved results over the traditional method when there are many stores of diverse sizes, and product mixes change rapidly over time.

A quadrant chart can be used to relate the rated importance of attributes of a product or service to the performance of competing firms on these attributes. Krieger and Green (2002) describe a DSS that extends this concept in various ways. It uses a two-stage heuristic in its optimization algorithm, allowing for user interaction, segmentation, sensitivity analysis, and optimum allocation of resources to improve market share.

## 6.6 Direct Mailing and Database Marketing

Jonker et al. (2005) divide customers into 55 states, based on the number of mailings they have received over a time period, the number responded to, and the amount spent. The aim is to get customers into states that are most beneficial to the firm as soon as possible, and decide on the optimal numbers of mailings for customers in each state. The DSS uses a Markov decision chain and dynamic programming, and allows for input of scenario parameters by marketers. It was tested with some success on data of a direct mailing organization, but the authors note that "management goals often conflict with the optimization criteria used in the mathematical model".

A DSS called Ensemble was used by Kim and Street (2004) to target customers for direct mailing. A genetic algorithm first greatly reduces the large initial set of consumer parameters, taking into account the percentage of customers to target. Using the reduced feature set, an artificial neural network then selects the customers with most profit potential. In the test case the set of 93 household characteristics was reduced in all cases to six or fewer, and the authors make a case for potential reduction of data collection and storage costs. Results are superior to those using only ANN.

## 6.7 Advertising Through Newer Channels

Advertising now takes place through a wider range of channels, including mobile phones. De Reyck and Degraeve (2006) describe a DSS for automatically scheduling and optimizing broadcasts of retailer advertisements to mobile phones using short message service (SMS) text messaging. Customers are segmented by age and gender, while advertising clients are rated by importance, and can also express their preferred times for advertisement broadcasts. Allowing also for certain constraints, integer programming was used to generate advertising schedules that in testing showed a number of improved aspects. In discussing the marketing implications of webcasting, Dubas and Brennan (2002) note that a DSS can be used to push appropriate information to relevant people, and state that benefits are to be found in all components of the marketing mix. Karuga et al. (2001) discuss a system called AdPalette, which uses elements of conjoint analysis, goal programming, and genetic algorithms with crossover and mutation, to generate dynamic online advertisements.

## 6.8 Web-Based Marketing Support Systems

The Web is where marketing potentially comes closest to the one-to-one marketing concept of Peppers and Rogers (1993). In some organizations it may only be a mirror image of a company's bricks-and-mortar marketing; in others it may additionally employ personalization, recommender systems or customer DSSs. The marketing decision maker now has a vastly expanded amount of data from another channel to use in existing MDSSs. Alternatively the whole basis of marketing planning and decision-making may be changed and augmented. The focus changes in some companies from market share to share of the customer. In this arena, DSSs have moved from being *run by the marketer to assist decision making about customers*, to being *provided by the marketer to assist decisions made by the customers.* The extent of involvement will vary from company to company, but this is clearly an additional area for which marketing should take responsibility, and integrate effectively with their traditional systems.

### 6.8.1 Recommender Systems

Recommender systems are used by e-merchandisers to implement a one-to-one marketing strategy on the Web, and to provide customers with contextually relevant information that can help them in making product purchase decisions. They can be classified into four main types (Adomavicius and Tuzhilin 2005, Eirinaki and Vazirgiannis 2003):

- Rule-based filtering systems typically ask users to answer a set of decision tree-based questions, leading to a tailored result.
- Content-based filtering systems use information retrieval and case-based reasoning techniques to compare Web documents and personal profile information obtained either implicitly or explicitly from users.
- Collaborative filtering systems typically take explicit user ratings or preferences and implicit data based on purchase history or Web usage activity, and through a correlation engine return recommendations predicted to most closely match the users' preferences. Collaborative filtering techniques allow users to take advantage of other users' behavioral activities and opinions, and items are recommended on the basis of user similarity rather than item similarity.
- Hybrid systems combine elements of these approaches.

Cheung et al. (2003) applied the support vector machine (SVM) machine learning algorithm to improve performance of content-based recommendations and avoid feature selection problems. Their use of the latent class model algorithm to address sparsity problems with collaborative recommendations gave mixed results.

Lee (2004) describes a multiagent decision support system for recommending products that a consumer does not buy frequently. Recommendations are based on the customer's preferences from interactions with the system, and from product knowledge from domain experts, as well as past behavior patterns of other consumers. The hybrid system uses dynamic programming to find previous users with similar behavior patterns, and multiattribute decision making to estimate optimality of each product. It has four agents: an interface agent for consumers and experts, a knowledge agent, a decision-making agent for calculating optimality, and a behavior-matching agent. The consumer may interactively modify requirements of different features on being presented with recommendations.

Software agents can play a major role in supporting decision-making in electronic trading and electronic commerce (EC). Karacapilidis and Moraitis (2001) describe a Web-based EC system with multiple agents for customers and merchants. This incorporates an interactive multiple-criteria decision-making tool for a purchaser agent to compare a range of seller proposals, and is illustrated with an example of an online purchase of a car. Liang and Huang (2001) present a three-layer framework for using intelligent agents to support EC. This allows for different decision models to aid choice and facilitate transactions, according to the type of trade.

### 6.8.2 Customer Decision Support Systems (CDSS)

Customer decision support systems (CDSSs) are defined by O'Keefe and McEachern (1998) as "supporting the decision-making process of an existing or potential customer". Building on the quality function deployment (QFD) approach, Grenci (2005) developed a matrix-based CDSS that caters for successively decreasing levels of customer abstractio". Expert information is entered that links technical product characteristics to possible customer requirements, and online customers assign levels of importance to those requirements, allowing for customized product configuration.

## 6.9 Event-driven Marketing

Gessner and Volonino (2005) discuss event-driven marketing systems, and stress the importance of quick response to a favorable change in a customer's lifetime value or behavior patterns. Two challenges for managers implementing event-driven marketing are relationship management and learning management (using feedback to improve the system's rule base and decision process). Zhang and Krishnamurthi (2004) use a dynamic optimization DSS to update customized price discount decisions at different times for individual households. This is based on the variety seeking/inertia parameter which they show varies over time for most households.

## 6.10 Geo-visual Marketing

Hess et al. (2004) make a powerful case for the increased use of geographical information systems (GIS) technology in MDSSs, viewing GIS as a DSS generator. As the four elements of the marketing mix each have a geographical component, spatially oriented technologies should help with decision making, and map-based presentation of results is appealing and effective for marketers. In addition there is great potential to use GIS to integrate information from disparate sources, including internal databases, and external marketing intelligence and market research. Potential advantages of incorporating geo-visualization in DSSs are given by Hernandez (2005), and a prototype for the retail industry is discussed.

## 6.11 Customer Relationship Management (CRM)

Customer relationship management (CRM) is an approach or strategy used with mixed results by marketing management in many companies. The CRM (or eCRM) applications software purchased by organizations may often not correspond well with their business objectives for CRM (Hart 2006). CRM has its own vast literature, and we mention only two recent articles that stress the

CRM/DSS interface. Jackson (2006) identifies the core components of an integrated CRM/DSS that can improve decision making in the acquisition, development and retention of customer relationships, and stresses the value of a cross-functional approach across company departments. The importance of properly integrating CRM and DSS is echoed by Noori and Salimi (2005). They discuss DSSs for business-to-business marketing, and illustrate it with a business to business MDSS developed for the service sector.

### 6.12 Improving Marketing Knowledge and Learning

Shaw et al. (2001) show how data mining can be integrated into a marketing knowledge management framework that can improve various MDSS applications. Key challenges are making the learning by experimentation approach more structured to improve productivity, managing knowledge across organizational boundaries and supply chain partners, and multiple classifications where customers may belong to more than one category. On a different, but parallel, track Davenport (2006) discusses the increasing importance in the corporate world of “competing on analytics,” mentioning a range of customer- and marketing-related models and applications that can improve profitability and competitiveness.

## 7 Conclusions

Systems to support marketing decisions are now in their fifth decade. Over that period of time the global market place has changed greatly, as have the requirements and expectations of marketers. At the same time both the availability and level of detail of data have mushroomed, and the capabilities of systems to store and analyze this data have increased exponentially. Many new management and marketing theories have emerged, and systems have been developed to take advantage of them.

This paper has drawn almost totally on academic literature, as opposed to an examination of the wide range of existing vendor-supplied products and their white papers. Commercially available DSSs for the marketing area have greatly increased, both in numbers and in functionality, and no attempt has been made here to survey the current extent of their capabilities. A few past surveys have revealed relatively low use of the more-powerful DSS attributes of these in practice, and low levels of satisfaction and faith in their ability to integrate the human elements of expertise, judgment, and creativity of professional marketers.

Lilien et al. (2004) offer these design suggestions to improve the future perceptions and acceptance of MDSSs: design DSSs to encourage discussion, to reduce problem complexity and encourage the consideration of additional alternatives and designs in feedback. In very broad terms this implies that sufficient attention must be paid to integrating the qualitative aspects of marketing variables and decisions with the quantitative aspects that the initial management science marketing models focused on. A cursory glance through this paper's references reveals that more are from scientific and systems-related journals than from marketing and management journals. It is, however, notable that most of the former display some awareness of the need for their MDSSs to communicate with marketing management and experts by allowing for input in a friendly way, and for generating meaningful output and feedback, sometimes in an ongoing dialogue. The greatest focus appears to be on the area of Intelligent MDSSs (Matsatsinis and Siskos 2003), with systems often being validated, albeit in a constrained context. The nature of marketing implies that only a limited number of decision problems will have clear-cut normative or optimal solutions. The attention now being paid to the less-deterministic, relatively unstructured aspects of marketing suggests that existing gaps between academic research, commercial marketing systems offerings, and marketing practice should be narrowing.

It can also be seen that much research is now being devoted to new channels and business models affecting marketing practice, as well as refining approaches to classic marketing decision needs by means of newer technologies and algorithmic methods, as well as hybrids and combinations of these. Through the combined efforts of academics with both marketing and decision support-related skills, and the experience and creativity of those in the marketplace, it is to be hoped that systems to support marketing decisions will continue to improve, and gain the increased confidence of those charged with developing marketing strategy and plans.

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# CHAPTER 56
# Financial DSS: Systems for Supporting Investment Decisions

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Market volatility and innovations in financial trading have made investment decision making increasingly complicated and risky. However, the availability of reliable financial market data and powerful software tools has never been greater. In this environment, decision support systems (DSSs) are playing more-important roles and improving the quality of decisions made by both professional and individual investors. This chapter illustrates the capabilities of financial DSSs with several examples of spreadsheet-based investment modeling and decision analyses. For investors seeking better decision performance, DSS tools are essential. The DSS illustrations include portfolio optimization, arbitrage trading models, and value-at-risk modelling. The examples highlight the basic features an investment DSS would provide. With some extensions, these are the features that would be evident in the most powerful commercial investment software packages.

**Keywords:** Financial systems; Financial analysis; Efficient frontier; Financial optimization; Simulation; Investment analysis; Investment decision making; Portfolio theory; Nonlinear programming; Value at risk (VAR); Volatility

## 1 Introduction

Greed and fear drive investment choices in financial markets. Increasingly, decision support systems (DSSs) also feature prominently in the process of making investment choices. For both individuals and professional fund managers, investment decisions are complex with catastrophic losses possible. Investors and portfolio managers today face daunting challenges in selecting the best investments from among an expanding range of alternatives. Investing though is well suited to computerized decision support. Today, DSS technologies have joined greed and fear as pervasive elements in making investment choices and managing financial portfolios.

Investing intelligently today requires computerized support. Market uncertainty and price risk make decision makers vulnerable to decision biases, and cognitive limitations can lead to poor-quality investment decisions (Dawes 1988). New instruments, derivatives, and hedging opportunities have expanded the choices in recent years. Yet, vast quantities of historic data, forecasts, and analytic models are available to investors to help guide their choices and determine the best portfolio given their requirements and tolerance for risk.

This chapter will illustrate the roles that DSSs can play in financial management and investing. Decision support tools are available today to give investors – professionals and individuals alike – well-grounded methods to make disciplined portfolio choices. With computerized tools, investors can perform better, even when confronted with the swelling number of investment alternatives, and overwhelming quantities of market data.

The focus will be on financial analysis tools implemented in DSSs to support individuals deciding how to invest their personal savings, or to aid more-sophisticated approaches used by investment institutions managing larger asset pools. The challenge in the design and development of DSS tools is to retain the investors' preferences and goals in a way that helps them overcome decision biases and cognitive limitations. The result is improved quality of investment decisions made by DSS-equipped investors, and greater profits with less risk.

Today, powerful DSSs for an individual investor can be created with a spreadsheet combined with the detailed, historical market data now available at, for example, Yahoo!-Finance. Yet, despite the promise of computer-based decision support, few investors take full advantage of the capabilities of DSSs to guide their investment choices.

## 2 Decision Support Systems

DSS are interactive computer-based systems that aid users in judgment and choice activities. By streamlining complex data analyses and providing rich presentation formats, DSS users are able to make more-informed decisions. Thus, the basic goal of a DSS is to provide the necessary information to the decision maker in order to help him or her get a better understanding of the decision environment and the alternatives available.

The typical structure of a DSS includes three main parts: the database/data warehouse, the model base, and the user interface. The databases available to a DSS should include all the information and data that are necessary to structure the decision problem at hand and perform the needed analyses. Data entry, storage, and retrieval are performed through a database management system that may not be under the user's control. The model base is a storehouse of methods, techniques, and models that are applied to the raw data to perform the analysis and support the decision-making process. It is important that these models produce understandable analyses and meaningful output for the decision maker. The model management system should perform tasks such as model development, changes, presentation, and retrieval. Finally, the user interface communicates between the DSS and the user, and links the database and the model base with the output. The design of the user interface is essential for the effectiveness of the whole system. Without a clean and consistent interface, users cannot take full advantage of the analytical capabilities that the system provides. For instance, information technology (IT) advances enable graphical user interfaces (GUIs) that are far more user friendly and intuitive than early 1970s-style DSSs. The result is a shorter learning curve and greater DSS use.

In financial markets, decision support technologies are essential to maintain the good health of any investment portfolio. Greed, the hope of outsize profits from an investment, needs to be balanced against fear, the risk of a large loss from an ill-chosen investment. As importantly, investors need to diversify and avoid having all their eggs in one basket. Advances in financial theory, and an explosion of data sources, have enabled risk and diversification to be calculated and analyzed.

## 2.1 DSS Applications in Financial Decision Making

In the time since their introduction in the late 1960s, DSSs have been implemented to tackle a variety of real-world decision-making problems, including financial management problems and portfolio management. The portfolio management process involves the analysis of a vast volume of information and data, including financial, stock market, and macroeconomic data (Elton and Gruber 1995). Digesting a vast flow of information for every available security to make real-time portfolio management decisions is a cognitive and technical challenge. The support of a specifically designed computer system is required to facilitate the data management process, and also the implementation and analysis of financial models.

Financial DSSs can be defined as computer information systems that provide information in the specific problem domain of finance using analytical decision models and techniques, as well as access to databases, in order to support an investor in making decisions effectively when their problems are complex and ill structured. Financial DSS software should directly support modeling decision problems and identifying the best alternatives (Palma-dos-Reis and Zahedi 1999). A financial DSS therefore formalizes domain knowledge about financial management and portfolio selection problems so that it is amenable to modeling and analytic reasoning.

The role of a financial DSS can be that of a normative system that leads to a clear solution – i. e., recommendations are based on established theoretical principles, or it can be a decision-analytic DSS that supports the process of decision making but retains subjective elements and does not necessarily lead to a clear ranking and a unique best alternative.

The components of a financial DSS are the same as those of other DSSs: the database, the model base, and the user interface. A DSS will retrieve information from large databases, analyze it according to user selections and suitable models, then present the results in a format that users can readily understand and apply. In the next section, illustrations will stress the contribution of the user interfaces to the ultimate quality of decisions and to the confidence the user has in their decision process.

Early research on DSSs predicted that computerized decision support would find widespread application in financial decision making. Tom Gerrity's 1971 *Sloan Management Review* article, "The Design of Man-Machine Decision Systems,"

| Financial management objective | Decision problem addressed | DSS models and tools – examples |
|---|---|---|
| Financial forecasting | Projections for planning purposes and budgeting | Smoothing, autoregressive/moving average models |
| Cost of capital calculations | Setting hurdle rates and measuring performance objectively | Discounted cash flow (DCF) and internal rate of return (IRR) |
| Capital budgeting | Allocating scarce funding across a set of internal investment projects | Net present value (NPV), payback period, real options valuation |
| Financial risk analysis | Cash flow shortfalls, liquidity risks | Simulation, sensitivity analysis |
| Financing growth business | Choosing among alternative funding sources for early-stage enterprises | Evaluation of discrete deals and alternatives, debt ratios, flexibility |
| Credit analysis/ borrowing qualification | Credit quality and willingness to lend | Ratio analysis, interest coverage |

**Figure 1.** Functions in financial management (Graham and Harvey 2001), and their associated problems and DSS tools and models for solving/supporting decision maker

details a DSS application for portfolio management that was designed to support money managers in their short- and long-term management of client stock portfolios. Since Gerrity's research, advances in asset management methods and more-powerful IT have led to more-sophisticated DSSs for portfolio management.

Financial planning also proved to be readily implemented as DSS tools. Early financial planning DSSs were intended to provide end-user functions and accessibility that would allow executives to build models without data processing expertise and programmer intermediaries. Solving a number of problems (see Figure 1) in financial management turned out to be readily accomplished using early personal computer (PC)-based DSS tools.

The interactive financial planning system (IFPS) was a popular DSS tool for financial analysis, and was widely used from its 1978 launch as a mini-computer package until the early 1990s. See "An Introduction to Computer-Assisted Planning Using the Interactive Financial Planning System" (Execucom, Austin, TX, 1978) for details of its functionality. IFPS, in common with other DSS packages, implemented models in a transparent, natural language that separated the financial model from the data. Spreadsheets, with their universality and their ease of use, eventually overtook specialized tools such as IFPS in popularity and features. Unfortunately, the separation of data and model in DSSs – highly recommended by Sprague and Carlson (1982) and other DSS researchers – is lacking in spreadsheet DSSs.

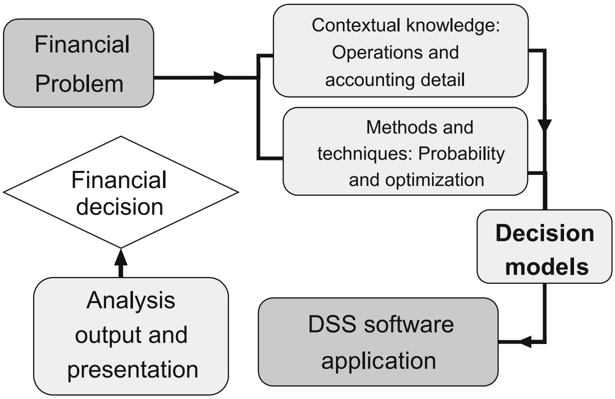


**Figure 2.** Flow diagram of steps and functions in supporting investment decisions

The standard DSS components can be found in a financial DSS (Figure 2). Context knowledge and experience, along with solution methods, are combined to develop the appropriate model for the problem. From there a decision model is implemented in a DSS, which provides the analytic capabilities and outputs to enable the financial decision to be arrived at confidently.

The next section will describe the flow of investment decision making and activities, and outline the applications of DSSs to investment decision making.

## 2.2 DSSs for Investment Decisions

Portfolio management is one of the central problems in modern financial theory. It involves the selection of a portfolio of securities (stocks, bonds, derivatives, etc.) that maximizes the investor's utility. The process of constructing such a portfolio consists of several steps (Figure 3). In step one, the investor or portfolio manager has to determine the securities that are available as investment instruments. The vast number of available securities makes this step necessary, in order to focus the analysis on a limited number of the best investment choices. A decision maker's investment policies and risk tolerance may narrow the field. For instance, some asset managers are only allowed to hold bonds that are rated investment grade by the major bond rating agencies (e. g., Moody's and Standard and Poor's). This investment policy restriction eliminates speculative grade securities from the available universe. Other funds avoid the so-called sin stocks of companies selling tobacco, firearms, or operating gambling venues.

On the basis of the screening stage, the decision maker in step two accesses and evaluates the relevant data for their screened securities universe. An optimization model is then used to select and assign weights (the percentage of total assets) to the far smaller number of securities that constitute the best investment portfolio in terms of risk and return. In the third step of the process, the decision maker must

| **Screening the universe of alternatives and asset class allocation** | → | **Evaluation of potential holdings in each class and construction of optimal portfolio** | → | **Trading orders to buy or sell. Communicate with market or broker** | → | **Monitoring the portfolio and its ongoing performance and characteristics** |
|---|---|---|---|---|---|---|
| Selecting among potential investment classes, such bonds, stocks, commodities, and real estate.<br>Screening by asset characteristics, objectives, and fund policy restrictions. | | Pre-processing of information and development of a data set from historic prices.<br>Determine volatility and correlation levels in order to diversify across stocks, bonds, sectors, borders, etc. | | Transmit investor orders to the appropriate marketplace for order matching, trade execution.<br>Trade details passed to clearing-house and portfolio accounting systems for safe settlement. | | Monitor exposure and identifying the need to rebalance and adjust the holdings as prices change and conditions change.<br>Mergers, tenders, proxy votes and other corporate actions, along with bond calls and convertibles bond provisions can require changes. |

**Figure 3.** Flow diagram of securities investment decisions

determine the number of shares or bonds that should be purchased or sold based on the amount of the available capital that should be invested in each security. The portfolio decisions should be implemented by trading in ways that keep transaction costs low (Schwartz et al. 2006).

The decision-making flow of an investor or fund manager has four components, beginning with investment decisions, and flowing through to trading and back-office and accounting operations.

Beyond portfolio recordkeeping, vendors and in-house systems groups have developed information technology to support all stages of the securities investment process from stock screening and portfolio risk modeling to trade order management systems[1].

Systematic approaches to portfolio management emerged from the work of Nobel laureate Harry Markowitz (1952, 1959) that underpins modern portfolio theory (MPT). Investors benefit by diversifying their investment portfolio by holding a range of securities. The value of diversification was quantified by Markowitz, who demonstrated that a diversified portfolio provides either a higher expected rate of return or a lower variance (risk) of return than an undiversified portfolio. Since the advent of MPT, investors have expanded their attention beyond selecting attractive individual investments to examining the overall characteristics of their portfolio.

Research based on Markowitz (1952) showed that systematic and disciplined approaches to investing outperform intuitive and unaided investment decision making.[2] Yet, MPT does not provide a single prescription for all investors. It allows for variation in investment horizons and individual preferences toward risk.

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[1] Leading commercial vendors of portfolio management systems include Barra, Northfield Information Services, Wilshire Associates, and Vestek.

[2] However, unreliable statistical estimates caused by empirical data allow other approaches such as naïve 1/*N* diversification (equal weights to all portfolio components) to do as well as Markowitz-optimized portfolios (DeMiguel et al. 2006).

Moreover, its optimal portfolios are sensitive to assumptions such as estimates of volatility and correlations levels. This means that the set of investments will differ as assumptions diverge, and what is suitable to one investor may not be for another. The use of a DSS can help to ensure a consistent process that is based on MPT, and that is adhered to in spite of the ebbs, flows, and emotions of markets.

Today's financial technology provides numerous alternatives for successful investment decision making. Sophisticated DSS tools are used for fundamental and technical analysis, back testing, and simulation, and can lead to improvements in performance. Even though individual interactions among the variables in a financial model may be well understood, predicting how the system will react to an external shock such as a volatility spike or interest rate shift is essential to enhancing decision making.

Investment decisions can fall anywhere on the structured to unstructured continuum of problems. For example, portfolio theory offers a precise tool for constructing a portfolio, but its input parameters are subject to misestimation and individual judgment errors. Unstructured decisions for investors involve assessing data quality, understanding risk tolerance, and forecasting parameter values. These are particularly strong challenges that arise when investing in new and illiquid or emerging market securities, where historic data is limited. For each of the DSSs to be described, we will give an example of a problem that it can solve for someone making an investment decision but desiring the ability to explore the consequences of their estimation results and other less-structured choices.

## 2.3 Basics of Investments Analysis

Just as greed and fear must be balanced, so investment returns must be assessed against the risks they entail. Decision models for investments include as parameters several standard calculations based on securities' price levels at different times, i. e., $P_0$, $P_1$, …, $P_T$. First, absolute return or price change in a period of time is generally represented by $\Delta P$, where for period 1,

$$\Delta P_1 = P_1 - P_0 ,$$

where $r_1$ is then the *percentage return* for period 1,

$$r_1 = \frac{\Delta P_1}{P_0} = \frac{P_0 + \Delta P_1}{P_0} - 1 = \frac{P_1}{P_0} - 1 \ .$$

Notice that $r_1$ has no maximum value, but its minimum value is –100%. To obtain a symmetric, unbounded returns distribution *logarithmic returns*, $r_1^*$ are often used:

$$r_1^* = \ln(1 + r_1) \quad = \ln\left(\frac{P_1}{P_0}\right) .$$

The *superscript reflects logarithmic returns. For the time interval 0 to 1, we can write the end of period price as a function of the logarithmic returns.

$$P_1 = P_0 + \Delta P_1 = P_0(1 + r_1) = P_0 e^{r_1^*} \ .$$

Second, given these representations of price dynamics, several constructs from statistics are used to support investment analysis. The most important are expected return, standard deviation, and correlation. Expected or mean return in a time period is the average return over the prior $T$ time periods.

$$E(R_T) = \sum_{t=1}^{T} r_t \,/T \ .$$

Risk is measured as the variance of investment returns over the prior $T$ time periods.

$$\mathrm{Var}(R_T) = \sum_{t=1}^{T} [r_t - E(R_T)]^2 / \, T \quad \text{and} \quad \sigma_{R_T} = \sqrt{\mathrm{Var}(R_T)} \ .$$

The square root of the variance is the standard deviation of returns, which is the most common measure of investment volatility.

The covariance between the returns on any two securities, or between a security and a market index, is the product of the standard deviation of the two returns, and the correlation coefficient between the two, $\rho_{i,m}$

$$\mathrm{Cov}(R_i, R_m) = \sigma_i \sigma_m \rho_{i,m} \, ,$$

where $i$ and $m$ are the two securities, or a security and the market index. Following from the landmark capital asset pricing model (CAPM, Sharpe 1964), the risk to an investor of holding an individual security is measured by $\beta$, which for a stock can be written:

$$\beta_i = \frac{\mathrm{Cov}(R_i, R_m)}{\mathrm{Var}(R_m)}$$

From the formula, a stock whose covariance with the market is the same as the market variance has a $\beta$ value of 1.0. In the example in Figure 4, 60 months (five years) of returns data for an individual security's monthly returns [symbol XLK, technology SPDR (Standard and Poor's depository receipts)] on the vertical axis are regressed against Standard and Poor's 500 (S&P500) returns on the horizontal axis. The slope of the regression line is $\beta$, which is 1.69 in this example.

According to CAPM, rational investors expect a return from any security $i$ that is proportional to its risk as measured by its beta, $\beta_i$. A $\beta$ value of 1.69 implies that a 1% change in the entire market is expected to result in a 1.69% change in security $i$'s price. In CAPM, the expected returns for security $i$ are based on its $\beta$ value,

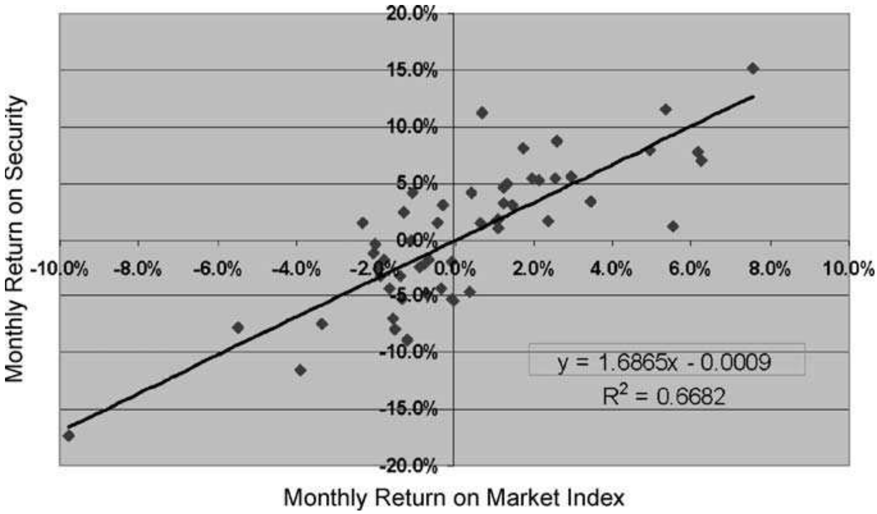


**Figure 4.** Calculating a security's $\beta$ value from the regression of the security's returns on the market index's returns

the risk-free return, $r_f$, from holding short-term government securities, and the securities market return, $r_m$, forecast for a broad market index. An investor can compute the CAPM required return for an instrument $i$ as:

$$E(r_i) = r_f + \beta_i \times [E(r_m) - r_f].$$

Example: Assume $r_f = 4.5\%$, $r_m = 9.5\%$, and $\beta_i = 1.1$:

$$E(r_i) = 4.5\% + 1.1 \times [9.5\% - 4.5\%] = 4.5\% + 5.5\% = 10.0\%.$$

For these parameter values, a security with a beta of 1.1 will need to generate a return of 10.0% to compensate investors for its *undiversifiable* risk. If an investor believes the return will be less than 10.0%, he or she would seek to sell the security. If the market collectively believes the return will be less than 10.0%, the security's price will decrease to an equilibrium level at which CAPM required returns are equal to its expected returns.

In practice, many investors and money managers will compare the returns they have realized on their investments with the expected returns from the CAPM equation above. For instance, if the security with a required return of 10.0% according to CAPM generates a 12.0% return, then the stock is said to have generated an $\alpha$ value of 2.0% for the portfolio. $\alpha$ can be thought of as the outperformance of an investment or a portfolio relative to its risk.

Broadly speaking, there are two investment approaches. The first is passive fund management, which entails tracking a market index and mechanically replicating the components in the index. This is a low-cost strategy and allows the investor to achieve the market return without any effort to select individually attractive securities (Clemons and Weber 1997). Active management, on the other hand, seeks to outperform the market benchmark by identifying over- and under-valued securities. Securities research and stock selection are the critical elements in active investing. Active fund managers must spend time and effort finding information that indicates those stocks whose prices do not reflect their fundamental value. Other elements of an investment management process are strategic asset allocation and tactical asset allocation. These choices are made when a manager feels the market is currently overvalued and due to decline. Therefore, the allocation decision will leave much of the fund's assets in cash or short-term instruments.

Next, four DSS examples in investment decision making are described. These are DSS tools for portfolio optimization, arbitrage trading, option hedging, and value-at-risk (VaR) analysis .

# 3 DSSs for Investment Decision Making

Three examples of analytic decision support systems for investment decisions are described in this section.

## 3.1 Portfolio Optimization

Holding a diversified portfolio is a way for investors to smooth out the risks and volatility associated with individual securities. Risk and return are conflicting objectives; to reduce risk, some return has to be sacrificed. An optimized portfolio gives the investor the maximum expected return for a portfolio subject to risk not exceeding a certain level. Equivalently, we can minimize portfolio risk or volatility for a given level of return that we want to achieve.

To illustrate, consider a simple model for portfolio optimization that can be built into a DSS. For simplicity, assume there are three securities and four equally likely scenarios in the market for the next month.

Suppose a portfolio consists of only security 2, i. e., the three portfolio weights are 0%, 100%, and 0%. From the table, this implies an expected return of 0.93% per month, i. e., $E(r_P) = 0.93\%$. The portfolio's risk is measured by its the *standard deviation* (*SD*) of returns, which is 2.95%. As defined in MPT and illustrated here, *risk* is the *uncertainty of achieving a particular return*.

Consider a sensible investor, who splits the portfolio evenly across the first two securities: 50%, 50%, 0%. She leaves out security 3 since it is the riskiest, and does not offer the highest expected return. Her portfolio's return in any scenario $i$ is a weighted sum of the returns of the $n$ individual holdings. Here, $n = 3$ and for $i = 1$ (i. e., scenario 1 occurs), then from the Table 1 data, we can compute the monthly return:

$$r_i = 0.5 \times 6.91 + 0.5 \times 1.95 + 0.0 \times 4.11 = 4.43$$

**Table 1.** Returns on three securities forecast for four scenarios. The example can be extended to more securities and more scenarios if desired

| | | Monthly returns (%) | | |
|---|---|---|---|---|
| **Scenario** | **Probability** | **Security 1** | **Security 2** | **Security 3** |
| 1 | 0.25 | 6.91 | 1.95 | 4.11 |
| 2 | 0.25 | −1.24 | 2.26 | −4.93 |
| 3 | 0.25 | 3.36 | −4.07 | −1.62 |
| 4 | 0.25 | −4.90 | 3.59 | 6.44 |
| Expected return | | **1.03** | **0.93** | **1.00** |
| Standard deviation | | **4.48** | **2.95** | **4.51** |

In general, the formula below gives the portfolio's return in scenario $i$, where $x_j$ is the fraction of assets invested in security $j$, and $r_{ij}$ is security $j$'s return in scenario $i$:

$$r_i = \sum_{j=1}^{n} r_{ij} x_j .$$

Since all four scenarios are equally likely, the result shown in Figure 5 is $E(r_P) = 0.98\%$ and $SD(r_P) = 2.04\%$. With equal probability scenarios, the standard deviation comes from the Excel function =STDEVP(F3:F6), which is the population standard deviation, since we assume the scenario returns are the entire population rather than a sample of the population.

$$SD_{\text{Population}}(r_i) = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(r_{ij}x_j - r_i)^2}$$

In this example, diversification across two securities increases the return *and* lowers the risk. However, can we do better? The answer comes from running a nonlinear program for the portfolio optimization model as shown in the solver parameters dialog box in Figure 5.

The model's decision variables in Figure 5 are the weights or percentage of investable assets put into the three securities, which are in cells C2:E2. Obviously these weights need to sum to 1.0, and we will constrain them to be non-negative, although that can be relaxed if the investor is willing to short-sell securities. In that case, a negative weight on a security implies shorting, or selling the security in that amount, in the hopes of profitably buying back later at a lower price. The second constraint is that the expected return be greater than or equal to the 0.9825% provided by the (50%, 50%, 0%) portfolio.

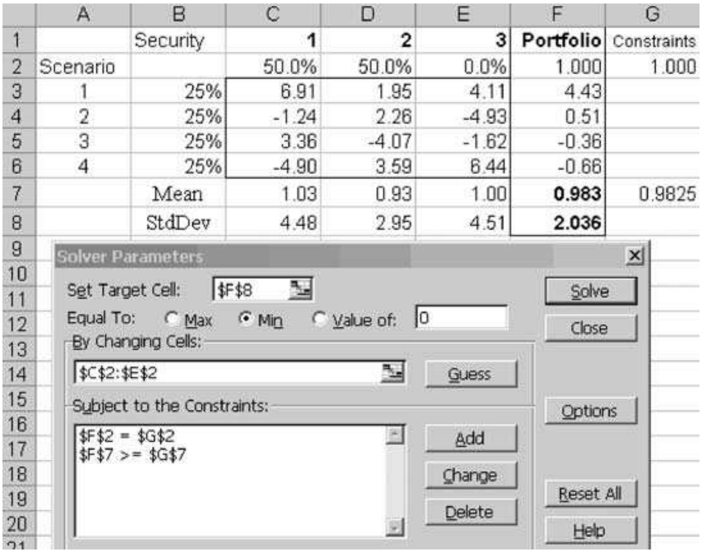


**Figure 5.** Portfolio optimization using Excel Solver to run a nonlinear program. The objective is to minimize the risk subject to two constraints and non-negative values for the decision variable, which are the portfolio weights

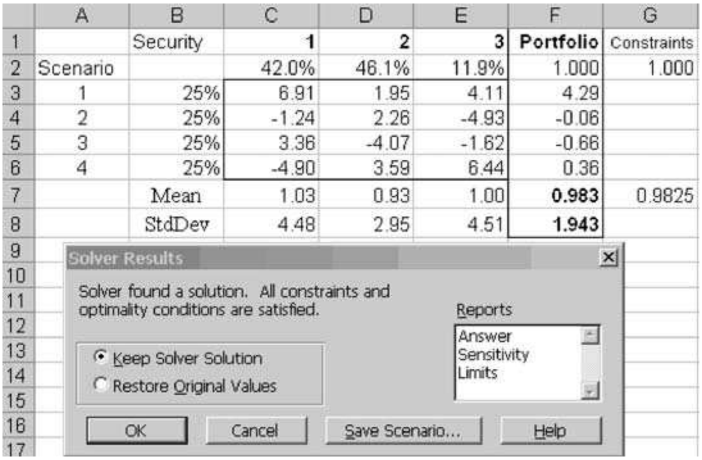


**Figure 6.** Portfolio optimization leads to a solution with equal expected return and lower risk

The objective is to minimize the portfolio risk as measured by the standard deviation of returns of the portfolio. Running the model (Figure 6) shows that the portfolio given by the weights (42%, 46.1%, 11.9%) has the same expected return as (50%, 50%, 0%) but has a standard deviation of 1.94%, which is nearly 10 basis points per month lower than the two-security portfolio.

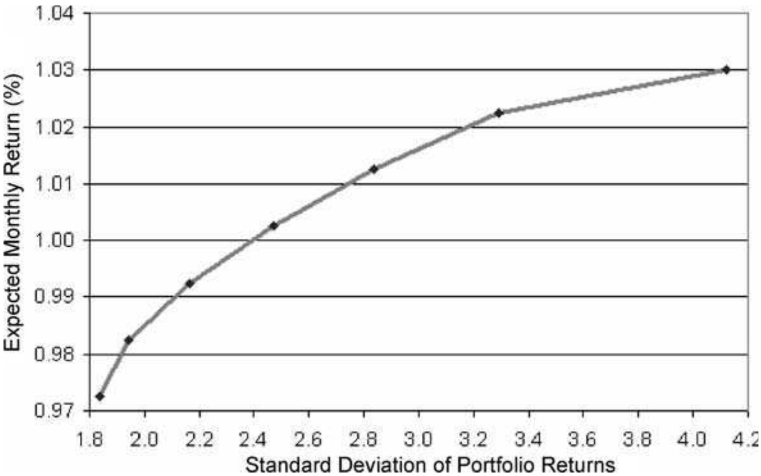


**Figure 7.** Efficient frontier of portfolio returns and risk for three security portfolio

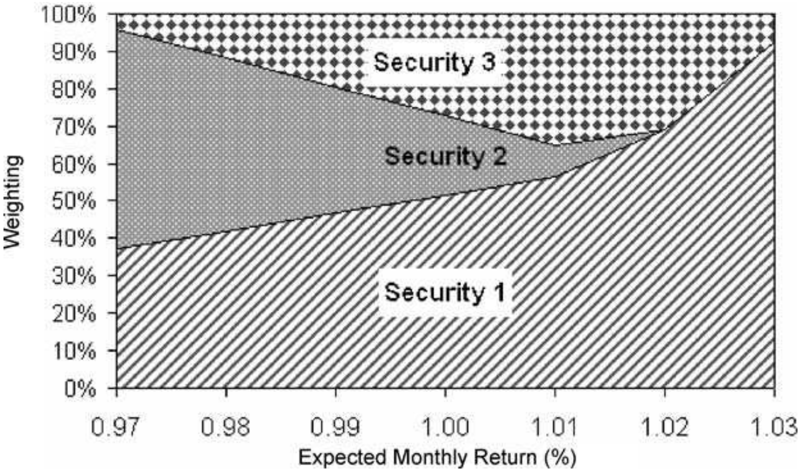


**Figure 8.** Optimal portfolio weights for varying levels of expected returns. As the return and risk level increases, security 2's weighting decreases

Having solved the model once, it is a useful exercise to vary the minimum mean return (cell G7) of the portfolio. Rerunning the model six times using Solver, we will trace out an efficient frontier by varying the minimum return constraint from 0.97% to 1.02% in 0.01% increments.

A DSS representation such as Figure 8 shows that a low-risk investor would hold most of his portfolio in security 2, while a more risk-tolerant investor will weight security 1 most heavily. The modeling and DSS approaches described for this simple three-security portfolio can be scaled to far larger problems. Below is

| | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | Investment Non-Linear Program | | | | | | | | | | | | | |
| 2 | | | | | | | | Sum of Portfolio Weights | | | | | | | | |
| 3 | | | Portfolio | Portfolio Weights x(j) | | | | 100% | = | 100% | | | | | | |
| 4 | Portfolio Average | | Stnd. Dev | Sun Micro(SUNW) | MSFT | GM | IBM | Apple (AAPL) | P&G (PG) | J&J (JNJ) | Merck (MRK) | Ford (F) | Intel (INTC) | CocaCola(K | Citi (C) | GS |
| 5 | | 0.80% | 6.17% | 4.3% | 9.4% | 0.0% | 0.0% | 0.0% | 5.0% | 3.4% | 6.0% | 0.0% | 5.5% | 30.0% | 9.5% | 27.0% |
| 6 | | >= | | SUN | MSFT | GM | IBM | APPLE | P&G | J&J | MERCK | FORD | INTEL | KO | C | GS |
| 7 | MinReturn | 0.80% | | 1.0% | 1.0% | 0.7% | 0.8% | 0.7% | 0.4% | 0.5% | 0.5% | 0.6% | 0.9% | 0.6% | 0.8% | 1.1% |
| 8 | | | Stnd.Dev= | 17.3% | 17.6% | 11.0% | 11.4% | 22.6% | 10.4% | 9.2% | 10.5% | 10.5% | 16.1% | 5.8% | 8.6% | 15.5% |
| 9 | | | | | | | | | | | | | | | | |
| 10 | Scen- | Proba- | Portfolio R | Security Returns by Scenario | | | | | | | | | | | | |
| 11 | ario | bilities | by Scenar | SUN | MSFT | GM | IBM | APPLE | P&G | J&J | MERCK | FORD | INTEL | KO | C | GS |
| 12 | 1 | 1/24 | -2.1% | -1.7% | -4.5% | -7.5% | -2.1% | 18.0% | 3.9% | -7.1% | -7.7% | -13.0% | 15.4% | 6.5% | -7.2% | -11.8% |
| 13 | 2 | 1/24 | 1.3% | 16.9% | 8.2% | 9.1% | -0.2% | 14.9% | 10.7% | 12.3% | -0.2% | 8.5% | 18.6% | 0.3% | -1.6% | -7.6% |
| 14 | 3 | 1/24 | -0.9% | 16.7% | -1.8% | -5.1% | -2.2% | -5.3% | -4.5% | -10.1% | -2.7% | -2.5% | -10.1% | -1.0% | -2.3% | 1.2% |
| 15 | 4 | 1/24 | 8.6% | 13.5% | 2.5% | 11.8% | -18.1% | 24.3% | 13.0% | 14.0% | 23.2% | 10.3% | 3.7% | -4.5% | 22.3% | 15.8% |
| 16 | 5 | 1/24 | 2.0% | 24.7% | -1.3% | 5.4% | 5.6% | 19.9% | 4.1% | -0.9% | -0.7% | -6.9% | -1.5% | -0.5% | -2.0% | 5.0% |
| 17 | 6 | 1/24 | 7.8% | 16.8% | 28.6% | -1.6% | 5.3% | 2.8% | 2.5% | -10.1% | -13.9% | 6.6% | 6.8% | -5.9% | 2.0% | 24.6% |
| 18 | 7 | 1/24 | 1.9% | 1.2% | -15.8% | 10.7% | 4.7% | -1.4% | -6.7% | -7.7% | 17.4% | -5.6% | 19.7% | 8.8% | 1.0% | -3.4% |
| 19 | 8 | 1/24 | -2.0% | 21.0% | -8.4% | -5.1% | -7.8% | 8.2% | -12.0% | -16.3% | -21.3% | -15.3% | 13.7% | 1.6% | -10.3% | 0.2% |
| 20 | 9 | 1/24 | 7.8% | -1.9% | 19.2% | 8.7% | 15.9% | 16.2% | -34.3% | -2.4% | 1.8% | 11.4% | 16.2% | 6.6% | 14.4% | 13.0% |
| 21 | 10 | 1/24 | -6.0% | -2.2% | -34.0% | 12.9% | -5.1% | -10.9% | 6.4% | 17.4% | 12.3% | 20.2% | -4.4% | -2.0% | -2.5% | -12.1% |
| 22 | 11 | 1/24 | -6.6% | -16.9% | -10.0% | -24.3% | -3.1% | -34.6% | 12.4% | 8.5% | 8.2% | -10.2% | -2.2% | -2.3% | 4.1% | -21.9% |
| 23 | 12 | 1/24 | 9.4% | 18.4% | 28.2% | -17.9% | 2.8% | 22.4% | -13.6% | 13.8% | 3.1% | -10.4% | 6.7% | -5.0% | -4.4% | 28.1% |
| 24 | 13 | 1/24 | 0.8% | 15.7% | -12.4% | -2.1% | 3.1% | -5.3% | 1.5% | -8.6% | -6.1% | 9.3% | -0.7% | -1.6% | 15.7% | 3.5% |
| 25 | 14 | 1/24 | 9.0% | 20.1% | 0.3% | 23.8% | 18.4% | 17.6% | 9.6% | -1.2% | -1.6% | -8.1% | 11.6% | -6.7% | 9.4% | 30.4% |
| 26 | 15 | 1/24 | -5.5% | -8.3% | -13.3% | -7.3% | -14.0% | -60.0% | 9.5% | 2.2% | 6.9% | 6.5% | -45.0% | 6.4% | -8.7% | -12.7% |
| 27 | 16 | 1/24 | -4.5% | -5.3% | 14.5% | -4.5% | -11.9% | -26.3% | 7.7% | -1.9% | 21.2% | 4.7% | 7.7% | -12.5% | -4.0% | -13.2% |
| 28 | 17 | 1/24 | -9.4% | -31.7% | -16.4% | -19.7% | -4.3% | -17.9% | 5.9% | 8.6% | 3.5% | -11.9% | -16.0% | -2.8% | -6.4% | -18.5% |
| 29 | 18 | 1/24 | 7.8% | -27.0% | -24.1% | 2.8% | -8.4% | -12.1% | 5.8% | 5.1% | 1.8% | 4.1% | -21.6% | 12.7% | 1.2% | 29.4% |
| 30 | 19 | 1/24 | 9.2% | 9.4% | 41.1% | 5.3% | 32.4% | 43.1% | -6.9% | -11.3% | -11.8% | 22.6% | 22.5% | 9.4% | 8.3% | 5.7% |
| 31 | 20 | 1/24 | -10.4% | -35.2% | -3.1% | 0.1% | -10.0% | -17.9% | -0.8% | 4.5% | -2.0% | -0.3% | -23.4% | -2.2% | -13.2% | -20.1% |
| 32 | 21 | 1/24 | -4.7% | -22.9% | -7.0% | -2.9% | -3.1% | 18.6% | -10.1% | -10.1% | -4.5% | 2.2% | -8.4% | 5.4% | -9.9% | -8.0% |
| 33 | 22 | 1/24 | 6.4% | 11.1% | 24.2% | 5.6% | 20.4% | 13.2% | -2.4% | 10.3% | 0.5% | 7.0% | 16.9% | -0.1% | 7.9% | 6.4% |
| 34 | 23 | 1/24 | 2.0% | -4.1% | 2.4% | 4.6% | -2.1% | -24.0% | 8.1% | 0.5% | -3.1% | -16.3% | -13.2% | 3.8% | 3.2% | 3.6% |
| 35 | 24 | 1/24 | -2.7% | -4.8% | 5.8% | 13.0% | 2.2% | 14.3% | 0.4% | 3.1% | -12.0% | 1.9% | 7.8% | -0.7% | 1.8% | -10.6% |

**Figure 9.** Portfolio optimization model in Solver for a universe of 13 stocks with 24 equally likely scenarios. The scenarios are based on the past two years of monthly data

an Excel-based model that could be part of an investment DSS to select the optimal portfolio from among 13 U.S. blue-chip equities including IBM, Microsoft, Ford, Coca-Cola, and Goldman Sachs.

Further steps in the analysis of this larger investment universe could include plotting the efficient frontier (Figure 10), and graphing how the optimal weightings change as risk and expected return are increased (Figure 11).

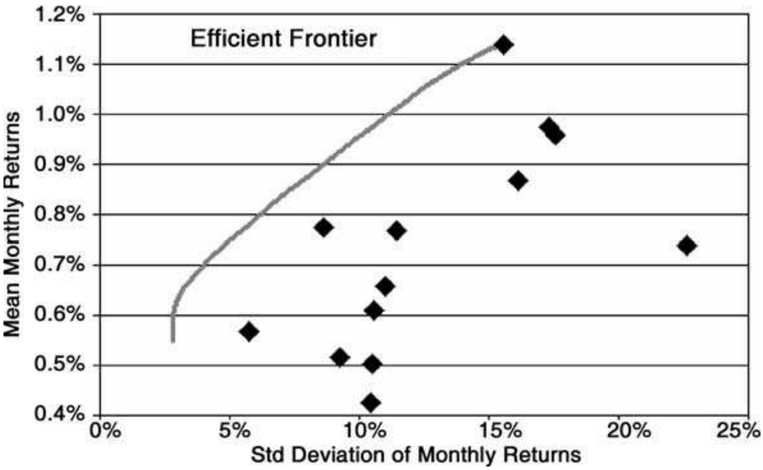


**Figure 10.** Efficient frontier line of portfolio returns and risk for portfolio with universe of 13 stocks shown with a diamond as individual holdings

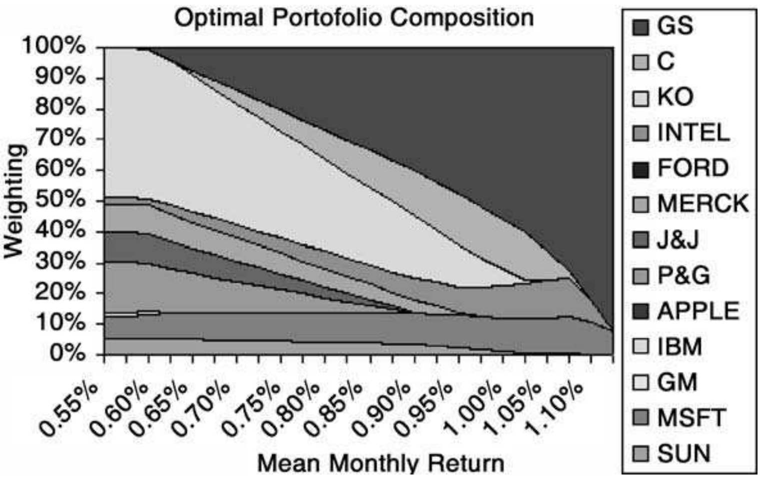


**Figure 11.** Optimal portfolio weights for varying levels of expected returns. As the return and risk level increases, GS's weighting decreases

These illustrations establish how a DSS that supports the development of portfolio optimization models will enable investors to diversify their risk more intelligently. The presentation layer of a DSS further supports the decision-making process, and helps the investor understand the analysis, and assess how robust the results are.

## 3.2 Arbitrage Trading Analysis

Finding optimally diversified investment portfolios suited to investors' risk preferences is a beneficial application for a DSS. Another role for an investment DSS is to identify arbitrage trading opportunities that arise. We next examine a less-subtle way to generate attractive investment returns by turning a DSS loose to try to find mispriced securities. A financial arbitrage exists when the same security, or substantially the same version of a security or underlying asset, trades at more than one price at the same time. Arbitrage trading generates a low- or no-risk profit by selling the overpriced instrument and buying the underpriced asset. The offsetting positions are later unwound in closing trades, or else the purchased security is delivered to the investor and then used to fulfill the settlement obligation for the security that was sold. Importantly, arbitrage traders need to ensure that any payments and settlement differences are accounted for, so that the purchased leg of an arbitrage does not create a costly borrowing need while awaiting the payment for the sold leg. For instance, U.S. stock trades settle on T + 3 (three business days after the trade) while foreign currency trades and some non-U.S. stock exchanges normally settle on T + 2. Same-day or T + 0 settlement occurs for exchange-traded futures and options trades via initial margin deposits, and for foreign currency trades when the continuous linked settlement (CLS) bank system is used.

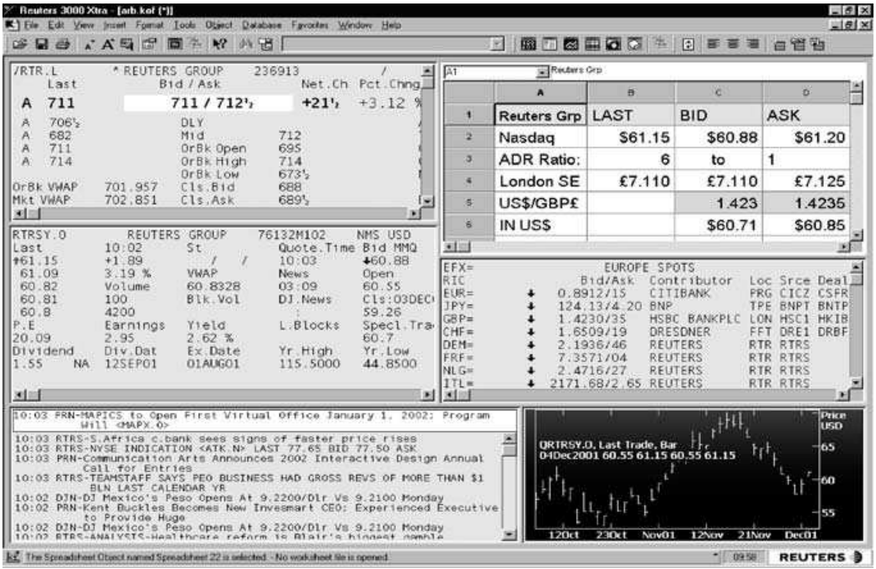


**Figure 12.** Spreadsheet from December 4, 2001 with live market prices for Reuters stock, ADRs, and European currencies

A simple arbitrage model is illustrated below in the Reuters 3000 Xtra workstation. Many large, global companies have a primary stock exchange listing in their home country as well as a secondary listing or American depository receipts (ADR) trading in the U.S. Reuters Group is a London-based global news, information, and technology company. The primary market for its stock trading is the London Stock Exchange (LSE). It also trades as an ADR on the U.S. Nasdaq stock market.

Several complications make the arbitrage trading model far from obvious. First, the London prices are in British pounds (GBP) while the ADRs are priced in U.S. dollars. In addition, the ADR shares each represent six of the underlying shares. Hence, six London shares must be traded for each ADR share bought or sold. Finally, a trader participating in these markets will buy shares or currency at the higher ask quote, and sell at the slightly lower bid quote.

In the upper left window in Figure 12, the London market quotes for Reuters are £7.110 bid and £7.125 ask. A buyer in London would pay the ask price of £7.125. In addition, there are currency conversions that need to be analyzed. For instance, if the investor is based in the U.S. and the London price looks underpriced, he or she will need to convert U.S. dollars to British pounds in order to buy in London. Again, the pounds will be bought at the ask price. In the Figure 12 screen shot under EUROPE SPOTS, the spot GBP exchange rate is given as \$1.4230 bid and \$1.4235 ask. To buy Reuters Group shares in London first requires the investor to deliver \$1.4235 for each £1 bought in order to buy Reuters stock on the LSE.

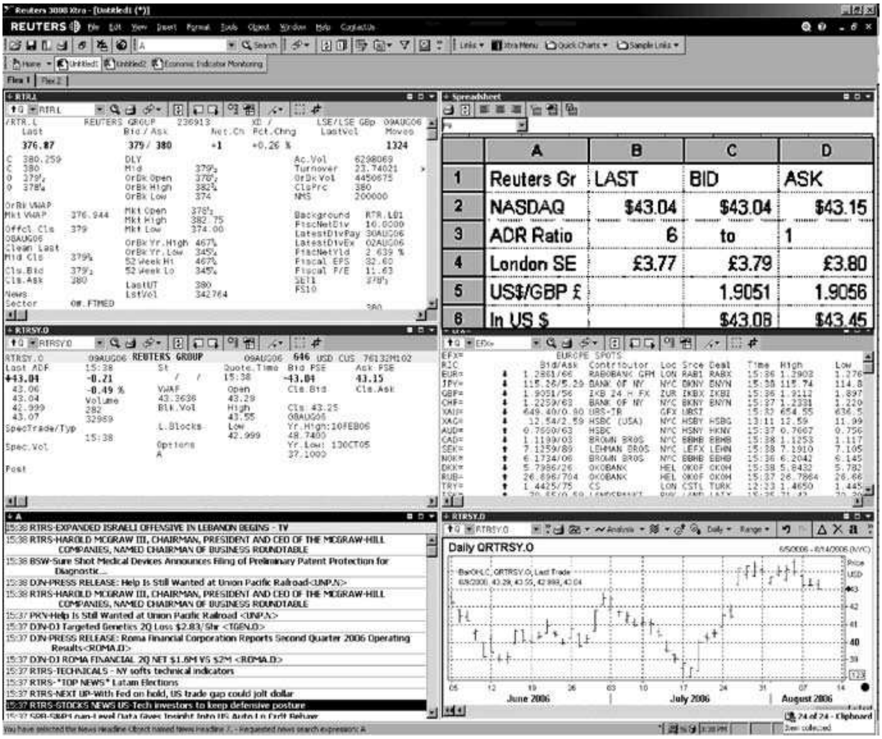


**Figure 13.** Spreadsheet with live market prices for stocks and currency from August 9, 2006. In this case the model in the upper right shows no arbitrageable mispricing

Reuters 3000 Xtra provides DSS functionality including a spreadsheet object that can be populated with live prices. As the market prices change, formulas and calculations are updated. In the example in Figure 12, applying the six-to-one ADR ratio and the real-time currency rates indicates the equivalent of one U.S. ADR share can be bought for

$$\text{ADR ratio} \times \text{LSE ask quote (£)} \times \text{exchange rate (\$s per £ ask quote)}$$

$$= 6 \times £7.125 \times \$1.4235 = \$60.85$$

on the London stock exchange. The ADR however can be sold at the bid quote, which is $60.88 on Nasdaq. A $0.03 theoretical arbitrage profit exists. While interesting, the price gap is probably not large enough to generate a profit after the commissions, fees, and risks associated with exchanging dollars for pounds, buying in London, and simultaneously selling on Nasdaq.

The no-arbitrage conditions for cross-listed securities are $\text{bid}_{\text{marketA}} < \text{ask}_{\text{marketB}}$ and $\text{bid}_{\text{marketB}} < \text{ask}_{\text{marketA}}$, where the quotes have been converted into the same currency. Figure 14 provides another version of the arbitrage model for trading a London stock with an ADR listed on a U.S. market.

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | | | **Bond Fund Daily VaR Simulation** | | | | | |
| 2 | | *Today* | 1 | 5 | 10 | 30 | Year | |
| 3 | | | 4.00% | 5.00% | 6.50% | 8.00% | Yield | |
| 4 | | Value | 0.9615 | 0.7835 | 0.5327 | 0.0994 | Discount factor | |
| 5 | Bond 1 | 100.00 | 104 | 0 | 0 | 0 | | |
| 6 | Bond 2 | 279.333 | 20 | 60 | 400 | 0 | | |
| 7 | Bond 3 | 96.70 | 25 | 25 | 25 | 400 | | |
| 8 | Total | **476.03** | | | | | | |
| 9 | | | 0.10% | 0.13% | 0.12% | 0.10% | Std dev of yield change | |
| 10 | | | **-0.07%** | **-0.01%** | **-0.04%** | **-0.02%** | Yield change | |
| 11 | | *Tomorrow* | 3.93% | 4.99% | 6.46% | 7.98% | Yield | |
| 12 | | Value | 0.9622 | 0.7839 | 0.5347 | 0.0999 | Discount factor | |
| 13 | Bond 1 | 100.07 | 104 | 0 | 0 | 0 | | |
| 14 | Bond 2 | 280.17 | 20 | 60 | 400 | 0 | | |
| 15 | Bond 3 | 96.99 | 25 | 25 | 25 | 400 | | |
| 16 | Total | **477.23** | | | | | | |
| 17 | P&L | **1.20** | (in $million) | | | | | |

**Figure 14.** Spreadsheet for the estimation of bond portfolio value and VaR simulation

Many other forms of arbitrage-driven investing can be supported by DSS technologies. In many cases, the DSS will alert the investor to prices that for short time periods are out of line, or that, while not a pure risk-free arbitrage, do reflect a divergence from a historical pattern or a substantial move away from a fundamental value. For instance, derivatives contracts such as futures or options are often analyzed in DSSs with reference to the underlying security and its cash market price. At some level of price dislocation, the investor will seek to buy the underpriced instrument and sell the more expensive one.

## 3.3 Value-at-Risk Analysis

In recent years value-at-risk (VaR) models have taken on greater importance, especially for risk-management purposes (Jorion 2006). Financial regulators are particularly eager to use VaR to set capital adequacy levels for banks and other financial institutions in a consistent way that reflects the risk of the positions held. The Basle II agreement (2004) among 13 central banks uses VaR as part of an international standard for measuring the adequacy of a bank's capital, and promotes greater consistency in the way banks and banking regulators approach risk management.

A VaR calculation is aimed at making a plain English statement: "We are $X$% certain that we will not lose more than $V$ dollars in the next $N$ days." An analyst would then say that $V$ is the $N$-day VaR for an $X$% confidence level. For example, if a one-day $V$ = $30 million, a bank would say that its daily VaR at a 95% confidence level is $30 million. That is, there is only 1 chance in 20 that a one-day loss of $30 million or more will occur. Regulators are in the processing of mandating that the capital a bank is required to keep as a cushion against losses correspond to its VaR with $N = 10$ and $X = 99$.

Three examples will help to illustrate how VaR(10, 99%) is computed. Returns are assumed to be normally distributed with mean zero (no positive or negative trend) and standard deviations as given below.

Example 1 – Assume:

- The volatility of the Google share price is 2% per day
- The size of the Google position is $10 million

Therefore, the standard deviation of change in value of position over one day is $0.02 \times \$10$ million = $200,000. The 10-day standard deviation is therefore $\sqrt{10} \times 200,000 = \$632,456$.

On the normal distribution with mean zero and standard deviation equal one, the number of standard deviations to estimate the probability 0.99 is 2.33. Therefore the 99% VaR = 2.33 × $632,456 = $1,473,621 over a 10-day period.

Example 2 – Assume:

- The volatility of Vodafone stock is 1% per day
- The size of the Vodafone position is $5 million

The standard deviation of change in one day is $50,000, and the S.D. of change over 10 days is $\sqrt{10}$ times this, or $158,144. Therefore, the 10-day 99% VaR = 2.33 × $158,144 = $368,405.

Example 3 – Assume:

- These Google and Vodafone positions are combined in a $15 million portfolio. Their daily returns have a correlation of +0.7.

For a portfolio, the 10-day standard deviation can be derived from the individual standard deviations and the cross-correlations, $\sigma$:

$$\sqrt{S.D._a^2 + S.D._b^2 + S.D._c^2 + \ldots + 2\sigma_{ab} S.D._a S.D._b + 2\sigma_{ac} S.D._a S.D._c} + 2\sigma_{bc} S.D._b S.D._c + \ldots$$

$$= \sqrt{S.D._G^2 + S.D._V^2 + 2 \times 0.7 \times S.D._G \times S.D._V}$$

$$= \sqrt{632,456^2 + 158,114^2 + 2 \times 0.7 \times 632,456 \times 158,114}$$

$$= \$751,665$$

Therefore, the 99% VaR is 2.33 × $751,665 = $1,751,379. Notice, this is about *5% less* than the sum of the VaRs from the two separate positions: $1,473,621 + $368,405 = $1,842,027. Again, the diversification of a portfolio of securities that have less than perfect (1.0) correlation provides benefits.

Now that the basic VaR computations have been reviewed, let us look at a spreadsheet-based DSS for VaR analysis. Often, an investment portfolio is made up of securities for which the precise volatility and correlation measures are not known. This could be due to a lack of historic data or conditions on the security that make its past data unrepresentative. As a result, the variables in the equations just described would not be available. Consider an investor with holdings of bonds that have coupon and principal payments due 1, 5, 10, and 30 years from now.

The investor does not have past prices of these specific bonds, but does have a forecast of the volatility of the interest rates for each of these time periods. In such cases, portfolio simulations can provide VaR estimates and help an investor to understand the volatility and risk level of the investment.

Consider the example below. The three bonds pay interest and principal according to Table 2 below (all cash flows in millions of dollars):

**Table 2.** The interest and principal paid by three example bonds

| | Year 1 | Year 5 | Year 10 | Year 30 |
|---|---|---|---|---|
| Bond 1 | 104 | 0 | 0 | 0 |
| Bond 2 | 20 | 60 | 400 | 0 |
| Bond 3 | 25 | 25 | 25 | 400 |

The market's yields by maturity date are used to graph out the *yield curve*, and are given in Table 3 below:

**Table 3.** The market's yield by maturity date

| Year 1 | Year 5 | Year 10 | Year 30 |
|---|---|---|---|
| 4.00% | 5.00% | 6.50% | 8.00% |

Based on standard discounting, the market value of bond 3 is:

$$\frac{25}{1.04^1}+\frac{25}{1.05^5}+\frac{25}{1.065^{10}}+\frac{400}{1.08^{30}}= \$96.70 \text{ million}$$

Similarly, the market value of bond 1 is \$100 million, that of bond 2 is \$279.3 million, and the total value of the portfolio is \$476.03 million.

What is the portfolio's daily VaR at a 95% confidence level? To answer this, a model of the portfolio's valuation is needed. In Excel (Figure 14), we calculate the portfolio's value at today's yields in cell B8. The assumptions about daily yield changes are in cells C9:F9, which indicate that interest rates will vary randomly from day to day with a normal distribution with an expected change equal to zero, and standard deviation, or volatility, of 10 to 13 basis points, depending on the point on the yield curve.

Based on one realization of the four random variable (cells C10:F10), we compute tomorrow's value as \$477.23 million, or \$1.20 million more than today. An

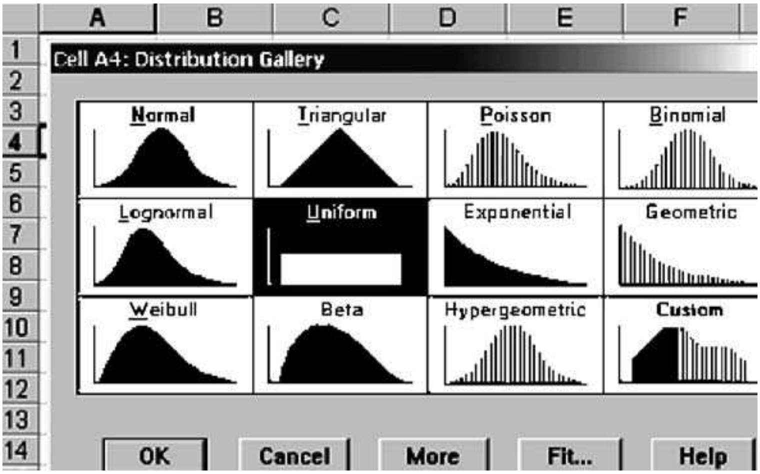


**Figure 15.** Specifying the distribution of the random variables in the model

important part of VaR modeling is to represent the correlations between the different securities accurately.

In the case of changes in interest rates on the yield curve, the shifts along the curve are not independent of each other. In other words, when 5-year interest rates rise, the 10-and 30-year rates tend to rise also. In this illustration, the CrystalBall add-in to Excel is being used to run the VaR simulation. In CrystalBall we can set correlation levels among the random variables or input cells that it will be generating.

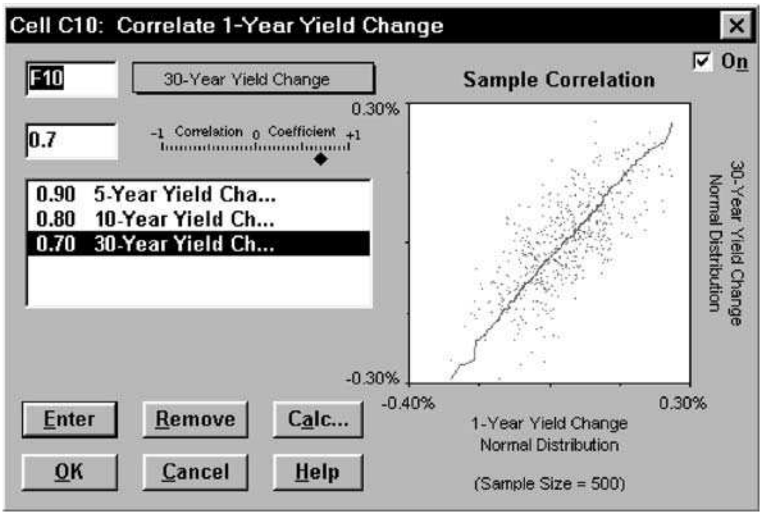


**Figure 16.** Entering the correlation assumptions across the investment portfolio holdings. In this case, the change in the one-year and 30-year yields have a 0.70 correlation

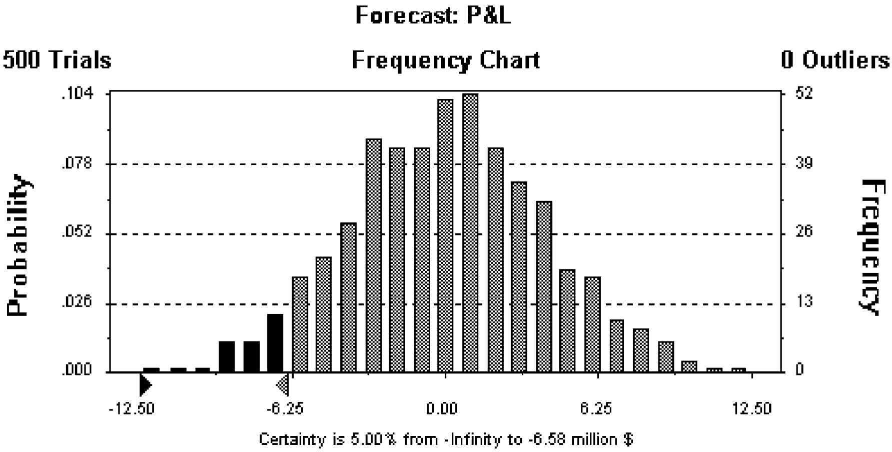


**Figure 17.** Distribution of outcomes for 500 runs of bond portfolio simulation to estimate its 95% one-day VaR = $6.58 million

Once the four interest rate variables have been specified, the model can be run for as many trials as desired. In this case, the simulation ran through 500 days of yield changes. The observed outcome variable is the daily profit and loss (P&L) of the portfolio. We are interested in the 95% VaR, which is the value, $v$, of the P&L for which Prob(P&L$\leq v$) = 5%. This point $v$ is at −$6.58 million from Figure 17. Therefore the 95% VaR is $6.58 million, which means that one day a month (1 in 20 trading days), the bond portfolio will suffer a loss of $6.58 million or more.

Value-at-risk modelling is an increasingly popular method for risk management. It has the advantage of allowing investors and financial institutions to make risk comparisons across asset classes (equities, bond, currencies, derivatives, etc.). DSS tools are increasingly used to carry out VaR assessments, and to find hedging and risk mitigating opportunities proactively. As with the portfolio optimization and arbitrage trade modelling examples already discussed, the greatest benefits from VaR come from using a DSS to empower the investment manager or decision maker to explore and analyze the complete range of alternatives, and to make well-grounded financial decisions in the face of price risk and market uncertainty.

# 4 Conclusions

Financial DSSs for investment decision making are in wide use today. Despite their presence, opportunities exist to exploit the power of DSSs more fully, particularly among small professional and individual investors. The standard components of DSSs (Figure 18) are evident in investment DSS: database, model base, and interfaces. The examples detailed in the previous section illustrated the specific instances of these components.

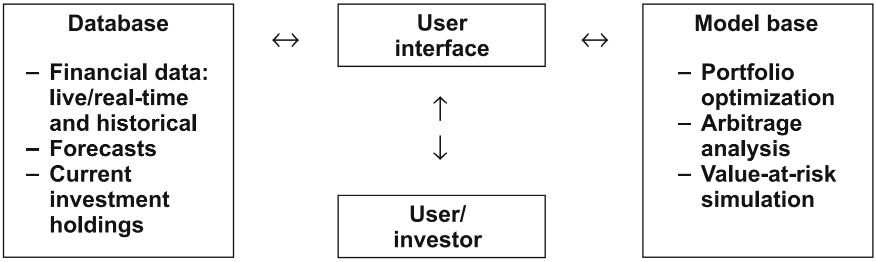


**Figure 18.** The key elements of a financial DSS for investor decision making

This chapter provided three illustrations of spreadsheet-based DSSs for investment modeling and decision making. In these specific examples and more generally, the role of DSSs for investment management is valuable and important for improving decision quality. As the methods and models in investment DSS become more widely understood and implemented, decisions and outcomes for investors will improve. While greed and fear continue to drive the challenge of investing, their harmful influences on decision making can be minimized by DSSs.

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# PART IX

# Decision Support Cases and Applications

# CHAPTER 57
# Flying High with Real-Time Business Intelligence

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Real-time data warehousing and business intelligence (BI), supporting an aggressive Go Forward business plan, have helped Continental Airlines transform its industry position from worst to first and then from first to favorite. With a $30 million investment in hardware and software over six years, Continental has realized conservatively over $500 million in increased revenues and cost savings in areas such as marketing, fraud detection, demand forecasting and tracking, and improved data center management. Continental is now recognized as a leader in real-time business intelligence based upon its scalable and extensible architecture, prudent decisions on what data are captured in real time, strong relationships with end users, a small and highly competent data warehouse staff, a careful balance of strategic and tactical decision-support requirements, and understanding of the synergies between decision support and operations, and new business processes that utilize real-time data.

**Keywords:** Business intelligence; Dashboard; Data warehouse; Decision support; Real time

## 1 Introduction

Real-time business intelligence (BI) is taking Continental Airlines to new heights. Powered by a real-time data warehouse, the company has dramatically changed all aspects of its business. Continental's president and chief operating officer (COO), Larry Kellner, describes the impact of real-time BI in the following way: "Real-time BI is critical to the accomplishment of our business strategy and has created significant business benefits." In fact, Continental has realized more than $500 million in cost savings and revenue generation over the past six years from its BI initiatives, producing a return-on-investment (ROI) of more than 1,000%.

Continental's current position is dramatically different from only 10 years ago. The story begins with the arrival of Gordon Bethune as chief executive officer (CEO), who led Continental from worst to first position in the airline industry.

A key to this turnaround was the Go Forward plan, which continues to be Continental's blueprint for success and is increasingly supported by real-time BI and data warehousing. Currently, the use of real-time technologies has been critical for Continental in moving from first to favorite among its customers, especially among its best customers.

Incidentally, some people prefer the term right time over real time in order to emphasize that data only needs to be as fresh as the decisions or business processes require. Depending on the business need, data can be hourly, daily, and even weekly or monthly and still be real time. We use the terms real time and right time synonymously.

Continental's real-time warehouse provides a powerful platform for quickly developing and deploying applications in revenue management, customer relationship management, flight and ground operations, fraud detection, security, and others. Herein we describe some of these applications, the quantifiable benefits they are generating, and the technology in place that supports. Continental's experiences with real-time BI and data warehousing have resulted in insights and practices from which other companies can benefit, and these lessons are discussed.

Decision support has evolved over the years, and the work at Continental exemplifies current practices. The chapter concludes by putting Continental's real-time BI and data warehousing initiatives into a larger decision-support context.

## 2 Continental's History

Continental Airlines was founded in 1934 with a single-engine Lockheed aircraft on dusty runways in the American Southwest (the company's history is available at www.continental.com/company). Over the years, Continental has grown and successfully weathered the storms associated with the highly volatile, competitive airline industry. With headquarters in Houston, Texas, Continental is currently the USA's fifth largest airline and the seventh largest in the world. It carries approximately 50 million passengers a year to five continents (North and South America, Europe, Asia, and Australia), with over 2,300 daily departures, to more than 227 destinations. Continental, along with Continental Express and Continental Connection, now serves more destinations than any other airline in the world. Numerous awards attest to its success as an airline and a company (see Appendix A).

### 2.1 An Airline in Trouble

Only 10 years ago, Continental was in trouble. There were 10 major US airlines, and Continental ranked 10$^{th}$ in terms of on-time performance, mishandled baggage, customer complaints, and denied boardings because of overbooking. Not surprisingly, with this kind of service, Continental was in financial trouble. It had filed for chapter 11 bankruptcy protection twice in the previous 10 years and was heading for a third, and likely final, bankruptcy. It had also gone through 10 CEOs in 10 years. People joked that Continental was a perfect 10.

## 2.2 Enter Gordon Bethune and the Go Forward Plan

The rebirth of Continental began in 1994 when Gordon Bethune took the controls as CEO. He and Greg Brenneman, who was a Continental consultant at the time, conceived and sold to the board of directors the Go Forward plan. It had four interrelated parts that had to be executed simultaneously.

- *Fly to win.* Continental needed to understand better what products customers wanted and were willing to pay for.
- *Fund the future.* Continental needed to change its costs and cash flow so that the airline could continue to operate.
- *Make reliability a reality*. Continental had to be an airline that got its customers to their destinations safely, on time, and with their luggage.
- *Working together.* Continental needed to create a culture where people wanted to come to work.

Most employees supported the plan, and those who did not left the company. Under Bethune's leadership, the Go Forward plan, and a re-energized workforce, Continental made rapid strides. Within two years, it moved from worst to first in many airline performance metrics (Bethune and Huler 1998).

## 2.3 Information Was Not Available

The movement from worst to first was, at first, only minimally supported by information technology (IT). Historically, Continental had outsourced its operational systems to EDS, including the mainframe systems that provided a limited set of scheduled reports, and there was no support for ad hoc queries. Each department had its own approach to data management and reporting.

The airline lacked the corporate data infrastructure for employees to access the information they needed quickly to gain key insights about the business. However, senior management's vision was to merge, into a single source, information scattered across the organization so that employees in all departments could conduct their own business analyses to execute better and run a better and more-profitable airline.

## 2.4 Enter Data Warehousing

This vision led to the development of an enterprise data warehouse. Janet Wejman, chief information officer (CIO) at the time, recognized that the warehouse was a strategic project and brought the development, subsequent maintenance, and support all in house. She believed the warehouse was core to Continental's business strategy, so it should not be outsourced. Work on the warehouse began, and after six months of development, it went into operation in June 1998.

The initial focus was to provide accurate, integrated data for revenue management. Prior to the warehouse, only leg-based (a direct flight from one airport to another) data was available. Continental could therefore not track a customer's itinerary from origin to destination through several stops. Thus, they could not study market and customer behavior, nor optimize the entire network of flights. The warehouse integrated multiple data sources—flight schedule data, customer data, inventory data, and more—to support pricing and revenue management decision making based on journey information.

The data warehouse provided a variety of early, big wins for the business. The initial applications were soon followed by applications that required integrating customer information, finance, flight information, and security. These applications created significant financial lift in all areas of the Go Forward plan. Figure 1 gives three examples of how the new, integrated enterprise data was initially used at Continental.

**Demand-driven dispatch**

Prior to the warehouse, flight schedules and plane assignments were seldom changed once set, regardless of changes in markets and passenger levels. Continental operated flights without a detailed, complete understanding of each flight's contribution to profitability. After the data warehouse, Continental created the demand-driven dispatch application that combined forecast information from the revenue management data mart (which is integrated with the enterprise data warehouse) with flight schedule data from the data warehouse, to identify opportunities for maximizing aircraft usage. For example, the system might recommend assigning a larger plane to a flight with unusually high demand. Continental uses this application to cherry-pick schedule changes that increase revenue. Demand-driven dispatch has lead to an estimated \$5 million dollars a year in incremental revenue.

**Goodwill letters**

An eight-month test of the airline making goodwill gestures to customers showed that even small gestures can be very important to building loyalty. To make these gestures, marketing analysts used the data warehouse to marry profitability data and algorithms with customer records to identify Continental's high-value customers. The marketing department then divided these high-value customers into three groups. When any of these individuals was delayed more than 90 minutes, one group received a form letter apologizing, the second group received the letter and a free trial membership to the President's Club (a fee-based airport lounge) or some other form of compensation, and the third group received no letter at all.

Customers who received regular written communication spent 8% more with the airline in the next 12 months. In addition, nearly 30% of those receiving the President's Club trial membership joined the club following the trial, resulting in an additional $6 million in revenue. The concept of goodwill letters was expanded across the company to include the top 10% of Continental's customers.

**Group snoop**

Group snoop refers to a fare rule and contract compliance application that attempts to reduce the risk and financial impact of no-show customers for any given flight. Because of the impact that groups can have on the final number of passengers boarded on a flight, advanced deposits and other contractual obligations are required for bookings of groups of 10 or more people traveling together.

However, travel agents can bypass this requirement and book a group of 16 by making two bookings of seven and nine without deposits or contracts. The fare rule has therefore created an incentive for agencies to block space in smaller groups to avoid making a deposit. Should the group not materialize, the financial impact to the airline can be significant. Sometimes agents convert smaller bookings to a group, but sometimes the bookings merely hold inventory space.

Using the booking and agency data from the warehouse, the group snoop application sorts reservations by booking agent and travel agent and then queries all groups of less than 10 to identify the same travel agent identification and itinerary. Continental can then assess seat inventory more accurately and get travel agents to comply with the group booking requirements. Group snoop has provided Continental an annualized savings of $2 million.

**Figure 1.** Three initial data warehouse applications

## 2.5 Raising the Bar to First to Favorite

Once Continental achieved its goals of returning to profitability and ranking first in the airline industry in many performance metrics, Gordon Bethune and his management team raised the bar by expanding the vision. Instead of merely performing best, they wanted Continental to be their customers' favorite airline.

The first-to-favorite strategy built on Continental's operational success and focuses on creating customer loyalty by treating customers extremely well, especially the high-value customers (who are called CoStars). The Go Forward plan identified more actionable ways the company could move from first to favorite. Technology became increasingly critical for supporting these new initiatives. At first, having access to historical, integrated information was sufficient for the Go Forward plan and it generated considerable strategic value for the company. However, as Continental moved ahead with the first-to-favorite strategy, it became increasingly important for the data warehouse to provide real-time, actionable information to support enterprise-wide tactical decision-making and business processes.

Fortunately, the warehouse team had anticipated and prepared for the ultimate move to real time. From the outset of the warehouse project, an architecture was built to be able to handle real-time data feeds into the warehouse, extracts of data from the warehouse into legacy systems, and tactical queries to the warehouse that required subsecond response times. Insights about the methods and challenges of providing real-time data feeds are provided by Brobst (2002). In 2001, real-time data became available in the warehouse.

# 3 Real-Time BI Applications

The amount of real-time data in the warehouse grew quickly. Continental moves real-time data (ranging from to-the-minute to hourly) about customers, reservations, check-ins, operations, and flights from its main operational systems to the warehouse. The following sections illustrate the variety of key applications that rely on real-time data. Many of the applications also use historical data from the warehouse.

## 3.1 Fare Design

To offer competitive prices for flights to desired places at convenient times, Continental uses real-time data to optimize airfares (using mathematical programming models). Once a change is made in price, revenue management immediately begins tracking the impact of that price on future bookings. Knowing immediately how a fare is selling allows the group to adjust how many seats should be sold at each given price. Last-minute, customized discounts can be offered to the most profitable customers, to bring in new revenue, as well as to increase customer satisfaction. Continental has earned an estimated $10 million annually through fare design activities.

## 3.2 Recovering Lost Airline Reservations

In 2002, an error in Continental's reservation system resulted in a loss of 60,000 reservations. Within a matter of hours, the warehouse team developed an application whereby agents could obtain a customer's itinerary and confirm whether the passenger was booked on flights.

Another similar situation happened in 2004 when the reservation system had problems communicating with other airlines' reservation systems. In certain circumstances, the system was not sending reservation information to other airlines, and, consequently, other airlines were not reserving seats for Continental's passengers. As a result, Continental customers would arrive for a flight and not have a seat. Once the problem was discovered, the data warehouse team was able to run a query to get the information on passengers who were affected but who had not yet flown. This information was fed back into the reservation system so that seats could be assigned, thus avoiding a serious customer relations problem.

## 3.3 Customer-Value Analysis

A customer value model using frequency, recency, and monetary value gives Continental an understanding of its most profitable customers. Every month, the customer value analysis is performed using data in the data warehouse, and the value is fed to Continental's customer-facing systems so that employees across the airline, regardless of department, can recognize their best customers when interacting with them.

This knowledge helps Continental react quickly, effectively, and intelligently in tough situations. For example, just after 9/11, Continental used customer value information to understand where its best customers were stranded around the world. Continental applied this information to its flight scheduling priorities, and, while the schedules were being revised, the company worked with its lodging and rental car partners to make arrangements for its stranded customers. The highest-value customer was in Zurich, and he used Continental's offices to conduct business until he was able to fly home.

## 3.4 Marketing Insight

Marketing Insight was developed to provide sales personnel, marketing managers, and flight personnel (e. g., ticket agents, gate agents, flight attendants, and international concierges) with customer profiles. This information, which includes seating preferences, recent flight disruptions, service history, and customer value, is used to personalize interactions with customers.

Gate agents, for instance, can pull up customer information on their screen and drill into flight history to see which high-value customers have had flight disruptions. Flight attendants receive the information on their final report, which lists the passengers on their flights, including customer value information. A commonly told story is about a flight attendant who learned from the final report that one of the high-value customers on board recently experienced a serious delay. She apologized to the customer and thanked him for his continuing business. The passenger was floored that she knew about the incident and cared enough to apologize.

## 3.5 Flight Management Dashboard

The flight management dashboard is an innovative set of interactive graphical displays developed by the data warehouse group. The displays help the operations staff quickly identify issues in the Continental flight network and then manage flights in ways to improve customer satisfaction and airline profitability.

Some of the dashboard's displays help operations better serve Continental's high-value customers. For example, one display, a graphical depiction of a concourse, is used to assess where Continental's high-value customers with potential service issues are located or will be in a particular airport hub (Figure 3). The display shows where these customers have potential gate-connection problems so that gate agents, baggage supervisors, and other operations managers can provide ground transportation assistance and other services so that these customers and their luggage do not miss flights.

Figure 2 shows that Flight 678 is arriving 21 minutes late to Gate C37 and eight high-value customers (3 and 5) need assistance in making their connections to Gates C24 and C29, will have only 12 minutes and 20 minutes, respectively, to make their flights.

On-time arrival is an important operational measure at Continental. The Federal Aviation Administration requires airlines to report arrival times and provide the summary statistics to the flying public. Therefore, another critical set of dashboard

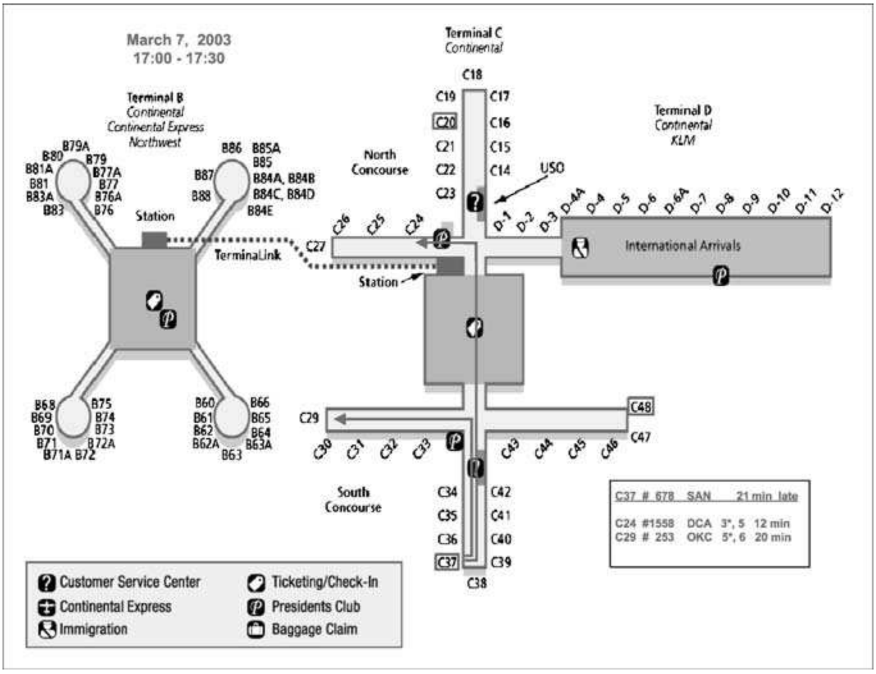


**Figure 2.** Concourse display of high-value customer activity

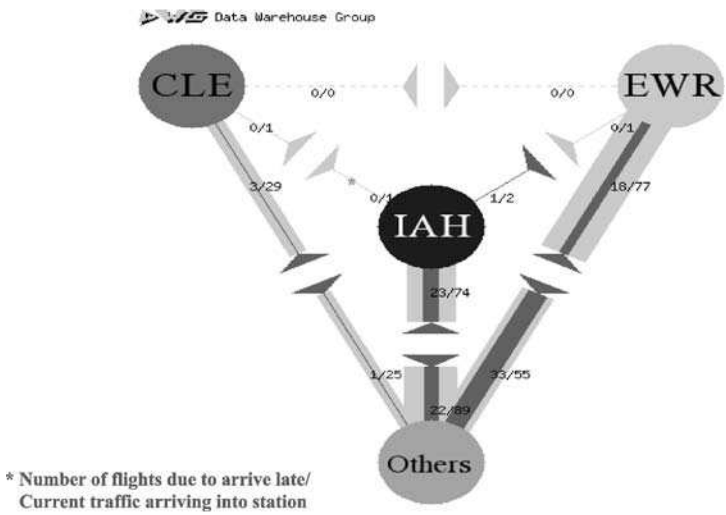


**Figure 3.** Display of flight lateness from/to hubs

displays helps operations keep arrivals and departures on time. One display shows the traffic volume between the three Continental hub stations and the rest of their network (Figure 3). The line thickness between hub locations is used to indicate relative flight volumes and the number of late flights so that the operations staff can anticipate where services need to be expedited. The ratio of the number of late flights to the total number of flights between the hubs is also shown. The operations staff can drill down to see individual flight information by clicking on the lines between the hub locations.

Another line graph summarizes flight lateness. Users can drill down to detailed pie charts that show degrees of lateness, and within each pie, to the individual flights in that category. Still another chart concentrates on flights between the US and Europe and the Caribbean. It can show similar critical flight statistics.

In all of these elements of the dashboard, high-level views can be broken down to show the details on customers or flights that compose different statistics or categories.

## 3.6 Fraud Investigations

In the wake of 9/11, Continental realized that it had the technology and data to monitor passenger reservation and flight manifests in real time. A prowler application was built so that corporate security could search for names or patterns. More than 100 profiles are run regularly against the data to proactively find fraudulent activity. When matches are found, an email and a message page are sent immediately to corporate security. Not only does this application allow corporate security to prevent fraud, but it also enhances their ability to gather critical intelligence through more-timely interviews with suspects, victims, and witnesses.

One profile, for example, looks for reservations agents who make an extraordinary number of first-class bookings. Last year, Continental was able to convict an agent who was manufacturing false tickets and then exchanging them for real first-class tickets that she sold to her friends. Continental received over $200,000 in restitution from that one case. In total, Continental was able to identify and prevent more than $15 million in fraud in 2003 alone.

### 3.7 Is it Safe to Fly?

Immediately after 9/11, planes were ordered to land at the nearest airport. Continental had 95 planes that did not reach their planned destination. Sometimes there were three or four planes at a little airport in a town with no hotels, and passengers had to move in with the local people. At Continental's headquarters, Federal Bureau of Investigation (FBI) agents moved into a conference room with a list of people they had authority to check. Queries were run against flight manifest data to see if potential terrorists were on flights, and it was only after a flight was deemed safe that it was allowed to fly. Continental Airlines was recognized by the FBI for its assistance in the investigations in connection with 9/11.

## 4 Supporting First to Favorite with Technology

Real-time BI requires appropriate technologies, that is, those that extend traditional BI and data warehousing. At Continental, real-time technologies, and the associated processes, are critical for supporting the first-to-favorite strategy.

### 4.1 The Data Warehouse

Continental's real-time BI initiative is built on the foundation of an 8-terabyte enterprise Teradata warehouse running on a 3 GHz, 10-node NCR 5380 server (Teradata uses the active data warehousing time to describe real-time data warehousing). The data warehouse supports 1,292 users who access 42 subject areas, 35 data marts, and 29 applications. Table 1 shows the growth of the data warehouse.

The basic architecture of the data warehouse is shown in Figure 4. Data from 25 internal operational systems (e. g., the reservations system) and two external data sources (e. g., standard airport codes) are loaded into the data warehouse. Some of these sources are loaded in real time and others in batches, based on the capabilities of the source and the business need. Critical information determined from analysis in the data warehouse (e. g., customer value) is fed from the data warehouse back into the operational systems.

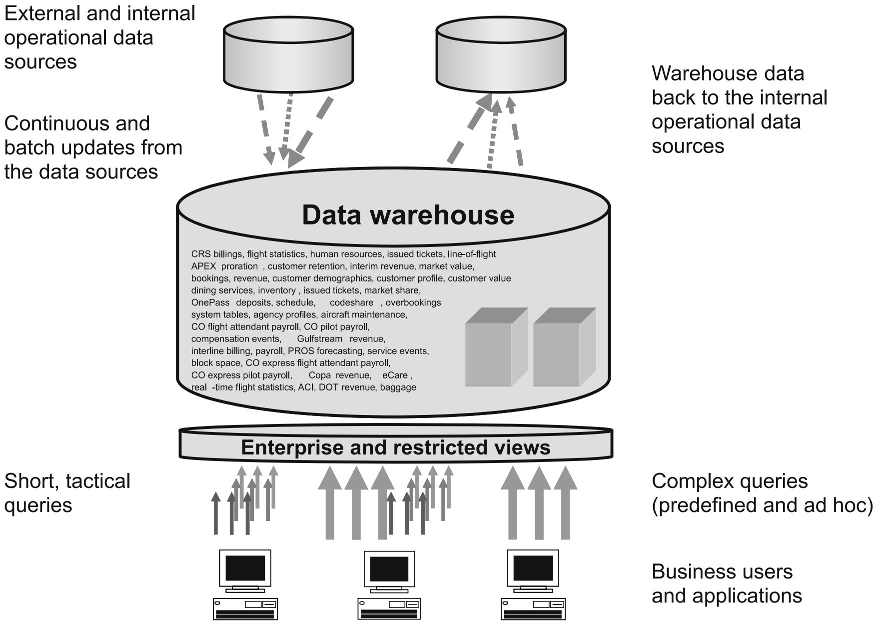


**Figure 4.** The data warehouse architecture

**Table 1.** Warehouse growth over time

| | 1998 | 2001 | Current |
|---|---|---|---|
| Users | 45 | 968 | 1,292 |
| Tables | 754 | 5,851 | 16,226 |
| Subject areas | 11 | 33 | 42 |
| Data marts | 2 | 23 | 35 |
| Applications | 0 | 12 | 29 |
| Data warehouse personnel | 9 | 15 | 15 |

## 4.2 Data Access

Users access the warehouse data in various ways (Table 2). Some use standard query interfaces and analysis tools, such as Teradata's QueryMan, Microsoft Excel, and Microsoft Access. Others use custom-built applications. Still others use either the desktop (i. e., fat client) or Web versions of Hyperion Intelligence. An estimated 500 reports have been created in Hyperion Intelligence, and many of these reports are pushed to users at scheduled intervals (e. g., at the first of the month, after the general ledger is closed). Other products include SAS Clementine for data mining and Teradata CRM for campaign management.

**Table 2.** Data warehouse access

| Application or tool | Types of users | Number of users |
|---|---|---|
| Hyperion Intelligence – Quickview (web) | Enterprise | 300 |
| Hyperion Intelligence – Explorer (desktop) | Enterprise | 114 |
| Access | Enterprise | 200 |
| Custom applications | Enterprise | 700 |
| Teradata CRM | Marketing | 20 |
| Clementine data mining | Revenue management | 10 |
| Teradata QueryMan | Enterprise | 150 |
| Excel | Enterprise | Many |

## 4.3 Real-Time Data Sources

The data warehouse's real-time data sources range from the mainframe reservation system, to satellite feeds transmitted from airplanes, to a central customer database. Some data feeds are pulled from the sources in batch mode. For example, files of reservation data are extracted and sent using the file transfer protocol (FTP) from a mainframe application on an hourly basis. An application converts the data into a third normal form and writes the updated records to queues for immediate loading into the data warehouse.

Other data feeds are loaded to the warehouse within seconds. Flight data in the form of flight system information records (FSIR) is sent in real time from airplanes via satellite to an operations control center system. FSIR data may include estimates for arrival time, the exact time of lift-off, aircraft speed, etc. This data is captured by a special computer and placed in a data warehouse queue, which is then immediately loaded into the warehouse.

Other data sources are pushed in real time by the sources themselves, triggered by events. For example, Continental's reservations system, OnePass frequent flier program, Continental.com, and customer service applications all directly update a central customer database. Every change made to a customer record in the customer database activates a trigger that pushes the update as extensible markup language (XML)-encoded data to a queue for immediate loading into the data warehouse.

## 4.4 The Data Warehouse Team

The data warehouse team has 15 people who are responsible for: managing the warehouse, developing and maintaining the infrastructure, data modeling, developing and maintaining data extraction, transformation and loading processes, and working with the business units. The organization chart for the data warehouse staff is shown in Figure 5.

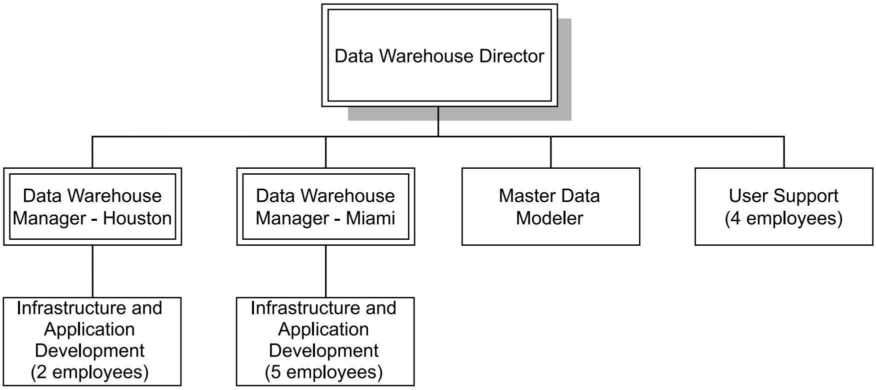


**Figure 5.** The data warehouse organization chart

## 4.5 Data Warehouse Governance

The data warehouse steering committee provides direction and guidance for the data warehouse. This large, senior-level committee has 30 members, most at director level and above. They come from the business areas supported by the data warehouse and are the spokespersons for their areas. Business areas that intend to participate in the warehouse are invited to join the committee. The warehouse staff meets with the committee to inform and educate the members about warehouse-related issues. In turn, the members identify business-area opportunities for the warehouse staff. They also help the warehouse team justify and write requests for additional funding. Another responsibility is to help set priorities for future directions for the data warehouse.

## 4.6 Securing Funding

The business areas drive funding for the data warehouse. There has always been one area that has helped either justify the initial development of the warehouse or encourage its later expansion. Revenue management supported the original development. The second and third expansions were justified by marketing to support the worst-to-first, and then first-to-favorite strategies. Corporate security championed the fourth, and most recent, expansion. This approach to funding helps ensure that the data warehouse supports the needs of the business.

The funding does not come directly from the business areas (i. e., their budgets). Rather, the funding process treats proposals as a separate capital expense. However, the business areas must supply the anticipated benefits for the proposals. Therefore, any proposal must have a business partner who identifies and stands behind the benefits.

# 5 The Benefits of Intelligence

Continental has invested approximately $30 million in real-time warehousing over the past six years. Of this, $20 million was for hardware and software, and $10 million for personnel. Although this investment is significant, the quantifiable benefits are orders of magnitudes larger. Specifically, over the past six years, Continental has realized over $500 million in increased revenues and cost savings, resulting in a ROI of over 1,000%.

The benefits range from better pricing of tickets to increased travel to fraud detection. Table 3 identifies some of the realized benefits. Because almost 1,300 users have warehouse access, it is impossible to know all the benefits. However, when big wins are achieved, the benefits are recorded and communicated throughout the company. This internal publicity helps preserve the excitement around warehouse use, and encourages business users to support warehouse expansion efforts.

**Table 3.** Sample benefits from real-time BI and data warehousing

| Category | Benefits |
|---|---|
| **Marketing** | • Continental performs customer segmentation, target marketing, loyalty/retention management, customer acquisition, channel optimization, and campaign management using the data warehouse. Targeted promotions have produced cost savings and incremental revenue of $15 to $18 million per year.<br>• A targeted CRM program resulted in $150 million in additional revenues in one year, while the rest of the airline industry declined by 5%.<br>• Over the past year, a goal was to increase the amount of travel by Continental's most valuable customers. There has been an average increase in travel of $800 for each of the top 35,000 customers. |
| **Corporate security** | • Continental was able to identify and prevent over $30 million in fraud over the past three years. This prevention resulted in more than $7 million in cash collected. |
| **Information technology** | • The warehouse technology has significantly improved data center management, leading to cost savings of $20 million in capital and $15 million in recurring data center costs. |
| **Revenue management** | • Tracking and forecasting demand has resulted in $5 million in incremental revenue.<br>• Fare design and analysis improves the ability to gauge the impact of fare sales, and these activities have been estimated to earn $10 million annually.<br>• Full reservation analysis has realized $20 million in savings through alliances, overbooking systems, and demand-based scheduling. |

# 6 Lessons Learned

The experiences at Continental confirm the commonly known keys to success for any enterprise-wide IT initiative: the need for senior management sponsorship and involvement, close alignment between business and IT strategies, careful selection of technologies, ongoing communication, clear vision and roadmap, and letting the business drive the technology. More interesting, though, are the following seven insights learned especially about the development and implementation of real-time business intelligence.

## 6.1 Lesson #1: Prepare Early On for Real-Time BI

Experienced BI professionals know there are continual demands for ever-fresher data. This demand is especially true for applications that are customer-facing or monitoring critical business processes. Even with traditional data warehousing, the trend is always for more-frequent warehouse updates.

Continental was able to move into real time quickly because the architecture had been designed with real time in mind. When the business needed real-time information, the warehouse team was prepared to deliver it.

## 6.2 Lesson #2: Recognize That Some Data Cannot and Should Not be Real Time

The decision to move additional data to real time should be made with care; data should only be as fresh as its cost and intended use justify. One reason for taking care is that real-time data feeds are more difficult to manage. Real-time processes, such as the flow of transaction data into queues, must be monitored constantly because problems can occur throughout the day (rather than just when a batch update is run). And, when problems with data occur, they must be addressed immediately, putting pressure on staffing requirements. Also, additional hardware may be needed to run loads and back up the data. Finally, obtaining real-time data feeds from some source systems can be prohibitively expensive (or even impossible) to implement.

## 6.3 Lesson #3: Show Users What Is Possible with Real-Time Business Intelligence

It is often difficult initially to get users to think outside the box. They typically want new systems to give them exactly what the old ones did. They need help visualizing what real-time information can do for them. Once they appreciate what is possible, they are more likely to say: “Help me change the way we do business.”

Continental's data warehousing staff addressed this problem by developing cool prototypes to show what is possible. One example is the concourse map application described earlier. When the users saw how data could be depicted in graphical ways (e. g., as an actual concourse with colors and lines with special meaning), they came up with their own ideas for how real-time data could help them operate the hubs better. At Continental, the current challenge is to find the time to support the many new ideas the users have.

## 6.4 Lesson #4: Adjust the Skill Mix on Both the Warehouse and Business Sides

In many companies, data warehousing staff generally has strong technical skills but limited business knowledge, while the business side has limited technical skills but good business knowledge. At the intersection of the warehousing and business organizations, there is a dramatic change in the technical/business skills and knowledge mix.

At Continental, this change is very gradual across the warehouse/business intersection. These warehouse personnel who work closest with the business users have considerable business knowledge. On the other hand, many business users have developed excellent technical skills; in fact, enough knowledge to build their own warehouse applications. The gradual shift in skills has reduced what can be a significant divide, and helps ensure that Continental's warehouse is used to support the business.

## 6.5 Lesson #5: Manage Strategic and Tactical Decision Support to Coexist

Strategic and tactical decision support have different characteristics, yet they must coexist in the same warehouse environment. Strategic decision support typically involves the analysis of large amounts of data that must be sliced and diced in various ways. Tactical (sometimes called operational) decision support often requires repeatedly accessing and analyzing only a limited amount of data with a subsecond response time.

Successful support for both requires both business and technical solutions. On the business side, priorities must be set for the processing of queries from users and applications. For example, a tactical query should have a higher priority than a strategic data-mining application. On the technical side, a query manager must recognize priorities, monitor queries, defer long-running queries for later execution, and dynamically allocate query resources.

At Continental, tactical queries that access single records are set to *high* priority. These queries usually come from applications such as continental.com that require instantaneous response time. All daytime batch data loads are set to *low* priority, and all daytime trickle feed loads are set to *medium* priority. Users who perform ad hoc queries are given *medium*-priority access.

### 6.6 Lesson #6: Real-Time BI Blurs the Line Between Decision Support and Operational Systems

For one thing, the performance requirements for real-time BI (e. g., response time, downtime) are similar to those of operational systems. In fact, the same personnel (or ones with similar skills) may be used for both. Whereas decision support and operational systems may previously have had their own standards, because of the need for the closer system integration, common standards become more important. In nearly all instances, the warehouse needs to be compatible with the overall IT standards. Furthermore, the data warehouse team must be made aware of any upcoming changes to any operational system that provides real-time data because these changes could have immediate and potentially disruptive impacts.

### 6.7 Lesson #7: Real-time BI Does Not Deliver Value Unless Downstream Decision-Making and Business Processes Are Changed

There are three sources of latency in real-time BI: the time to extract data from source systems, the time to analyze the data, and the time to act upon the data. The first two can be minimized using real-time technologies. The third requires getting people and processes to change. Unless downstream decision-making and business processes are changed to utilize real-time data, the value of the data decreases exponentially with the passage of time.

## 7 Putting the Work at Continental in a Decision Support Perspective

The initial thinking, research, and practice of computer-based decision support started in the late 1960s. Prior to this, computers were used almost exclusively for transaction processing (with the exception of scientific applications). Books by Scott Morton (1971) and Keen and Scott Morton (1978) helped create awareness of the potential of computer-based decision support. Decision support system (DSS) was the name given to this type of application, and this continues in academia to be both the name of a discipline and a specific type of application. Throughout the 1970s and into the 1980s, DSSs were the hot topic in both academia and practice. Sprague and Carlson's book (1982) codified much of what had been learned about DSSs, including the need for a dedicated decision-support database.

In the early 1980s, the decision support focus turned to executive information systems (EISs). The Rockart and Treacy (1982) article, “The CEO Goes Online,” and Rockart and DeLong’s (1988) book, *Executive Support Systems: The Emergence of Top Management Computer Use,* did much to publicize and create interest in EISs. Research and work on EISs provided many insights that have influenced current practice. For example, many EIS failures were related to an inadequate data infrastructure, a recognition that led to the emergence of data warehouses (Gray and Watson 1998). The use of critical success factors is now seen in business performance management (BPM), digital dashboards, and balanced scorecards, all popular today (Gregory 2004). In successful decision-support applications, there are continuing pressures to provide users with ever-fresher data (Paller and Laska 1990).

In the late 1980s, data warehousing emerged to provide the data infrastructure needed for decision-support applications. The writings of Inmon (who is widely recognized as the father of data warehousing) and Kimball helped many organizations think about and develop data warehouses (Inmon 1992). Among the first warehouse adopters were telecommunications, retail, and financial services firms, which are highly competitive and need to understand and use customer data to be competitive.

Initially, data warehouses were perceived as a repository for historical data and were used primarily to support strategic decision making. As companies recognized the need and potential to support tactical and operational decisions, they developed operational data stores (ODSs) to meet the need for very fresh data (Gray and Watson 1998). For the warehouse itself, ETL processes became more frequent, once again to provide more-current data for decision support. Recognizing the need for real-time data, in the past few years, vendors have introduced products that allow companies to move to real-time warehousing. As companies make this move, the distinctions between operational and decision support systems blur (Atre and Malhotra 2004).

Data warehouses differ in the ways companies use them. In some cases, warehouses primarily support reporting and queries, while in others they provide critical support for applications that are aligned with a company’s business strategy. For examples of the different ways that data warehouses are used, see Watson et al. (2002) and Goodhue et al. (2002).

When companies move to real-time warehousing and BI, they are better able to support tactical and operational decisions. This is both a natural evolution and a dramatic shift. It is natural in terms of the movement toward providing ever-fresher data, but is a significant change in how the data can be used. With current data, it is possible to support many additional kinds of decisions and use the data to support internal operations and interactions with customers. For example, business activity monitoring (BAM) is dependent on the availability of up-to-date data (White 2004).

As decision support has evolved over the years, a new term has emerged in the industry for analytical applications. In the early 1990s, the influential Gartner Group began to use the term business intelligence (BI), and it is now well entrenched. BI applications include DSSs, online analytical processing (OLAP), EIS, and data mining. The term BI is only now beginning to find its way into academia's vocabulary.

## 8 Conclusion

Continental Airlines provides an outstanding example of how decision support is changing in many leading companies. Real-time data warehousing and BI allow Continental to use extremely fresh data to support current decision making, business processes, and affect the organization's fate. Continental has put in place a decision-support infrastructure that is able to evolve with the needs of the business. Organizations must understand the natural evolution of decision support – how far the field has come and its future possibilities – so that they, too, can be prepared to harness the power of real-time BI to make the right decisions at the right time.

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## Appendix A. Honors and Awards

| | |
|---|---|
| **Best customer service** | J.D. Power, SmartMoney, Ziff Davis Smart Business |
| **Best international or premium-class service** | OAG, National Airline Quality Rating, Nikkei Business Magazine, Travel Trade Gazette Europa, Inflight Research Services, Condé Nast Traveler, Smart Money, Wall Street Journal |
| **Best airline** | Fortune, Air Transport World, Investor's Business Daily, Hispanic Magazine, Aviation Week, OAG |
| **Best technology** | #1 Airline, #2 of 500 Companies – InformationWeek, #1 Web, by Forrester, Gomez Advisors, NPD New Media Services and InsideFlyer, TDWI 2003 Best Practice Award – Enterprise Data Warehouse, TDWI 2003 Leadership Award, CIO Enterprise Value Award |

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# CHAPTER 58
# Decision Support for Security: A Mixed Reality Approach to Bioterror Preparedness and Response

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The Purdue Homeland Security Institute assisted in a live bioterrorism response exercise organized by the Indiana Department of Homeland Security and Jennings County at the Muscatatuck Urban Training Center. A simulation environment is developed to complement the live exercise. In this mixed reality environment, actions and outcomes in the live exercise influence the simulated population, and the actions and outcomes of the simulation affect the live exercise. The simulation modeled the public health aspect of the virtual population as well as a public approval rating, giving a measure of support for the decisions and actions the government is taking on their behalf. The simulation provides the capability to analyze the impact of the crisis event as well as the government response. Furthermore, the simulation allows us to scale the scenario to a much larger geographical area than possible with just a live exercise, thereby allowing key decision makers to keep the bigger picture in mind. The simulation can execute faster than real time, allowing the participants to analyze the long-term impacts of their actions. The simulation also provides the ability to analyze possible future implications of current actions, or to go back and retry the response to achieve better results.

**Keywords:** Dynamic data-driven application systems (DDDAS); Computational experimentation; Mixed reality

## 1 Introduction

From a bystander's perspective, a true emergency caused by a weapon of mass destruction (WMD) is underway. People are running, paramedics are loading the injured into ambulances, police are setting up a command center, and the government is mobilizing. In reality, however, the bystander is seeing a living laboratory – a simulated event in which real emergency personnel, national security experts, government agencies, and scientists capable of simulating the physical-chemical-biological effects of WMDs, are working together anticipating possible attacks and testing the effectiveness of different responses.

This living laboratory is an integral element of an innovative new method for strengthening United States homeland security. Innumerable pieces of data are collected through the living laboratory, integrated into the synthetic environment for analysis and simulation (SEAS) simulation software, and then scaled up to accurately portray a much larger, much higher-impact event, such as a terrorist attack on a dense urban area. This integrative facility, entitled the preparedness and response testbed (PRT), is an evolving resource that combines human ingenuity and simulated reality to identify and address homeland security concerns.

## 2 Living Laboratory Concept

A living lab was built on the concept of mixed reality – integrating a living and computational laboratory by leveraging existing resources, infrastructure and ongoing research. The participants in this mock event knew that they are participating in the event, but were unaware of any specifics before the event unfolded. The event took place in a two-storey office building located at Muscatatuck. The end goal, however, is not to study crises in two-storey buildings at Muscatatuck. Live data from the living lab will be integrated into a computational environment. The living lab's two-storey building becomes a high-fidelity model for another location, for example, an Indianapolis city block. Innumerable other pieces of data are also included into the computational experimentation, ranging from cell-phone usage to healthcare capabilities, and a virtual city is born. Overlaid on the virtual city are different models such as the plume model, fire dynamics, infrastructure model, and so on. Inside this city are millions of artificial agents who emulate human psychological, physiological, and emotional behaviors.

With this large-scale, highly detailed PRT, the end goal is to analyze and study the entire spectrum of human behavior during a high-consequence event, and then apply that knowledge to heightened U.S. preparedness, decision-making skills, and deterrent abilities. The living lab experiments are meant to identify gaps in current thinking and to validate the computational models.

The simulation used for operation SINBAD modeled the Muscatatuck Urban Training Center (MUTC). This 1000-acre facility in rural southern Indiana, nearly equidistant from Indianapolis to the north and Louisville, Kentucky to the south, was formerly a state mental hospital with a functioning small community to support doctors and staff that lived on the campus. Now operated by the Indiana National Guard as an urban training center, the MUTC offers Homeland Security and response agencies a unique simulated community with a number of functional buildings such as a school, hospital, dining hall, chapel, administrative buildings and residential housing, both apartments and single-family residences. The presence of a steam/powerhouse and its warren of steam tunnels stretching across the grounds add a unique dimension to tactical entry training normally not found in other training facilities.

## 2.1 Live Exercise Component of the Living Laboratory

This event took place over two days in December of 2005, on the grounds of the MUTC. A detailed map of the location and key areas that were used for the exercise is seen in Figure 1. Four hundred and seventy-four participants took place in operation SINBAD as shown in Table 1 below.

The map in Figure 1 shows where specific training events occurred within the Muscatatuck training facility. The scenario began with a resident of a rural, south-central Indiana community calling the Federal Bureau of Investigation (FBI). The anonymous caller gave details about suspicious activity in the rented house next door (number 1 of Figure 1). Based on the specific information given, the Joint Terrorism Task Force (JTTF) squad elected to send an Indiana state trooper and an FBI special agent to the residence under the pretense of doing a background check for a job application. Upon arriving at the house and identifying themselves, shots were fired and the police officer was hit. The special agent returned fire, and called 911 on his cell phone for emergency medical services (EMS), and then made another call for backup. At the same time, the neighbor behind the house

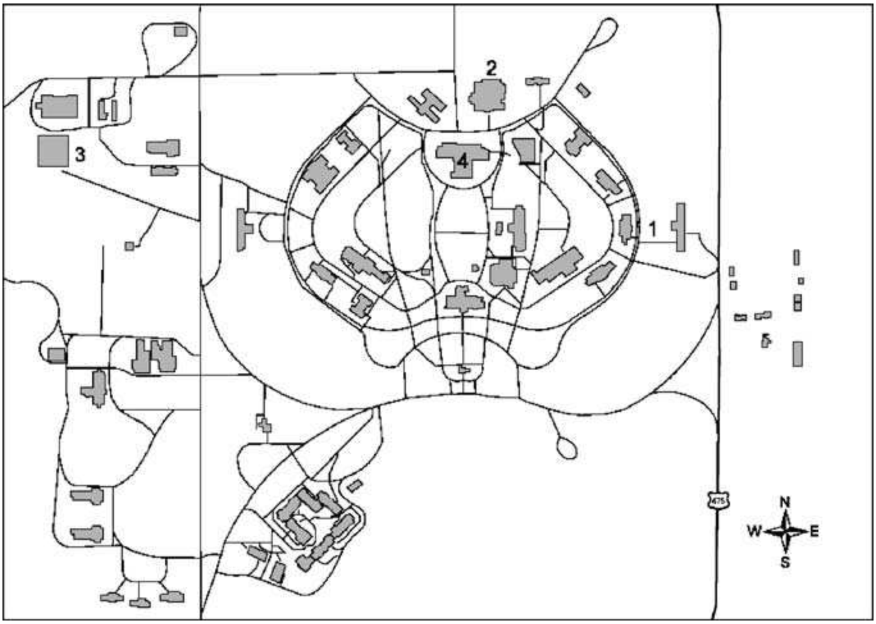


**Figure 1.** The Muscatatuck urban training center. Key areas that were used in scenario are indicated as 1–4

**Table 1.** List of each agency involved with Operation SINBAD and the number of people from each agency

| | | | |
|---|---|---|---|
| Public health | 91 | District coordinator | 2 |
| Emergency medical services | 12 | State coordinator | 1 |
| 911 dispatch | 3 | Epidemiologist | 3 |
| Hospital | 33 | Indiana state police | 62 |
| Fire | 24 | Indiana Department of Homeland Security | 3 |
| EMA | 3 | Film crew | 20 |
| North Vernon police/sheriff | 18 | Observers | 30 |
| PIO | 6 | Actors | 5 |
| 53rd Civil support team | 22 | Purdue software simulation seam | 7 |
| Federal Bureau of Investigation | 28 | U.S. attorney | 10 |
| National Guard | 40 | Fire marshals | 10 |
| Controllers | 3 | Evaluators | 15 |
| Moulage/standardized patients | 17 | | |

called 911 to report the gunshots and seeing two men carrying equipment into a van, which then sped off. A command to be on the lookout for the van was issued while a command post and perimeter were established under the incident command system (ICS) at the shooting scene. The Indiana State Police Emergency Response Team (ERT) entered the house and two suspects were found and surrendered. Debris in the house appeared to be a lab of some kind, and a laptop was found with floor plans to the RCA Dome football stadium in Indianapolis and printed material about weaponizing plague. Search warrants were obtained via standard procedures involving the U.S. Attorney's Office, which identify one of the suspects as being on the Immigration and Naturalization Service (INS) hot list. Hazmat was called in to assess the scene and they in turn called the 53rd WMD civil support team. An emergency operation center (EOC, number 2 of Figure 1) was activated and requests were made for the appropriate local public health support (Graham 2005).

The search continued for the van and the vehicle was spotted by a local sheriff's deputy who called it in, and followed it to a dead-end street at the local power plant (number 3 of Figure 1). An FBI special weapons and tactics (SWAT) team arrived to find the men had gone into the power plant. They secured the area as well as the tunnel system that leads to the power plant. The suspects were ultimately cornered at the tunnel's end in a department store where they activated a device that emitted a fog-like spray through the store and into the ventilation shaft leading to a housing area. Later in the day, the substance had tentatively been identified as *Yersinia pestis* and samples were sent to the Center for Disease Control (CDC) and a state laboratory. Decisions were made to prophylaxis and isolate the potentially exposed persons at the scene. During the afternoon the media showed up asking questions and a press conference was held by the incident command's public information officer (number 2 of Figure 1).

The second day of the field training exercise (FTX) handled the scenario 48 hours into the future. The media confronted the local public health officials about the rumors of the attack being larger than previously stated in the press conference. The state and local health teams established a mass prophylaxis point of dispensing (POD, number 4 of Figure 1) from the strategic national stockpile (SNS) for 10,000 potentially exposed victims. A media plan was put into place to inform the public of directions. Media reports about the attack raised fears across the region, increasing the number of psychological casualties, and overrunning hospitals, clinics, and the POD. The EOC directed an EMS response with potentially contaminated equipment and crews. The 911 call center dealt with a variety of questions from the public. Mortuaries across the region informed the coroner's office of a surge in deaths from a flu-like illness causing an overflow of morgue facilities and requesting additional support. Laboratory tests returned from the initial location of the *Y. Pestis* indicating that the particular strain seemed to be more resistant to the antibiotics that were used to treat the people exposed. The exercise concluded as public health officials had to adapt their response to this new development by requesting additional resources and leading to an orderly transition to the CDC, Department of Homeland Security (DHS), Department of Health and Human Services (HHS), and principle federal officials, followed by a final press conference.

## 2.2 Computation Model

The simulation used for operation SINBAD modeled the MUTC. In addition to modeling Muscatatuck, Jennings County, the city of Vernon, district 9, and the state of Indiana were also modeled. The population of each of these locations was modeled, with the simulation only modeling the effects of the actions taken in the live exercise for the areas of North Vernon, Jennings County, district 9 and Indiana. This simulation received various data as inputs from the live exercise and then computed outputs based on that data.

### 2.2.1 Action Inputs

The different types of actions that the participants took that affected the computational model were quarantining and decontaminating the affected regions; setting up a triage area and treatment for the public; and establishing an EOC. The output from the simulation included the health status of the public in each region in terms of the number of exposed, sick, recovered, and dead. The simulation also provided the government's public approval rating as well as the economic impact of the attack.

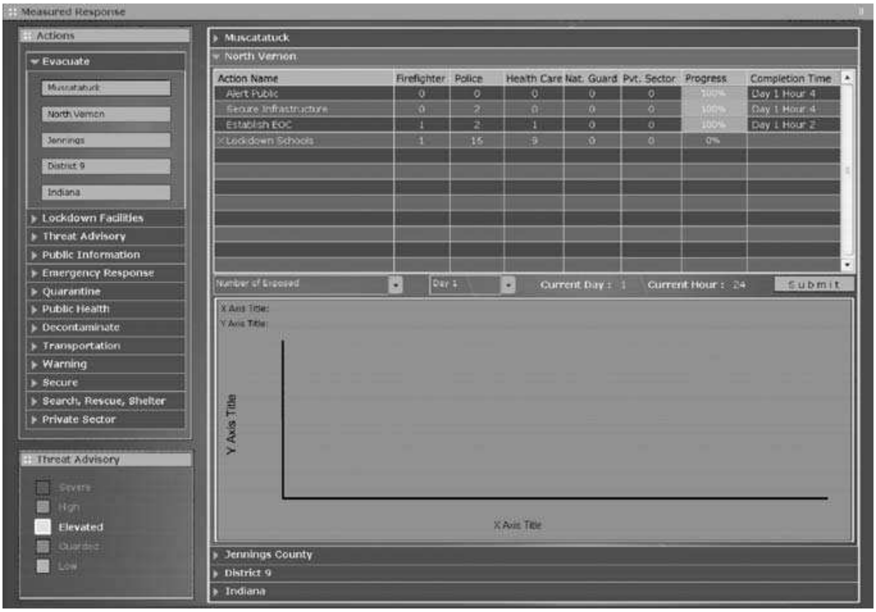


**Figure 2.** Action input screen, where users are able to select actions to complete in various locations, and allocate resources to complete those actions. The user has added "lockdown schools" to the actions list, and has allocated one firefighter unit, 16 police units and nine healthcare units to complete the tasks

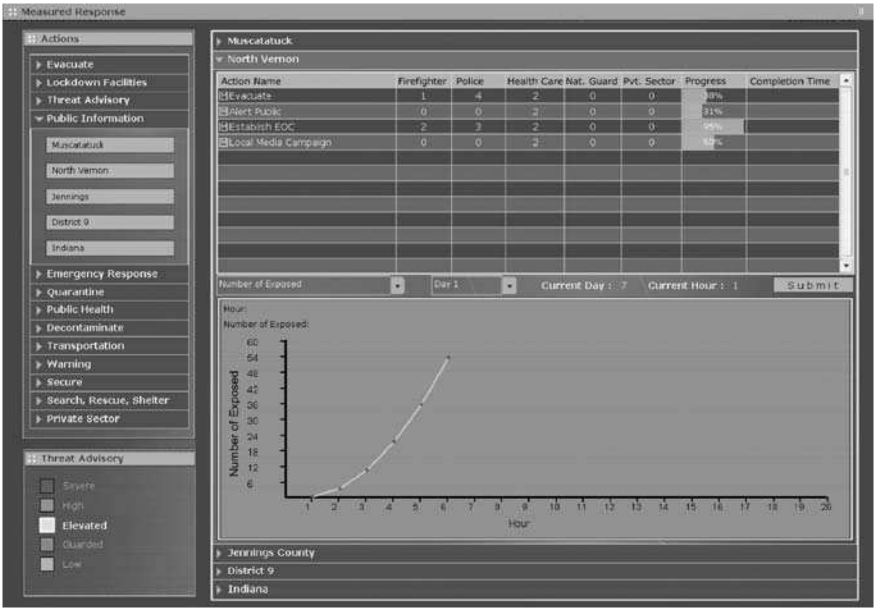


**Figure 3**. Action input screen, showing the graph shown to the user, which displays the number of dead across time as the plague spreads in the area

The first user interface is the main action input screen, Figure 2. The top left corner of the screen consists of a list of actions such as evacuate and lockdown facilities. The participants can select an action tab and choose a geographical location where the action will be performed. Furthermore, the participants can allocate health care, fire fighter, or police resources to complete the task. An estimated time of completion will be provided to the participants.

The right side of the action input screen is divided into five columns. In each column, the participants can view the actions that were taken, the amount of each type of resource that was allocated to that action, the progress of the action, and the action completion time. On the bottom half of the screen, the participants can bring up graphs and analyze the public health, economic loss, and the public approval rating of the virtual population. The graph in Figure 3 shows the number of dead across time.

The interface also provides participants the current threat advisory which can be seen on the bottom left of Figure 3, and the current simulation time which is displayed in the middle right of Figure 3.

### 2.2.2 Resource Allocation

Resources were also modeled such that there was only a certain amount of police, fire and health departmental resources available in each location. If the resources were used up in one area, officials had to request help from neighboring counties

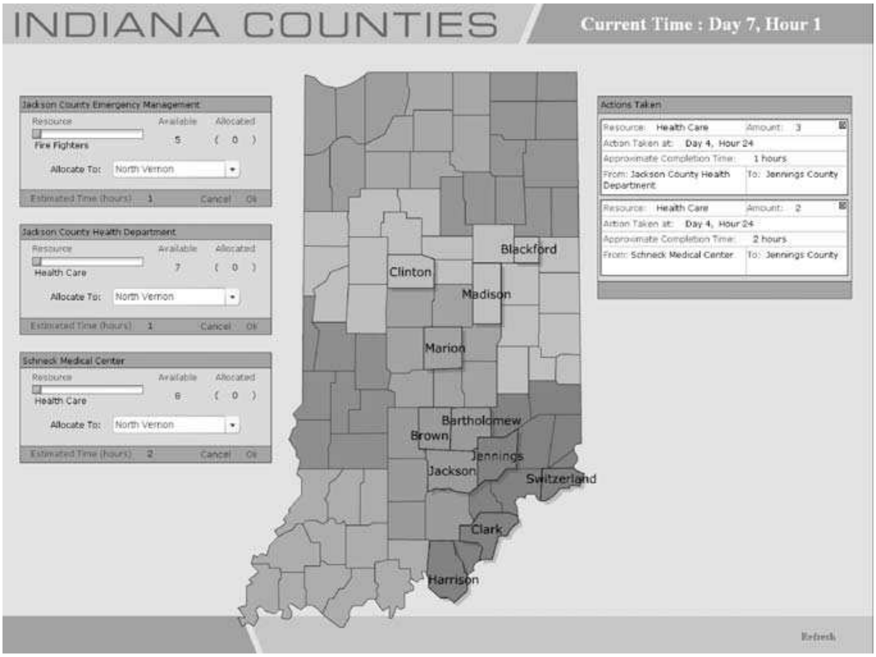


**Figure 4.** User interface for resource allocation between counties

and the time taken to complete various actions was affected by the number of resources available.

The resource allocation screen allows the participants to allocate resources between counties. In the current case, only the counties that were represented in the live exercise were modeled for resource allocation. On the left side of the screen, the participants can select a county from where they would like to take the resource and select the location where the resources will be allocated to. The available resource types are based on the department. An estimated time for the resource allocation to be completed is provided in red at the bottom of each allocation box. A history of actions taken is displayed on the right side of the screen.

### 2.2.2 Media

The media also affected the computational model. Based on the actions that the government took, the media is able to rank those actions on a scale of 1 to 5, where 1 is bad and 5 is excellent. This ranking, in turn, affects the artificial agents of the population, their health, the public approval of the government, as well as the economic impact in the area. Figure 2 shows a screenshot from the computational model.

The media screen allows the media participants to evaluate actions taken by the officials for each location and input their ranking, as seen in Figure 5. This screen also provides to the media players the current threat advisory in the lower

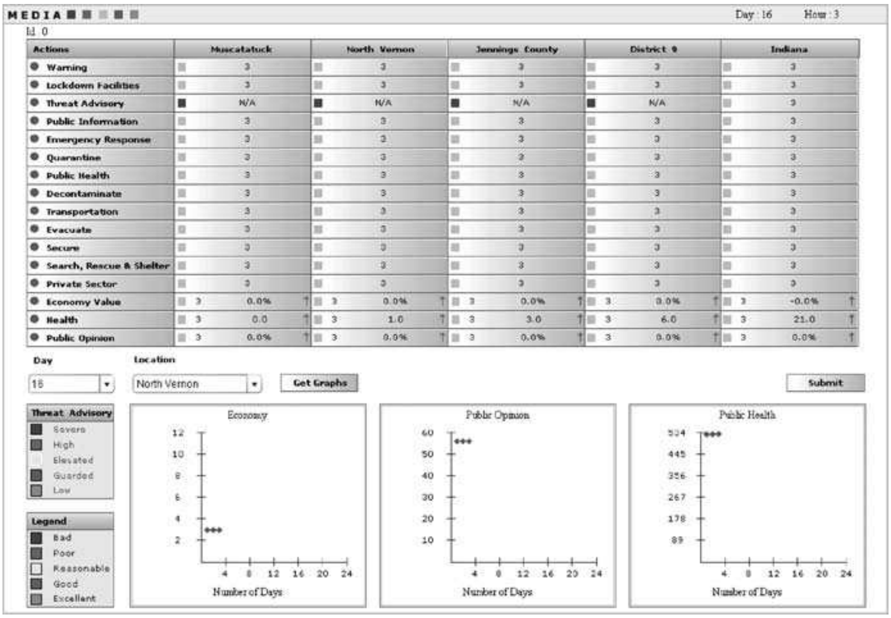


**Figure 5.** Media input screen

left-hand box, and graphical economic projections, public opinion, and public health data to analyze and rate how well the government is doing. These graphs are located at the bottom right side of Figure 5. These inputs from the media will in turn influence how the public feels toward the government's decision.

## 2.3 Synthetic Society Modeling

The synthetic society contains two parts, a multilayered cellular automata grid (MCAG) and a social network graph (SNG).

### 2.3.1 Multilayered Cellular Automata Grid

The MCAG is used to model the population density over a specific geographic area. It is modified from the classical cellular automata concept. We divide a geographic area into different layers, each layer with an increase of resolution. In the SINBAD simulation, there are four layers: state, district, county and township. Figure 6 shows a simple example which the state of Indiana is divided into 40 grids, the grids for Indianapolis is again divided into nine grids. The simulation is run on a layer with the highest resolution, the result is then passed to the next layer, and the layer with least resolution is run last. For Figure 6, the county layer is run initially and the result is passed to the state layer. The result of the county layer is represented by its respective grid in the state layer.

A grid can be classified into four types. Each type has a different role in the simulation.

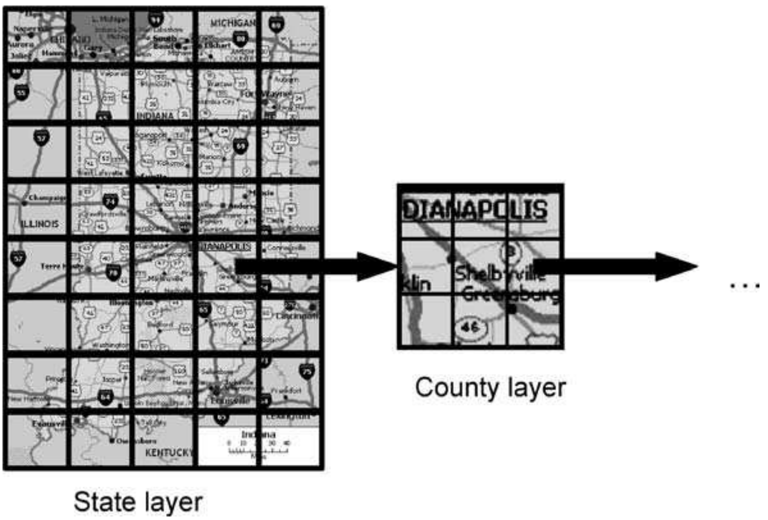


**Figure 6.** A simple example of the multilayered cellular automata grid

- High-population-density residential area: an area with high population density has a higher probability of a disease outbreak. A person in those areas has a higher probability of being infected compared to areas with a low population density.
- Low-population-density residential area: a person in the low-population-density residential area grid has a lower probability of being infected compared to the high-population-density residential area grid.
- Commercial area: while commercial areas have a low residential population, they have a very high mobile population, as people enter these areas during the day for work or socializing and leave these areas to return to their residential areas at night. Shopping malls, industrial areas, financial districts, etc., are considered commercial areas. These cells are similar to the power cells which will be discussed in the social network section.
- Uninhabitable area: forests, deserts, unused lands, etc. They have zero population density.

### 2.3.2 Social Network Graph

The social network is a graph $G = (V, E)$ subjected to the following conditions:

- $V$ is a set of vertices that represent the grids on the MCAG
- $E$ is a set of unordered pairs of distinct vertices, i. e., edges. The edges represent the contact relationship between two grids. The value of an edge represents the contact rate between two vertices.

The SNG models the contact relationship between people in the MCAG. It governs the infection rate of an epidemic disease. This section discusses the concept of SNGs and the different type of edges. Figure 7 gives a graphical representation of an SNG.

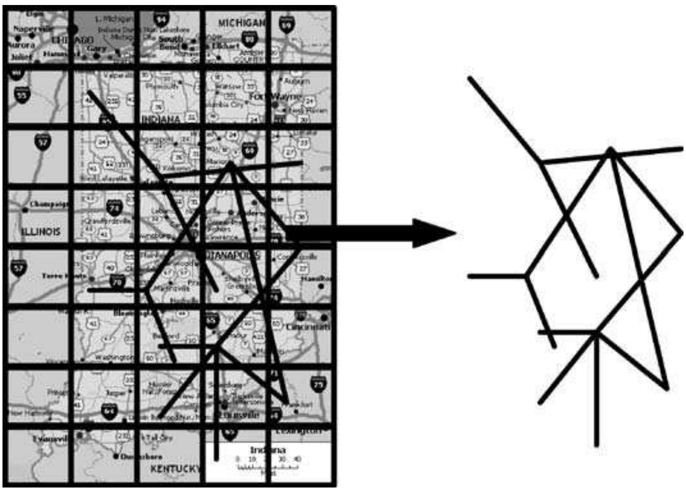


**Figure 7.** Social network graph of Indiana

The concept of an SNG is adapted from the small-world social network. The small-world theory states that there are local clusters where everyone connects to everyone else in the cluster. Moreover, there are also some long connections between nodes in a cluster and nodes in other clusters. For our model, we adapted the model proposed by Kasturirangan (Kasturirangan 1999) which contains power nodes. These power nodes, which are linked to a widely distributed set of neighbors, give the small-world effect, which in turn gives a more-realistic representation of the real world. Power nodes are represented as commercial area grids in our model. Figure 8 from Newman (2000) shows what the power cells graph looks like.

There are three types of edges in SNGs. Each type represents a different kind of contact relationship between people and also affects the infection rate of an epidemic disease. The edge value is different for each type and also depends on the population density of the grid, which is represented as a vertex.

- Self-contact: applies only to the grid itself. It is represented as a self-loop in the graph. The edge value is high, which represents the high probability that a person will get into contact with everyone else. As a result, a disease spreads very quickly within the grid. The population density of the cells therefore has a large impact on the rate of spreading.
- Neighborhood contact: similar to the basic principle of cellular automata, the number of infected people in a cell will affect its neighboring cells, and vice versa. The magnitude of how a cell can affect its neighbor depends on its population over the total population of all the neighbor cells. Neighborhood contact edges capture this effect.
- Commercial contact: as introduced in the small-world theory above, the model gives a realistic representation of the real world by having power nodes. In our design, the commercial areas are treated as power nodes. Any vertex (grid) that connects to the commercial area vertex is in contact with all other vertices (grids) connected to the commercial areas.

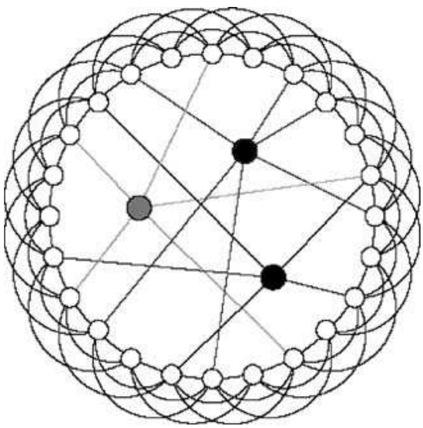

**Figure 8.** The shaded cells in the middle are power nodes that are connected to many widely distributed acquaintances

### 2.3.3 Air Disposal Model and Epidemic Model

The air disposal model for modeling the explosion of phosgene gas is adapted from the Gaussian plume model of:

$$C_{(x,y,z)} = \frac{Q}{2\pi\sigma_y\sigma_z U}\exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-0.5\left(\frac{z-H}{\sigma_z}\right)^2\right]+\exp\left[-0.5\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}$$

$C$ = pollution concentration at coordinates $(x,y,z)$, $g/m^3$ or $OU/m^3$ (OU = odor units), averaged over time
$x$ = the distance downwind from the source to the receptor (m)
$y$ = the crosswind distance from the center of the plume to the receptor (m)
$z$ = the height above ground level of the receptor (m)
$Q$ = mass emission rate of pollutant (g/s or OU/s)
$U$ = mean wind speed of the plume (m/s)
$H$ = effective emission height (m), equal to 0 for a ground source
$\sigma_y$ = standard deviation of plume concentration in the crosswind direction (m)
$\sigma_z$ = standard deviation of plume concentration in the vertical direction (m)

The epidemic model is modeled and calibrated from a modified version of the susceptible-exposed-infected-removed (SEIR) model from Kaplan (Kaplan et al. 2002). As shown in Figure 8, the model divides people into different groups. The equations and the rate of transition of people from one group to another are discussed in Appendix A.

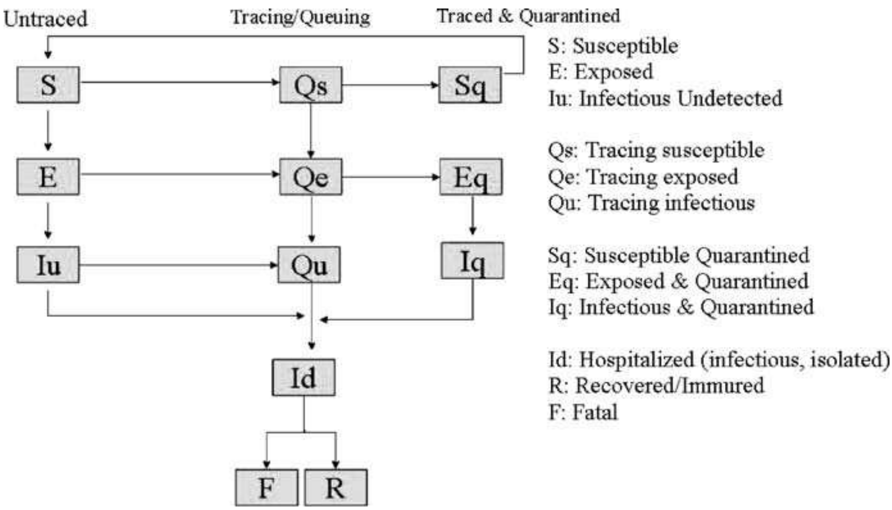


**Figure 9.** Epidemic model of plague

The following assumptions were made for the epidemic model:

- Quarantined and hospitalized means 100% isolation that gives a zero infection rate
- When an infected person recognizes his/her symptoms, which may occur sometime after the symptoms first appear, we assume that he/she will seek help immediately and therefore will be considered hospitalized and isolated immediately
- Disease transmission is derived from free mixing among susceptible, infectious individuals in the population within a cell.

## 3 Experimentation

This living lab concept was used in operation SINBAD, and an FTX was created to conduct a local response to a mass-casualty event caused by a weapon of mass destruction. The event was the terrorist release of weaponized *Y. Pestis* bacteria, causing an outbreak of pneumonic plague in a small rural community south of the originally intended target of Indianapolis, Indiana.

The exercise focused on developing a coordinated response involving multiple agencies, jurisdictions, and the various resources available to assist in responding to a terrorist incident involving a WMD. The exercise was centered on participating Indiana public health county-level agencies and their ultimate response to the bioterrorism outbreak. However, it was also designed to allow other various local, state and federal emergency response agencies to participate in their responsive roles. Participants focused on issues addressing both the outbreak and containment of a terrorist-induced biological incident including protocols necessary to serve and protect the public through public health measures in the event a biological agent were to be released. Players operated within the confines of a simulated community employing jurisdictional agency responses, incident command posts, emergency operations centers, and the ultimate goal of a functional joint field office (JFO), joint information center (JIC), and a public health point of dispensing of antibiotics. Those operations that were performed in the FTX were then inputted into the computer simulation.

In the SINBAD simulation, the MCAG has four layers: Indiana state, district 9, Jennings County and Vernon. Each layer has over 1000 grids to model the geographic location. The classification and the population density of each grid are obtained by analyzing the data set from the 2000 U.S. Census Bureau report (Census 2004).

# 4 Results

During the training exercise at Muscatatuck several actions were taken by the participants, and those actions affected the progression of the scenario. As a result of those actions the following effects were noticed.

## 4.1 Public Health Impact

The quick response of the local agencies participating in the exercise resulted in fewer casualties in the City of North Vernon and Jennings County. The limited representation of the state and federal agencies created a need to simulate the state and federal level response in the simulation. This created a dramatic difference (saving almost 1.3 millions lives) in the public health statistics compared to the worst-case scenario. Figure 10 shows a graph of the public health impact.

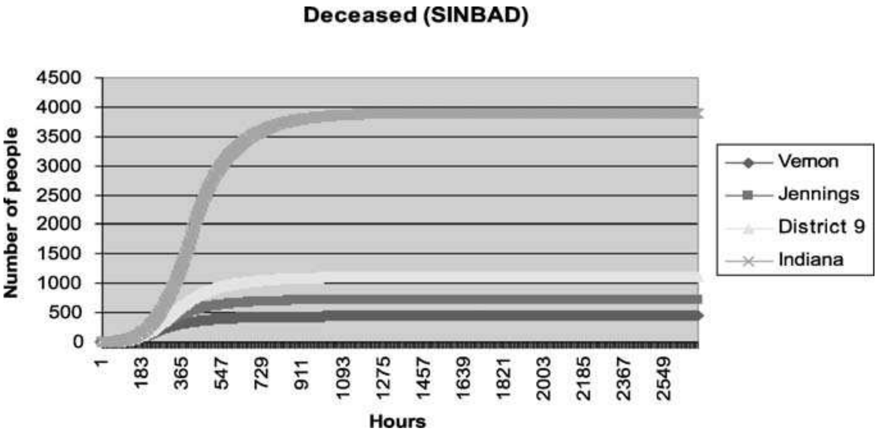


**Figure 10.** A total of 3,900 lives were lost due to the bioterrorist attack, far fewer than the 1.3 million worst-case scenario

## 4.2 Economic Impact

Figure 11 shows the projected economic impact of this attack. While initial projections of the economic loss of 7 billion dollars were closer to the worst-case scenario of 14 billion dollars, due to the government response and public health actions, that projection was dramatically reduced to 2 billion dollars in the long term. Enormous long-term economic loss could have crippled the entire state if not handled properly. This situation was avoided during operation SINBAD due to positive and proactive government action.

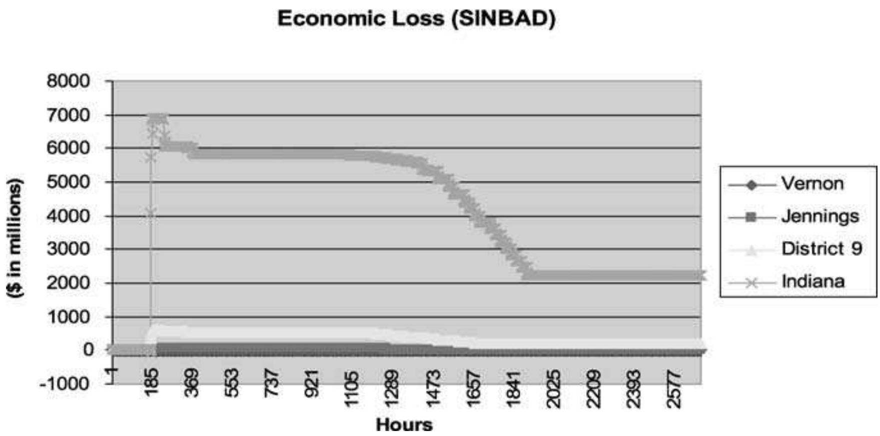


**Figure 11.** Economic loss projected into the future due to the bioterrorism attack

## 4.3 Public Approval Rating

Figure 12 shows the public approval of the government as it changes over the course of the simulation. The initial drop in public approval rating was due to the inability of the government to prevent the terror attack from taking place. However, in the long term, the government response and getting the situation under control gained back most of the public confidence to almost normal levels (although not completely back to normal).

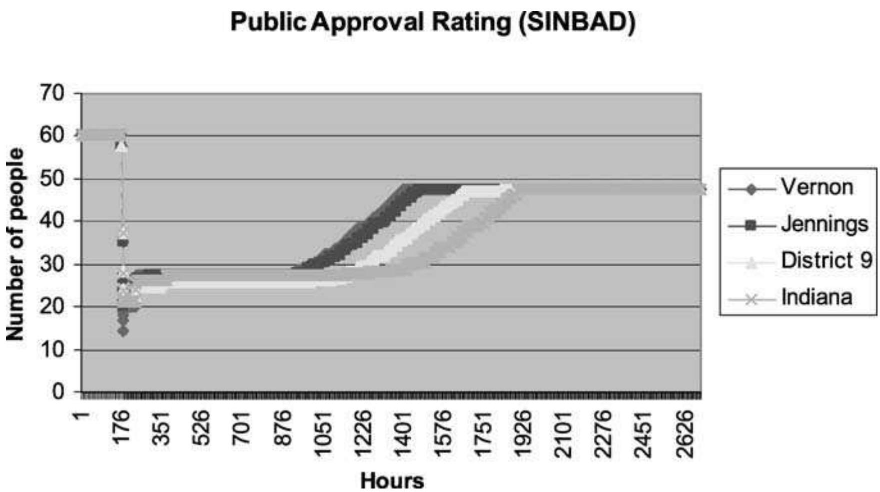


**Figure 12.** Long-term effects of the public approval rating

## 5 Conclusions

It is logistically and economically infeasible to test a high-consequence event using a major city such as Indianapolis or Chicago as a full-scale exercise venue. Nevertheless, in a terrorist attack, a prime target is likely to be a large urban area. This paper has shown a scientifically based solution: using living labs at a training facility such as Muscatatuck, then integrating that data into realistic simulation programs and replicating it for an area more likely to be attacked. This approach will drive research that is needed by the U.S. to respond economically to the threat of terrorism. For example, the SEAS simulator will soon have more than 10 million simulated people that can endure attack after attack, each time accounting for geographical concerns, transportation capacity, cultural influences, and even financial and political factors. When combined with the other types of simulations, we will have the capacity to test a wide array of threats. By creating a virtual environment directed towards homeland security and connecting it to the real world through living laboratories, completing large-scale emergency response training exercises will be much more feasible for the protection of our nation.

The overall outcome of SINBAD was positive, based on the simulation results compared to the worst-case scenario calculated. The actions taken during the live exercise had a positive impact not only on public health, but also on the economic and public approval ratings of the government. However, there was a certain level of hesitancy to block off and quarantine the area once the contagious disease was confirmed. Due to the large number of local agencies present for the second day of the exercise, there was a more-localized response in the simulation. While this saved a lot of lives locally, the situation quickly got out of hand in other regions of the state. The presence of state and federal agencies would have improved this overall situation. To simulate a plausible real-world scenario, the research team used the actions taken by the local players, and simulated actions that would have been taken by state and federal agencies. As one can imagine, this would have happened in the days following the live exercise scenario, and was an important aspect of the government response. This state and national response strategy, extrapolated from the local response, resulted in a realistic, epidemiological analysis of the public health as well as the economic aspects of the simulation.

## 6 Future Work

Future exercises will allow the participants to have greater interaction with the simulation. The participants will receive continuously updated statistics from the simulation and the live exercise. This will allow them to make more-strategic decisions during the scenario. With hands-on simulation training provided, or technical support staff taking actions on behalf of the participants, more time can be spent analyzing the results of the simulation than dealing with the simulation itself. The simulation is intended to be used as a tool for the support of critical issues and problems in a response and recovery scenario. With the live exercise and simulation connecting in real time, the accuracy of decisions greatly improves, thereby enabling a more-effective response to the situation.

## Appendix A. Equations

Equations for the modified SEIR model adapted from Kaplan (Kaplan et al. 2002):
The Functions $R_0(t)$ :

$$R_0(t) = \int_0^{t+\gamma} e^{-r_i x} \beta[S(t-x) + Qs(t-x)]dx \approx \frac{\beta[S(t) + Qs(t)]}{r_i}$$

On average $R_0(t)$ people will be infected by a newly symptomatic severe acute respiratory syndrome (SARS) case at time $t$. However, some of the $R_0(t)$ people will already have been named at random by other infected persons even though there is no transmission. The rate that anyone in the population is randomly traced at time $t$ larger or equal to zero is given by

$$\kappa(t) = \frac{[c - pR_0(t)]r_i I_i(t)}{N}$$

At time $t$, the expected number of untraced people previously infected by an infected person who are in the exposed ( $\lambda_1$ ) and infectious ( $\lambda_2$ ) disease stages are:

$$\lambda_1 = \frac{q_1 \beta S(t)}{r_i + \kappa(t)}$$

$$\lambda_2 = \frac{q_2 \beta S(t)}{r_i + \kappa(t)}$$

At time $t$**,** the conditional probability that a contact of an infected person detected in the exposed ($q_1$) and infectious ($q_2$) disease stages, provided that the contact has not been traced, is

$$q_1 = \frac{r_i + \kappa(t)}{r_e + r_i + \kappa(t)}$$

$$q_2 = \frac{r_e}{r_e + r_i + \kappa(t)} + q_1$$

Untraced stage:

$$\frac{\mathrm{d}S}{\mathrm{d}t} = -\beta I_i S - [c - pR_0(t)]\frac{S}{N} r_i I_i + r_q Sq$$

$$\frac{\mathrm{d}E}{\mathrm{d}t} = \beta I_i S - \left\{[c - pR_0(t)]\frac{E}{N} + p\lambda_1(t)\right\} r_i I_i - r_e E$$

$$\frac{\mathrm{d}Iu}{\mathrm{d}t} = r_e E - r_i Iu - \left\{[c - pR_0(t)]\frac{Iu}{N} + p\lambda_2(t)\right\} r_i I_i$$

Tracing/queuing stage:

$$\frac{\mathrm{d}Qs}{\mathrm{d}t} = [c - pR_0(t)]\frac{S}{N} r_i Ii - \beta I_i Qs - Qs \min(1, \mu n / Q)$$

$$\frac{\mathrm{d}Qe}{\mathrm{d}t} = \beta I_i Qs + \left\{[c - pR_0(t)]\frac{E}{N} + p\lambda_1(t)\right\} r_i I_i$$

$$- Qe \min(1, \mu n / Q) - r_e Qe$$

$$\frac{\mathrm{d}Qu}{\mathrm{d}t} = r_e Qe + \left\{[c - pR_0(t)]\frac{Iu}{N} + p\lambda_2(t)\right\} r_i I_i - r_i Qu$$

Quarantine stage:

$$\frac{\mathrm{d}Sq}{\mathrm{d}t} = -r_q Sq + Qs \min(1, \mu n / Q)$$

$$\frac{\mathrm{d}Eq}{\mathrm{d}t} = -r_q Eq + Qe \min(1, \mu n / Q)$$

Hospital, fatal, and recovery stage:

$$\frac{\mathrm{d}Id}{\mathrm{d}t} = ri[Iu + Qu + Iq] - r_h Id$$

$$\frac{\mathrm{d}F}{\mathrm{d}t} = f r_h Id + f_q r_q Eq$$

$$\frac{\mathrm{d}R}{\mathrm{d}t} = (1 - f) r_h Id + (1 - f_q) r_q Eq$$

## Acknowledgements

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# CHAPTER 59
# DSS in Healthcare: Advances and Opportunities

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Decision support systems (DSSs) in healthcare have generally targeted quality, risk mitigation, productivity, and profitability outcomes of hospitals. This chapter reviews advances made by DSSs in supporting these areas and opportunities that remain. We argue that the role of DSSs in improving learning for decision makers is crucial and present steps to facilitate this. Changes in the behavior of physicians and administrators will be critical to the success of DSSs. We cite information technologies available to improve healthcare decision making and frame research questions for future information systems researchers. Finally, we propose that the future of DSSs in healthcare will involve the development of capabilities to integrate various types of data, recognize patterns, and take proactive actions.

**Keywords**: Decision support systems; Healthcare; Productivity; Profitability; Patient care quality; Hospitals

## 1 Introduction

The contribution of decision support systems (DSSs) in health care has been far-reaching and still evolving. This is evidenced by the large number of references that appear in PUBMED, a widely used healthcare search engine. Increasing healthcare costs make it imperative that hospitals and physicians make optimal decisions to improve the quality and efficiency of healthcare delivery. Due to recent advances in DSSs for healthcare, we believe that DSSs will have a prominent and growing role in improving clinical as well as administrative decision making.

The objective of this chapter is to review salient DSS advances and identify opportunities for future applications. Our focus will be upon the providers, i. e., hospitals, in healthcare delivery. We classify healthcare DSS contributions and opportunities into four key areas: quality and patient satisfaction, efficiency and profitability, risk mitigation, and learning. We recognize that the areas are not mutually exclusive, for example, lower quality can lead to higher patient care costs, and learning can occur in the other three areas of DSS opportunities. We separate learning to highlight the importance of DSS contributions to improving managers' decision-making processes through learning as well as their decision outcomes. Furthermore, our goal is to emphasize the importance of taking action resulting from learning. We will cite information technology and complementary capabilities needed to support opportunities for continued progress in healthcare DSS.

One of the early applications of decision theory is found in methods for evaluating the quality of medical care as outlined by Donabedian (1966). The Agency for Healthcare Research and Quality (AHRQ) funded early research that led to the use of information technologies to monitor and evaluate clinical decision making (Fitzmaurice et al. 2002). As the economics of healthcare evolved, the role of DSSs likewise shifted in support of oversight. For instance, early healthcare DSSs focused on optimizing hospital resources for higher revenue. As the focus shifted from fee-for-service arrangements to a prospective payment system, in which hospitals are reimbursed a predetermined amount for patient care, the DSS focus evolved to address cost management and renewed focus on clinical quality outcomes.

Decision making in clinical areas was enhanced with the use of artificial intelligence and expert system techniques such that decision makers were provided with an expert's recommendation, as opposed to alternatives offered by traditional DSSs (Duda and Shortliffe 1983). Later, DSSs exploited administrative claims data to examine variations between clinical treatment plans to identify those plans that led to improvements in clinical and quality outcomes (Dubois and Brook 1988). However, differences in the acuteness of patients' disease, comorbidities and other conditions raised doubts about the accuracy of DSS recommendations, given that previous patient conditions can influence clinical quality, thus influencing the comparison. Advancements in computing helped adjust patient outcomes for severity by taking into account patient health history and comorbidity data. Thus quality outcomes such as expected resource consumption and expected length of stay (LOS) were viewed in the light of patient sickness and comorbidities, collectively referred to as severity adjustment. This provided physicians with an unbiased view of which treatment plans were effective, thus overcoming a long-standing obstacle in the use of DSSs (Horn et al. 1991). These advanced DSS capabilities of severity adjustment helped answer several questions: are the costs and efficiency of primary care physicians comparable to subspecialists (Zarling et al. 1999b)? Does verification from subspecialty colleges matter (Piontek et al. 2003)? What is the cost of reducing medical errors (Becher and Chassin 2001)? Are excess length of stay, charges, and mortality attributable to medical injuries during hospitalization (Zhan and Miller 2003)? Thus, the overarching focus on DSS today is to improve quality of care and reduce costs. Below we discuss how DSSs have contributed to quality, efficiency, risk mitigation, and learning areas, and what opportunities remain.

## 2 Areas of DSS Contribution

In order to make better decisions, healthcare organizations have actively incorporated DSS capabilities into their existing systems. In some cases, clinical and administrative systems incorporate DSS capabilities into operational systems. After all, as Keen argues, the objective of DSSs is support, the first ‘S’. The second ‘S’ represents technology, which is likely to evolve over time (Keen 1987). For example, a rule-based DSS capability to monitor drug interactions may later become part of a computerized physician order entry (CPOE) system due to advanced computer networking technology.

## 2.1 Quality

### 2.1.1 Advances in DSSs

Quality remains the cornerstone of healthcare decision making. As such, DSSs have made significant advances in healthcare in the U.S. and other parts of the world. Many computerized interventions that are commonplace today, such as drug interaction alerts, had their genesis in early pursuits of quality. While most early works utilized information technologies to abstract information from medical records, subsequent refinement and standardization led to the use of DSSs to identify the effectiveness of medical decision making (Wigton 1988). These advances in the study of how medical knowledge is created, shaped, shared, and applied are referred to as medical informatics (Coiera 1996). Several DSS advancements in supporting quality are copresented with cost and efficiency outcomes discussed below. For example, physician profiling systems present physicians with quality and cost outcomes while comparing them with their peers. Physician profiling systems further support physicians by providing guidance for improvement in various clinical areas.

DSSs have made advances in using administrative discharge data to examine variables that impact on patient care quality such as the incidence of complications, readmission, and mortality. In doing so, decision makers use historical discharge data to identify clinical treatment protocols that result in desirable outcomes. Of growing interest is patient satisfaction with services during the hospital stay.

### 2.1.2 Opportunities

The awareness of the role of computing and DSSs has created many opportunities for information systems and decisions sciences. We are beginning to exploit data mining to convert a wealth of data into quality improvements effectively (Bates et al. 2001, Bates and Gawande 2003) as well as methods measuring the benefits of decision support activities (Rosenstein 1999). The era when the physician knew best is evolving into an era where the physician knows where to find the best information (Teutsch 2003). Enabled by the technology, physicians and information specialists aim to draw upon vast amounts of geographically dispersed information and produce a set of best practices known as evidence-based medicine. Thus future DSSs will have a dual role – to support decision making and to integrate disparate data sets to support such decision making. Bates (2005a) summarizes this as "…we will be getting better decision support than we're delivering now, and that will substantially shorten the time that it takes us to get evidence-based medicine into practice" (pg. 8).

Patient satisfaction is another indicator of healthcare quality. There is an increasing focus upon dispensing practices that are not only effective but mitigate patient suffering at the time of treatment as well as preserve quality of life post-treatment. As such, insurers and providers are paying attention to patient satisfaction as a quality measure. Consequently, researchers are including patient satisfaction as a variable of interest in their analysis (Kohli et al. 1999). Future DSSs will incorporate patient satisfaction among their quality criteria and as a factor when recommending treatment protocols.

## 2.2 Efficiency and Profitability

### 2.2.1 Advances

Supra-normal escalation in health care costs is a major issue for providers as well as payers. The prospective payment system (PPS) of reimbursement to providers based upon predetermined criteria was designed to stem the costs of healthcare. While the PPS slowed the rate of cost increases, healthcare costs continue to grow faster than the rate of inflation. The interdependence of costs and the quality of clinical decisions has been demonstrated (Donabedian 1993). Several research initiatives have further explored what role hospitals play (Conrad et al. 1996), and how differences in patient types, their diagnosis and treatment, and the healthcare industry as a whole contributes to quality (Bodenheimer 2005). The focus on the costs and how various players in the healthcare industry influence them led to a transition from chart reviews to examination of large data sets and complex computing to adjust for disease severity (Iezzoni et al. 1999, Iezzoni et al. 1992). Identification of cost components is a key input into DSSs and must be applied to assess the efficiency of clinical and administrative operations.

Hospitals are well aware of how much they charge for a given service; few know what it really costs to offer the service. Without knowing the true cost, decision making is akin to driving an automobile in the dark. Healthcare researchers recognized the slow progress in the adoption of information technology (IT) for the identification of costs and efficiency and have called for the use of information as a resource (Lashmett and Schmitz 1994). Accountants joined the information technologists to work with clinical managers in identifying the costs of providing services. Activity-based costing (ABC) was deployed as a method to identify activities and associated costs, and influence decision making (Player 1998). Kohli et al. (1999) proposed a methodology to allocate direct and indirect costs fully to appropriate services instead of allocating an overhead cost. Once the fully allocated cost per unit for a service is calculated, it is integrated with clinical, satisfaction, and other quality outcomes into the DSS. With accurate cost information, patient care outcomes in DSS can then be used to improve decision making in various functional areas as well as to assist in process redesign and improve overall efficiency.

Steps to reduce costs and gain efficiency at the operational level have become a mainstay in hospitals, particularly due to their razor-thin profit margins. Hospitals fear that, without constant scrutiny over costs, their profitability could rapidly disappear. However, much remains to be done as new challenges emerge such as nursing shortages, increasing underinsured and uninsured populations, an aging population, and rural health, all of which have the potential to further escalate healthcare costs.

### 2.2.2 Opportunities

One of the greatest potentials for efficiency in hospitals is to implement evidence-based action beginning at the patients' bedside. Most decision support results are based on retrospective data and are provided to physicians and administrators long after the decisions were made. While such findings of the consequences of prior actions are important for learning, significant benefits can be obtained when support is provided to clinicians at the time of decision making. For instance, with the help of proactive decision support, timely physician intervention can avoid patient complications, thus avoiding longer length of stays and higher costs. Zarling et al. (1999a) demonstrated a prototype DSS to caution physicians about patients who were most likely to experience complications during their hospital stay. The preemptive advice from the DSS was based on analysis of the history of a large number of patients.

Intelligent agents built within DSSs present a significant opportunity to inform decision makers about the alternatives available to them and the consequences of each alternative. Interoperability of various information systems will be the foundation on which DSSs can draw to execute this analysis. Efforts to create community-wide interoperable systems to link healthcare providers, ancillary labs, and physicians are underway. While other countries have adopted such interoperability extensively, specifically for electronic health records, reimbursement issues, not technology, impede such implementations in the U.S. (Bates 2005b). A promising interoperable point-of-care information system, similar to the worldwide electronic banking network, is currently being developed by the U.S. government (Walker et al. 2005). Such a network of longitudinal health information offers vast opportunities for DSSs to manage costs and improve efficiency and quality of healthcare.

## 2.3 Risk Mitigation

### 2.3.1 Advances

The patient bill of rights published by the American Hospital Association states that patients have a right to expect a clean and safe environment during their hospital stay (AHA 2006). Safety of patients remains a persistent and troubling issue for hospitals. Healthcare providers must ensure that the risks to patients as well as employees are properly managed.

While there are several types of risks (Chassin 1996) involved in running complex organizations, a critical and widely discussed risk is that of hospital errors (Leape et al. 1995). Errors ranging from mislabeling of patient samples to dispensing the wrong drug (Laura 2006b), from miscommunication among the staff at hand-offs (Laura 2006a) to adverse events (Brennan et al. 1991) or adverse drug interactions (ADEs) (Sanks 1999), can have devastating implications for patient care. Studies have shown that preventable ADEs add over two days to length of stay (LOS) and over $3,000 in hospital costs (Bates et al. 1997), in addition to patient discomfort and potential legal ramifications. Recent advances in process as well as DSSs have mitigated such hospital errors. By tracking each stage of the drug ordering and dispensing patient care process, DSS tools have served to flag up potential errors for intervention (Yan and Hunt 2000). Computerized physician ordering entry (CPOE) systems, integrated with hospital information systems, have decreased communication and hand-off errors, thus reducing costs and insuring compliance with dispensing guidelines (Kuperman and Gibson 2003).

### 2.3.2 Opportunities

The use of DSS in risk mitigation is still in its infancy. Information technology has significant potential in supporting efforts to make healthcare safe. Much of the opportunity lies in the integration of information systems. For instance, integrating CPOE with pharmacy systems can alert the physician to potential drug interactions and prompt alternatives to alter the prescriptions. Rule-based ADE systems currently flag up such interactions at the time of dispensing. Integration of CPOE with ADE systems will mitigate errors in tests and procedures ordered by physicians at the time of ordering, thus bringing us closer to proactive intervention at the patient bedside.

Bates et al. (2001) discuss a number of IT opportunities, such as bar-coding communication systems to highlight abnormal laboratory results, which enhance the effectiveness of DSSs in reducing medical errors while using natural language processing to detect errors when they occur (Bates et al. 2003). In a review of clinical DSSs, Garg and colleagues (2005) found evidence of improvements in physician practitioner performance, but the effects of DSSs on patient outcomes were inconsistent. A nagging issue that limits the use of such DSSs is the large number of false positives, which threaten widespread adoption. Thus, the efficacy of clinical decision rules to guide accurate positive alerts is critical to the successful implementation and use of DSSs (Reilly and Evans 2006).

## 2.4 Learning

### 2.4.1 Advances

In addition to improved outcomes, another objective of DSSs is to improve the process of human decision making (Forgionne and Kohli 1996). Consistent with Simon's phases of decision making (intelligence, design, choice, and implementation) in which the implementation phase provides feedback to the intelligence phase for the next iteration of decisions (Simon 1977), DSSs offer an opportunity for decision makers to learn from the steps followed when using DSSs technology, so they can make better decisions in future situations.

Many of the advances in quality and efficiency discussed above have been a result of learning gained to support administrative and clinical decision making. Advances in healthcare informatics are assisted by progress in information science, statistical modeling, and computer science. The use of quality management tools has renewed the scientific approach to continuous improvement, for example, by reducing the risk of ventilator-assisted pneumonia (Joiner et al. 1996) or understanding the learning curve involved in the implementation of picture archival and communication systems (PACS) (Reiner et al. 2002).

Standardized administrative data gathering by regulatory agencies, for example, the Centers of Medicare and Medicaid Services (CMS) in the United States and the Healthcare Commission in the U.K., have enabled widespread use of large datasets for learning. Advances in severity-adjusted clinical outcome data (Leary et al. 1997) have not only generated insights but also removed the impediment of comparability in clinicians' use of this knowledge for the redesign of clinical processes (Durieux et al. 2000). Such learning serves as a feedback into DSSs to facilitate changes that must take place on the hospital floor.

### 2.4.2 Opportunities

DSS support for learning in healthcare holds enormous promise as well as challenges. The extent of potential benefits from data repositories is limited only by the effort and imagination of decision makers. Knowledge available to decision makers reduces the risk of harm to patients. Paradoxically, DSSs can also introduce risk, the very thing they attempt to reduce. The following quote touches upon this issue.

> *"Technology can bring its own risks. Inadequate operator training and equipment maintenance may lead to misuse and malfunction. If a clinician or other person believes that a device or machine essentially eliminates risk, they may be less vigilant and less likely to detect errors as they are happening" quoted in Hammons et al. (2000).*

Thus while significant technological advances are evidence of the potential, the social and organizational issues will be more challenging. Among the organizational issues, applying learning in order to change decision makers' behavior is particular important. There is evidence that attempts to change physician practice behaviors are met with resistance, yet well-planned DSS implementation plays a pivotal role in overcoming such resistance and establishing a rapport between hospitals and physicians (Kohli et al. 2001).

In Figure 1 we propose four iterative steps to facilitate DSS-based learning. First, explicit policies to ensure the integration of information systems and linking of appropriate data fields are needed. Second, information technologies must develop tools to exploit patient care data repositories for knowledge creation. Third, such knowledge must be linked to the decision makers' actionable work. Finally, the decision makers must be persuaded to alter their actions on the basis of the new knowledge. Kohli and Kettinger (2004) propose an approach to deliver the learning from DSSs and guide physicians to change their behaviors. Referred to as 'Informating the Clan', they propose that to utilize new learning, physicians must feel that they can trust the information. As such, hospital administrators must provide legitimacy to the message, as well as the messenger, in order to see changes in physician actions as a result of learning.

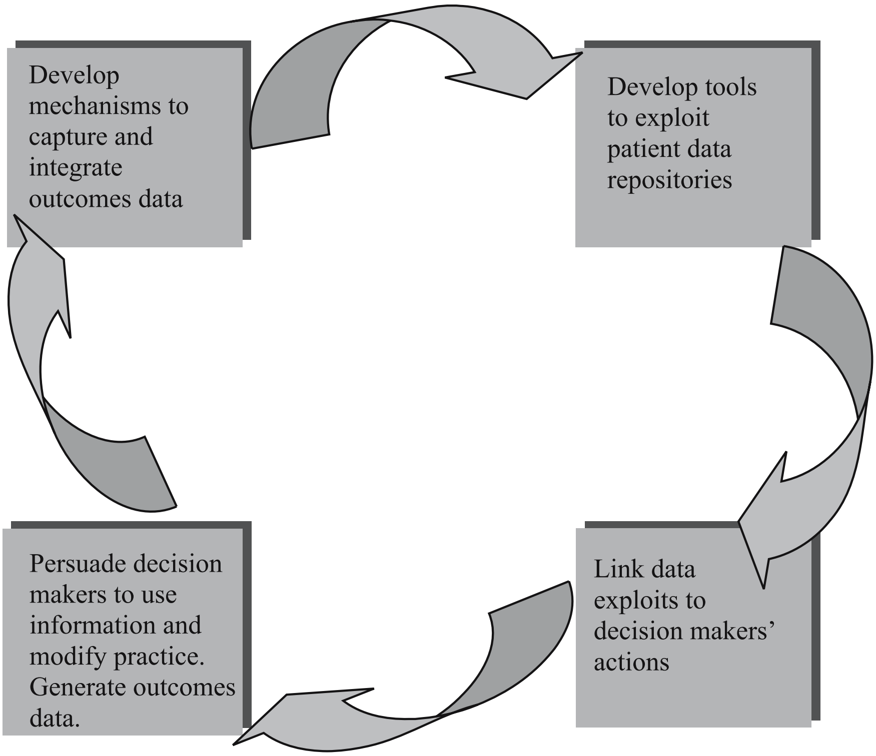


**Figure 1.** Steps in the process of creating and capturing DSS data for learning

**Table 1.** Summary of areas of DSS advances and opportunities in various areas of contribution

| Areas of contribution | Advances | Key opportunities | Major supporting capabilities |
|---|---|---|---|
| Quality and patient satisfaction | • Move away from a focus on abstracting information from medical record reviews<br>• Measuring effectiveness of clinical and patient satisfaction outcomes<br>• Era of assessment and accountability | • Emerging as a scientific discipline of medical informatics<br>• Physician's role in evidence based medicine<br>• Technology improves quality by increasing adherence to guidelines<br>• Incorporating patient satisfaction as a quality outcomes | • Timely alerts to physicians, e. g., through computerized physician order entry (CPOE) systems<br>• Physician profiling and pattern analysis systems |
| Efficiency, profitability | • Focus on health care costs<br>• Creation of prospective payment system | • Enhanced costing methodology for determining and producing improved<br>• Integrated cost-outcomes information<br>• Measuring return on investment (ROI) of decision-support activities | • Intelligent agents in DSSs<br>• Interoperable systems |
| Risk mitigation | • Patient bill of rights'<br>• Understanding of errors and adverse events | • Integration of clinical and administrative data<br>• Proactive availability of data<br>• Reducing false positives in ADE systems | • ADE systems<br>• CPOE |
| Learning | • Availability of severity adjusted data sets<br>• Availability and proliferation of evidence based medicine | • Use in of information science, statistical modeling and computer science in quality management<br>• Informed consumers<br>• Ensuring physician adoption of DSS and change in behavior | • Web based knowledge<br>• Web-based quality report cards<br>• Real time decision making availability |

DSSs will also play a major role in consumer choice of healthcare services and providers. We are beginning to see online patient resources to understand disease symptoms, treatment options, and prognoses, for example, WebMD.com, and the quality and cost of healthcare providers, for example, healthgrades.com. With increased information, patients will be able to create models for treatment plans that incorporate the risks, costs, and provider quality to decide which treatment option to adopt. This will lead to informed healthcare consumers, competition among healthcare providers, and subsequently higher quality and lower healthcare costs.

Future opportunities for healthcare providers appear to be in making real-time decision support information available to physicians and administrators. In the following section we discuss questions that IT researchers can explore to create accurate and robust DSS-based support to decision makers. Table 1 summarizes the advances, opportunities and supporting capabilities in the four areas of DSS contribution.

## 3 The Future of DSSs in Healthcare

To some extent, the future of DSSs in clinical areas of healthcare is dependent upon the successful implementation of source data and knowledge systems. As such, there are generally three areas that must advance. First, the creation of an integrated enterprise archiving system will be the cornerstone of an effective DSS strategy. While some institutions are beginning to initiate such approaches, an industry-wide approach that implements data standards and exchange would improve clinical intervention. Second, pattern and trend recognition from archival sources will lead to the construction of rules and triggers to create knowledge among clinical practitioners. DSSs can draw upon this knowledge to deliver decision support at the point of decision making. Finally, this knowledge must be proactively utilized to preempt critical patient conditions such as cardiac arrest or stroke.

Enterprise-wide DSSs in healthcare require that clinical DSSs are integrated with administrative DSSs so that financial consequences and patient experiences are combined with clinical treatment pathways for a comprehensive view of patient care. Benchmarking information will be required to assess the effectiveness of patient care against that of competitors or other healthcare standards. Several challenges remain for the optimum use and benefits of DSS. For instance, since quality indicators are updated with metrics, they face the challenge that consistent data for longitudinal analysis will be lacking. In the areas of efficiency and profitability, the challenges pertain to the limits of cost information. Over time, the incremental benefits from cost information will decline and hospitals may be less inclined to invest in DSSs. Similarly, successful risk mitigation can breed complacency. As ADEs and other risks recede, hospitals may be tempted to divert resources from DSSs to other initiatives. Although the technical challenges facing information systems integration remain, the greatest challenge will come from changing decision makers' behaviors. Proper incentives must be incorporated into and accounted for in the decision alternatives so that decision outcomes are optimal. After all, the best DSS alternative is of no consequence if it is not implemented by the decision maker.

## 4 Research Questions in Healthcare DSSs

The growing complexity of healthcare continues to challenge researchers as well as practitioners. However, advances in information technologies are creating new opportunities for addressing them. IT researchers can assist in tracking social, organizational and technical challenges relating to the development and implementation of DSSs in healthcare. Some research questions are:

- How can IT, such as radio frequency identification (RFID) and bioelectronics combined with wireless technologies, assist in tracking and integrating patient care data with administrative data as inputs to a DSS?
- How can DSSs be deployed so that support is available to clinical and administrative decision makers at the time and place of decision making?
- How can DSSs be integrated with data-mining and business intelligence capabilities so that the discovery of business logic is available to decision makers?
- How can expert systems capabilities help in enhancing the decision quality, for example, in preventing adverse drug events?
- What social and organizational structure is best suited to deploy DSSs among physicians and clinicians?
- What incentive structures need to be put in place so that DSSs are used to modify behavior?
- How do DSSs or other ITs reduce litigation risks? Conversely, can DSSs serve as evidentiary material, and will it be open to scrutiny and interpretation during litigation?
- What intermediate variables must be tracked to assess the impact of DSS on hospital performance?

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# CHAPTER 60
# Decision Support Systems in Forest Management

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Numerous decision support systems have been developed for forest management over the past 20 years or more. In this chapter, the authors briefly review some of the more important and recent developments, including examples from North America, Europe, and Asia. In addition to specific systems, we also review some of the more-significant methodological approaches such as artificial neural networks, knowledge-based systems, and multicriteria decision models. A basic conclusion that emerges from this review is that the availability of DSSs in forest management has enabled more-effective analysis of the options for and implications of alternative management approaches for all components of forest ecosystems. The variety of tools described herein, and the approaches taken by the different systems, provide a sample of the possible methods that can be used to help stakeholders and decision makers arrive at reasoned and reasonable decisions.

**Keywords:** Decision support; Natural resources; Forest management

## 1 Introduction

Forest management has been a hotbed of decision support system (DSS) development since at least the early 1980s. One of the earliest reviews on the broader topic of natural resource management (Davis and Clark 1989) catalogued about 100 systems, and subsequent reviews of systems suitable for forest management in particular (Mowrer 1997, Schuster et al. 1993) catalogued many more. Somewhat later, Oliver and Twery (2000) and Reynolds et al. (2000) laid theoretical and practical groundwork, respectively, for thinking about how to apply DSSs to the much more formidable goal of forest ecosystem management.

Throughout this chapter, we shall have occasion to refer to concepts such as ecosystem management and sustainable forest management, so a few definitions are in order at the outset. Put simply, the basic goal of ecosystem management is to maintain the states and processes of biophysical systems in good working order while attempting to satisfy the needs of society for the goods and services derived from those systems (Grumbine 1994). The term sustainable forest management builds on the basic concept of ecosystem management, adding its own temporal component. Sustainable forest management emphasizes the need to address contemporary demands for goods and services from ecosystems while not precluding opportunities for future generations (Maser 1994).

The majority of what we might call first-generation systems were typically hard-coded, and designed to address relatively narrow, well-defined problems such as supporting silvicultural prescriptions (e. g., practices concerned with forest cultivation) for individual species (Rauscher et al. 1990), or pest management for specific pests on specific species (Twery et al. 1993), which partly accounts for the seeming plethora of systems. However, especially over the past 10 years, there has been a pronounced trend toward the development of far fewer, but more-general-purpose, multifunctional systems. This trend was significantly enabled bythe rapid advances in computing hardware and software systems engineering that have facilitated DSS development in general. Perhaps, at least as important, this trend was also strongly motivated by the needs of forest-management organizations to address the complex issues of ecosystem management effectively (Rauscher 1999). FORPLAN (Johnson and Stuart 1987) was among the earliest DSSs to implement an ecosystem-based approach to forest management in North America. In the period, 1977–1992, it was, in fact, the pre-eminent DSS used by the U.S. Forest Service for forest planning on its 120 national forests, which encompassed about 77 million hectares (Kent et al. 1991). The successor to FORPLAN, Spectrum, is still in relatively wide use today in North America, but some powerful and somewhat painful lessons were learned along the way. Commenting on the original system's fall from grace, as it were, FORPLAN lead scientist K. Norman Johnson (Johnson et al. 2007) explains:

> *"Thus began a futile 15-year odyssey of the Forest Service that consumed hundreds of millions of dollars and thousands of person years of effort to develop the optimal amount of timber harvest given the many goals of the national forests. In the end, very few of the plans developed by FORPLAN were ever implemented and many, many people became disenchanted with decision support models for forest planning."*

Perhaps the three most salient explanations for the disenchantment with FORPLAN have also been provided by Johnson:

1) FORPLAN was difficult to explain. Thus, optimal harvest levels were produced without the planners being able to explain why these solutions were best. This created a sense of powerlessness and frustration among both the Forest Service planning teams and the public.
2) Use of FORPLAN assumed that the central resource planning problem of the national forests was to find a sustainable harvest level within environmental constraints. But, as history shows, it turned out that the central resource planning problem was to find scientifically credible conservation strategies for at-risk species.
3) FORPLAN was imbedded in a technical rather than a social planning process. The heart of planning was viewed as technical analysis rather than a social negotiation.

With this cautionary tale in mind, let us consider contemporary systems. Our roadmap for this chapter is as follows. In the next section, we provide brief overviews of some of the more important systems developed over the past 10 years or more. The coverage is certainly not exhaustive. However, we have attempted to strike a balance between comprehensiveness and level of detail. The resultant set of systems reflects contributions from Europe, Asia, and North America, and is also reasonably representative of the diversity of successful approaches to decision support for forest management over this timeframe. For three of the systems discussed in this section [ecosystem management decision support (EMDS), landscape management systems (LMS), and NED], Reynolds (2005) has previously provided an analysis of how well these systems are meeting the challenges posed by ecosystem management and sustainable forest management. Section 3 discusses three important examples of decision frameworks — multicriteria decision systems, artificial neural networks, and knowledge-based systems — that may or may not be integral parts of general-purpose, multifunctional DSSs, but that have proven sufficiently important in forest management in their own right that they deserve separate discussion. Section 4 is devoted to conservation biology — a hot topic in contemporary forest management — due to the pervasive impact of human activities on natural systems. Indeed, DSSs emphasizing conservation of biodiversity constitute a significant subset of modern DSSs in forest management and natural resource management more generally. Finally, in section 5, we conclude with what we see as the most promising lines for DSS development in forest management in the near future, considering some of the lessons learned along the way.

## 2 Major Systems

Each of the following subsections describes a specific DSS for forest management. For each system, we provide a brief descriptive overview, discuss some of the more-significant applications of the system, and summarize the benefits that can be derived from its use. Table 1 provides a quick synopsis of the systems discussed.

**Table 1.** Synopsis of systems described in Sections 2.1 through 2.10

| Criterion | AFFOREST | DSD | EMDS | ESC | FORESTAR | Forest-GALES | LMS | NED | SADfLOR | Woodstock |
|---|---|---|---|---|---|---|---|---|---|---|
| Primary scope/domain | Effects of afforestation of agricultural land | Supporting forest extension services | Integrated landscape evaluation | Suitability of tree species for planting | Protection, restoration and harvesting | Vulnerability of forest stands to wind damages | Forest management of large properties | Forest management for multiple values | Forested landscape management planning | Formulate strategic management |
| Basic unit of analysis | 1 km²/1 ha | Stand | User-defined unit | Stand to landscape | Stand | Stand to landscape | Stand | Stand | Stand | User-defined unit |
| Alternatives options | Afforestation strategies | Stand treatments | User-defined landscape units | Tree species | Maximizations | Silvicultural practices | Stand treatments | Stand treatments | Stand treatments | User-defined landscape units |
| Basis of evaluation | Environmental impacts | Goal satisfaction | Strength of evidence | Suitability | User interpretation | User decision of acceptable risk | User interpretation | Goal satisfaction | Goal satisfaction | Goal programming |
| Planning horizon | 0–30 years | 0–100 years | NA[a] | NA[a] | 0–50 years | 0–80 years | 0–200+ years | 0–50+years | 0–100 years | User defined |
| Offers multi criteria analysis | Yes | Yes | Yes | No | No | No | Yes | Yes | Yes | Yes |
| Includes artificial intelligence | No | No | Yes | Yes | No | No | No | Yes | No | No |
| Includes predictive models | Growth models | Growth models | None | Yield class | Growth model | Wind damage | Growth models | Growth models | Growth models | Yes |
| Allows spatial analysis | Yes | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

**Table 1.** Continued

| Criterion | AFFOREST | DSD | EMDS | ESC | FORESTAR | Forest-GALES | LMS | NED | SADfLOR | Woodstock |
|---|---|---|---|---|---|---|---|---|---|---|
| Supports knowledge management | No | No | No | No | No | No | No | No | No | No |
| Primary users | Policy makers, managers | Managers | Scientists, managers | Managers, policy makers | Managers | Managers | Managers | Managers | Scientists | Managers |
| Input requirements | High | Low | Medium | Medium | High | Low | High | High | High | High |

[a] The criterion is not applicable to this system.

## 2.1 AFFOREST

AFFOREST was developed under the Fifth Framework Programme for Research and Technological Development of the European Union from 2000–2004 (http://www.fsl.dk/afforest). The general aim of the AFFOREST project was to enhance knowledge on the environmental effects of afforestation (conversion of land use back to forest) of agricultural land in north-western Europe. One major motivation of the project was to develop a tool that could support the implementation of the Kyoto Protocol by providing knowledge on the efficiency and environmental impact of Kyoto forests established for the purpose of carbon sequestration with regard to groundwater recharge and nitrate leaching. The focus of DSS development was clearly on afforestation, but attempts were made to extend the framework to forest management in a more-general sense, including management of existing mixed species forests, conservation of tropical forests, and plantation forestry (Garcia-Quijano et al. 2005).

AFFOREST is a spatial DSS and has been implemented as an extension of ArcView™ 3.2 (Environmental Systems Research Institute, Redlands, CA[1]), which provides the full ArcView™ functionality to the user. A user is guided through a number of dialogue windows in which they can make choices. Afforestation strategies are defined by the combination of tree species, site preparation level, and a stand-tending regime. Additionally, restrictions regarding the location of afforestation activities within a given region can be set by the user. Currently, four optional tree species are included in the system (*Picea abies*, *Pinus sylvestris*, *Quercus* spp., and *Fagus sylvatica*). Growth and environmental performance of monospecies stands is modeled by a metamodel that was developed from the output of the SECRETS growth model (Sampson and Ceulemans 2000). Growth performance is affected by climate and site quality. The maximum rotation length (time from planting to harvest) is 100 years. The spatial data required to run the system are site quality, the initial system (i. e., the baseline), and climate. AFFOREST was designed to answer specific questions, which are processed one at a time. Questions may be of the following kind: (i) What environmental performance can be expected when a given afforestation strategy is applied within a given spatial domain for a given number of years? (ii) Where should afforestation activities take place with a given strategy for a given number of years to achieve a desired level of environmental performance? (iii) Which strategy should be applied to a given initial system for a given number of years to yield a desired level of environmental performance? (iv) How long should a strategy be continued on a given initial system to yield a desired level of environmental performance? A multicriteria option can be activated which uses a goal-programming algorithm to find optimal areas, strategies, or durations for afforestation activities, which allows all three environmental impacts (carbon sequestration, groundwater recharge, nitrate leaching) to be combined in one question.

Currently the system has been implemented for four northwestern European countries (Sweden, Denmark, The Netherlands, Belgium) as one spatial unit at 1-km$^2$ resolution, and for each country individually at 1ha resolution.

## 2.2 DSD

With the first prototype being implemented in 2001, Decision Support Dobrova (DSD) was one of the first computerized silvicultural decision support systems in central Europe (Lexer et al. 2005). DSD targets stand-level decisions for individual stands, and is designed to support two main silvicultural decision-making problems: (i) the establishment of new stands where a decision is sought as to which tree species and species mixtures are suitable at particular locations within the project area, including considerations of the effects of climate change, and (b), a decision concerning stand treatment programs for existing stands aiming at a future targeted species-mixture type given a particular set of management objectives. DSD has been developed to support the staff of forestry extension services in the Dobrova region in preparing informed recommendations for forest management to small private landowners based on the owner´s goal preferences.

In a typical DSD session, the user is guided through a generic decision-making process (Mintzberg et al. 1976). One of the first steps is to assign a particular forest property to one of the predefined site and stand categories represented in the comprehensive DSD database. For this task, easily available site and stand characteristics are used in a decision-tree approach. Gaps in the database of DSD are communicated to the user with the offer to assign the stand to the most similar case available within DSD. The landowner is then asked to articulate preferences for predefined management objectives employing pairwise comparisons on a ratio scale (Saaty 1992). Currently three management objectives are offered for the Dobrova project area: (a) timber production, (b) nature conservation and biodiversity, and (c) maintaining or improving site productivity. Due to the individual-stand approach of DSD management, objectives such as hunting for roe deer were not included in DSD. After the user has identified the current state of the forest and prioritized the objectives of the landowner, he or she can select potentially suitable management alternatives from the DSD database, which are then compared with regard to how well they satisfy the objectives for a particular stand.

For each objective, a short- to mid-term (i. e., 30 years) as well as a long-term planning horizon are distinguished. In cases for which no quantitative values for the indicators can be provided to measure progress towards objectives, alternatives are directly compared in pairwise comparisons, employing Saaty´s ratio-scale approach and expert judgment (Saaty 1992). In DSD, mostly quantitative measures of stand-treatment performance for a 30-year period are thus combined with more-qualitative ratings for the long-term effects.

Via the graphical user interface, the user can input customized data, which are linked to prefabricated growth and yield data of the selected management activities to calculate costs and revenues. Based on further quantitative and qualitative information related to forest structure and composition, indicators are calculated for the performance of management options with regard to timber production, nature conservation, and the maintenance of site productivity. Indicators for timber production are economic success and market opportunities, as well as biotic and abiotic risks. For nature conservation, the naturalness of tree species and structural diversity were considered. For site productivity, among others, litter decomposition and potential loss of nutrients were selected.

A core component of DSD is a multicriteria evaluation which, in the current version of DSD, builds on an additive hierarchical utility model (Pukkala 2002). For each indicator, a value function (Kamenetzky 1982) has been constructed in the course of DSS development. Parameters of the utility model, as well as the value functions, were estimated from pairwise comparisons employing Saaty´s eigenvalue method (e. g., Vacik and Lexer 2001). This hard-coded expert-based preference information is linked with interactively generated owner preferences for objectives and employed to produce a ranking of the available alternatives. The user can loop back to any of the prior phases of the process, store the scenario session in the database of DSD, view results on screen, or print a comprehensive report.

The DSD software is implemented in Borland® C++™ as a client/server architecture, with Oracle® as the relational database management system. The interface component of the program resides on the desktop computer of the user, and the application logic is on the central server of the regional forest authorities. Via a local area network, the DSD software uses the computing power of this server. The graphical user interface is completely based on Borland´s VCL™ (Visual C Library). The generation of reports is based on Quickreport™, which uses components of the Borland® C++™ programming environment.

Currently, the DSD system is in use in one district in southern Austria. The focus of that implementation is on Scots pine forests (*Pinus sylvestris* L.). DSD is also applied in afforestation planning within afforestation programs aiming for the conversion of agricultural land into forest land. Results of an evaluation study are reported in Vacik et al. (2004). Currently, there are plans to extend the range of application of the DSS to risk-prone Norway spruce forests (*Picea abies* (L.) karst.) at low-elevation sites in lower Austria naturally supporting mixed broadleaved forests.

Approximately 2 of Austria´s 3.9 million hectares of forests are small private properties (BMLFW 2001), most of which are just a few hectares of forested land each. In Austria, professional expertise on how to manage these small-scale forests is traditionally provided via the extension services of chambers of agriculture and the district forest authorities. DSSs such as DSD have the potential to meet several requirements of forestry extension: (a) improved efficiency of the extension process, (b) increasing demand for transparent decision making in forest management, and (c) acknowledgement of the rapidly expanding knowledge base on the management of forest ecosystems. The generic decision-making process implemented in DSD is easily adapted to specific needs of other regions. Moreover, the whole system is database driven. Transferring DSD to another project area, or to include new stands or silvicultural treatment options, would just mean providing new data.

## 2.3 EMDS

The ecosystem management decision support (EMDS, http://www.institute.redlands.edu/emds) system is a general solution framework for integrated landscape evaluation and planning (Reynolds et al. 2003). The system provides decision support for landscape-level analyses through logic and decision engines integrated with the ArcGIS™ geographic information system (GIS, Environmental Systems Research Institute, Redlands, CA). The NetWeaver™ logic engine (Rules of Thumb, Inc., North East, PA) evaluates landscape data against a formal logic specification (e. g., a knowledge base in the strict sense) designed in the NetWeaver™ Developer system, to derive logic-based interpretations of ecosystem conditions. The decision engine evaluates NetWeaver™ outcomes, and data related to the feasibility and efficacy of land management actions, against a decision model for prioritizing landscape features built with its development system, Criterium DecisionPlus™ (CDP, InfoHarvest, Seattle, WA). CDP models implement the analytical hierarchy process (Saaty 1992), the simple multi-attribute rating technique (Kamenetzky 1982), or a combination of the two methods. The system has been used in a wide variety of applications (Table 2).

EMDS developers use NetWeaver™ Developer (http://www.rules-of-thumb.com/) to design the knowledge bases used in EMDS. The logic engine allows partial evaluations of ecosystem states and processes based on available information, making it ideal for use in landscape evaluation where data are often incomplete. A second feature provided by the logic engine is the ability to evaluate the influence of missing information on the logical completeness of an assessment. The engine supports diagnostic tools for determining which missing data are most influential in terms of obtaining a logically complete analysis, given currently available data, and for determining how much priority to give to the missing data, given other logistical information. The ability to evaluate data influence can have important implications for contemporary ecosystem analyses, which often involve large, complex, abstract problems with numerous data requirements. It turns out that the influence of missing data is a very dynamic property, depending on the information that is presently available, and the specific values. The EMDS diagnostic tools for evaluating data influence have the potential to reduce the time and costs associated with broad-scale ecosystem analysis significantly.

The priority analyst (PA) implements multicriteria decision models developed with CDP (http://www.infoharvest.com/), and is a planning component to assist with setting priorities for management activities, given results of a landscape evaluation performed by the logic engine. Whereas the logic engine addresses questions about the current state of the assessment area, PA addresses questions about where to direct management for best effect. For most applications of evaluation and planning, maintaining this distinction is important because the landscape

**Table 2.** Examples of significant EMDS applications

| Decision support topic | Organization |
|---|---|
| Conservation biology | Sierra Checkerboard Initiative[a] |
| Desert tortoise habitat | University of Redlands (CA)[b] |
| Forest land classification | National Taiwan University[c] |
| Landscape pattern analysis | USDA Forest Service[d] |
| Mercury remediation | Sacramento River Watershed Plan (CA)[e] |
| Oak woodland restoration | University of California, Santa Barbara[f] |
| Regional watershed monitoring | USDA Forest Service, Northwest Forest Plan[g] |
| Roads analysis | University of California, Davis[h] |
| Salmon recovery planning | National Oceanic and Atmospheric Administration[i] |
| Watershed assessment | North Coast Watershed Assessment (CA)[j] |

[a] http://www.consbio.org/cbi/applied_research/sierra_assessment/sierra_assessment_pdf.htm
[b] http://www.redlands.edu/x12968.xml
[c] http://www.isprs.org/istanbul2004/comm7/papers/35.pdf
[d] http://www.fsl.orst.edu/emds/manuscripts/pdf/pnw_2004_hessburg001.pdf
[e] http://www.sacriver.org/subcommittees/dtmc/documents/DTMCMercuryStrategyPlan.pdf
[f] http://www.bren.ucsb.edu/research/1999Group_Projects/valleyoak/valleyoak_final.pdf
[g] http://www.reo.gov/monitoring/watershed/index.htm
[h] http://www.fsl.orst.edu/emds/manuscripts/pdf/GirvetzShilling.pdf
[i] http://www3.csc.noaa.gov/salmonid/html/manage/about.htm
[j] http://www.ncwap.ca.gov/default.html

elements in the poorest conditions are not necessarily also the best candidates for management activities. PA rates the landscape elements not only with respect to their condition, but also with respect to factors related to the feasibility and efficacy of management.

Perhaps the most compelling feature of EMDS is the relative transparency of solutions. Both the logic-modeling and decision-modeling components emphasize graphic interfaces in which modeling results are conveyed to system users in an easy-to-understand, intuitive manner, making it relatively feasible to communicate with the broad audiences that commonly participate in contemporary analysis and planning to support ecosystem management.

## 2.4 ESC

Over the past 8,000 years leading up to the beginning of the 20th century, U.K. forest cover decreased from about 80% to 5% of the land area as a result of clearance (Yarnell 2002). Since 1905, successive forestry expansion policies have brought about an increase in forest cover, which now stands at 12% of the land area (Anon 2005). It is generally recognized that one of the first steps towards sustainable forest management, and on which many other decisions depend, is to ensure that tree species selected for planting are suited to the site conditions (Anon 2004). The professional ability of foresters to read the site conditions and select well-suited tree species is of fundamental importance. Much commercial forestry practiced in the U.K. through the 20th century involved a limited selection of species, and relied on the unsustainable practice of adjusting site conditions (ground preparation and fertilization) to ensure optimal growth. Consequently, the skill of matching species to site type declined, so ecological site classification (ESC) was developed (Pyatt et al. 2001, Ray 2001) to rekindle these skills and to draw together the accumulated knowledge of species-site selection for a range of species and native woodland types.

ESC (http://www.forestresearch.gov.uk/esc) is a methodology for assessing tree species suitability, and predicting yield in the form of a site index, on the range of site types encountered in the U.K. Both the U.K. Forestry Standard and the U.K. Woodland Assurance Scheme (Anon 2000) support the use of ESC as an objective methodology for auditing site-species suitability and estimating the yield potential of a site.

The ESC yield class prediction is intended to give an indication of the potential maximum mean annual increment of stem volume per hectare per year for plantations, and therefore to offer commercial evidence of yield, along with the ecological suitability of a particular species of tree (Ray 2001). The estimates of yield made by ESC assume climatic warmth (accumulated temperature) as the principal factor determining the potential rate of growth, which may be modified by the most limiting of the remaining five factors: moisture deficit, windiness, continentality (inverse of oceanicity), soil wetness, and soil fertility. These six ESC factors are calculated using a set of empirical models (see Pyatt et al. 2001). In ESC, the link between the biophysical factors and tree species suitability is defined by a set of knowledge-based rules that represent an accord based on the combined discussion of a panel of forest scientists with knowledge and experience of the site-related growth potential of the 26 species of tree presented. ESC site-yield estimates have been judged acceptable by many foresters and scientists at ESC courses and demonstrations across a range of climatic zones and site types in the U.K. The model for Sitka spruce [*Picea sitchensis* (Bong.) Carr] has been validated (Ray et al. 2001). This work showed the knowledge-based approach to slightly underestimate site-yield estimates for sub-compartments containing Sitka spruce in the Clashindarroch Forest, in north-east Scotland.

ESC has been formulated as a site-based decision support tool written in C++, for which detailed site information from soil and vegetation surveys can be used to predict site suitability for 25 species of tree and 19 native woodland types (Ray 2003) of the national vegetation classification (NVC, Rodwell 1991). The model lends itself to GIS analysis, and was first tested within EMDS (see section 2.3)

(Ray et al., 1998), before being successfully implemented within ArcView 3.*™ (Clare and Ray 2001). The ESC DSS is recommended by the U.K. Forestry Standard as an authority on species choice.

The ESC DSS is used in the U.K. for forest scenario planning, from the strategic national and regional scales to landscape-scale analyses through to suitability assessments on a site-by-site basis (Ray and Broome 2003) for forest design plans. In addition, the published climate change scenarios from the U.K. Climate Impacts Programme (Hulme et al. 2002) have been adapted for use in ESC (Ray et al. 2002). With this information, ESC-GIS has been successfully used to predict the impact of future climate scenarios on yield and species suitability in the U.K. (Broadmeadow and Ray 2005, Broadmeadow et al. 2005). These analyses are now being used in the development of forest policy, to produce guidance on how to adapt species and provenance selection to U.K. climate change scenarios.

## 2.5 FORESTAR

FORESTAR (forest operation and restoration for enhancing services in a temperate Asian region) was developed to promote sustainable forest management under the reformed forestry system in China (Shao et al. 2005). FORESTAR was programmed with the customization MapObjects™ (Environmental Systems Research Institute, http://www.esri.com) geographic information environment. FORESTAR is composed of multiple models and practical user interfaces that are linked with geospatial data. It includes functions for data query and display, statistical analysis, decisions on forest management, data update and maintenance, etc. The core of FORESTAR involves three modules: forest harvesting, protection, and restoration.

The forest harvesting module implements a two-step decision-making process. The first step selects forest stands (sub-compartments) for harvesting within a landscape and the second step determines harvesting at a stand level. The first step compares and optimizes landscape structure by selecting different forest stands for harvesting. After excluding protected forests, harvest stands are selected, considering operating costs (for example, clustered harvesting is less costly than scattered harvesting), timber yield (harvesting stands with the most volume), landscape integrity (avoiding further fragmentation of forest patches), and non-wood products (protecting forests that produce other valuable goods and services). Once a forest stand is selected for harvesting, a matrix-model interface is used to optimize harvesting schemes.

The forest protection module identifies forest areas for protection, locates forest pests and diseases, and forecasts risk of forest fire. Forest protection is determined by referring to the nationwide criteria of forest classification. Forest classification maps were made at the forestry-bureau level under the guidance of provincial forestry bureaus. FORESTAR allows revision of the forest-classification maps based on finer-resolution geospatial data. Forest pests and disease are located and recorded based on available records of field observations. The accumulated information is used to provide guidance for forest cleaning. Forecasting forest fires is based on a model of fire risk, which links the risks of forest fire with forest fuels, topography, and anthropogenic activities (Xu et al. 2006). The fire risk map has helped the local forestry organization relocate some forest-fire-prevention check points to areas of greater risk.

The forest restoration module includes three activities: (1) removing shrubs and herbs within five years after seedlings were planted at harvesting sites, (2) thinning secondary forests, and (3) tending low-productivity forests. The purpose of this module is to help foresters make the best use of funds at local forestry units. The module can be used to select forest stands for silvicultural treatments based on the availability of funds. It can also be used to determine the range of funds required for necessary silvicultural activities. The former assures the best use of government funds, whereas the latter helps foresters plan and apply for funds from the government.

This DSS was originally developed and applied to the Baihe Forestry Bureau, a state-owned forest enterprise in eastern Jilin Province in the early 2000s. It was later modified and applied to the Benxi City Forestry Bureau, a local forestry unit in Liaoning Province. Both Jilin and Liaoning Provinces are located in northeast China, neighboring North Korea. FORESTAR is still in a trial stage in northeast China. Initial experience with developing and using FORESTAR has been more exciting than disappointing. It is suitable for a forestry bureau or forest farm as an implementation unit. The most difficult barrier to using FORESTAR thus far has been the lack of reliable data. Existing data, available from forest inventory organizations, are often inconsistent and contain various random errors. It has taken time and resources to correct these errors. Another difficulty is to translate silvicultural activities into computer code. Each forestry unit tends to have different site-specific silviculture measures. This makes it very difficult, if not impossible, to develop a general model that can be used for every forestry unit in a region. Therefore, although FORESTAR is highly portable in principle, customization for each new location has been the reality in practice. A third issue is that local foresters have traditionally managed forests based on personal experience; they are not familiar with data- and model-driven decision-making processes, and it takes time for them to learn how to benefit from the system.

FORESTAR provides a mechanism for local foresters to pursue long-term sustainable management of forest resources. Firstly, the up-to-date, timely forest information associated with FORESTAR assures the data requirements for running the forest dynamic model. Secondly, future forest conditions can be simulated and compared with a variety of forest management options by using the modules of FORESTAR. Lastly, forest management decisions can be balanced between short-term utilization and long-term conservation of forest resources. For example, for Baihe Forestry Bureau in Jilin Province, total forest stocking can increase by 20% in the next three decades, while timber production stays the same every year if the optimal forest logging plans are implemented. Under the traditional logging plan, forest stock would continue to decline.

In past decades, forest managers and scientists in China rarely communicated. However, FORESTAR is valuable as a framework within which managers and scientists can share experiences and knowledge much more effectively. Feedback from managers to scientists and explanations from scientists to managers are helping forest managers and scientists work closer and share their thoughts in a mutually understandable language. Although FORESTAR was developed to resolve real-world problems in China's forestry, it can also be used as a learning tool. By using FORESTAR in their daily work, forest managers can compare their own recommendations with those suggested by FORESTAR. This practice is helping forest managers think about forest management in new ways.

## 2.6 ForestGALES

Forests in Britain are periodically affected by strong winds, causing losses in quality and financial value (Quine 1995). Indeed, the U.K. is a very windy country (Palutikof et al. 1997), with 100–150 gales in the last century, when wind speeds were in excess of 40 $ms^{-1}$. ForestGALES (geographical analysis of the losses and effects of storms in forestry) is a probability-based model, designed to replace the former windthrow hazard classification system (Miller 1985), and has been delivered as a DSS. The program provides a better treatment of variability in the wind climatology of forests, an estimation of the critical wind speed that will cause damage, and the return period for that damage to occur. The use of a mechanistic model to estimate critical wind speed allows greater flexibility for testing different forest-management scenarios such as the choice of cultivation, thinning options, drainage improvements, the impact of clear-cutting, or the creation of retentions.

ForestGALES (http://www.forestresearch.gov.uk/ForestGALES) is based upon a better understanding of forest climatology and windthrow, and explicitly links the wind profile and mechanical forces exerted across the forest stand as a function of tree characteristics. The system estimates the threshold wind speeds that are predicted to overturn and break stems within the canopy, as a function of tree height, diameter, current spacing, soil type, cultivation, drainage and choice of species (Dunham et al. 2000, Gardiner and Quine 2000, Stacey et al. 1994).

Resistance to overturning is based on more than 2,000 samples from past tree pulling on a variety of soils, species, and cultivation types, thereby integrating a major data resource in a new way (Nicoll and Ray 1996, Ray and Nicoll 1994). The best regressions were obtained against stem weight. Critical wind speeds for overturning and breakage are assumed to produce bending moments in excess of the resistive factors at the base of the stem for overturning and at 1.3 m above the base of the stem for breakage (Gardiner et al. 2000).

The probability of the critical wind speed occurring at a particular site is estimated in ForestGALES by the detailed aspect method of scoring (DAMS) system (Quine and White 1994), which is a function of elevation, topographic exposure, aspect, funneling effects, and wind zone classification across Britain (Bell et al. 1995). The DAMS score was related to parameters of the extreme value distribution, thereby linking the mean and strong wind climatologies (Quine 2000). Changing probabilities of damage over the life of a forest stand are calculated using the U.K. Forestry Commission's yield class models (Edwards and Christie 1981). The program estimates the annual probability of damage at different time steps. The temporal dimension of the model is very important for the estimation of risk during the life of the crop and for testing alternative silvicultural practices that may affect the stability of a crop. Initial validation of the model with data from wind tunnels and field experiments (Gardiner et al. 2000) has shown how sensitive the model is to silvicultural practices that alter height-spacing ratios, drainage, stem taper, and distance to new edges, representing changing stand conditions.

The ForestGALES DSS was written in Delphi™ as a personal computer (PC)-based system, and is used by forest planners and managers to assess the degree of risk of wind damage (overturning and stem breakage) prior to intervention. The application has also been adapted to link to the ArcView™ GIS system using Avenue™ scripting. This adds basic functionality to the system such as displaying maps, zooming, panning, selection of layers, and basic queries. The GIS functionality provides forest managers with an excellent tool for decision making at the forest landscape scale (Gardiner et al 2003). It allows a visual analysis of the implications of silvicultural strategies in terms of wind risk such as thinning, retentions, design of felling coupes, new forest roads, or the effect of clear-cutting over neighboring stands (edge effect).

## 2.7 LMS

The landscape management system (LMS, McCarter et al. 1998) is a software application designed to assist forest ecosystem management planning and analysis at a landscape level. It is an ongoing development project of Yale University, the University of Washington, the Cradle of Forestry in America, and the United States Department of Agriculture (USDA) Forest Service. LMS and its companion tools run in a Microsoft Windows environment on individual, stand-alone computers. Prerequisites to using LMS include tree inventories, stand attribute information, and GIS data. The system is built around an independent inventory entry program and has built-in links to spatial analysis tools (GIS), independent visualization models (SVS and Envision) developed by McGaughey (1997, 1998, 2000, 2002), previously developed growth models (FVS, Dixon 2002) and ORGANON (Hann et al. 1997), and alternative analysis tools developed specifically as companions to LMS (Toggle, Comnick 2002). LMS is available for download free of charge at http:/lms.cfr.washington.edu/.

LMS is organized around a portfolio of stands that may or may not be physically adjacent, but which are managed within an overall framework. In LMS the portfolio can be manipulated to create a variety of scenarios with a variety of treatments using an internal treatment engine that translates information into a form usable by the linked growth simulators. LMS is able to track changing conditions through time and evaluate stand structure relative to resource values such as timber production, carbon sequestration, wildlife habitat, and fire risk, and display the results of varying management scenarios. The companion analysis tool

Toggle follows a scoping and grouping procedure to assess representative classes of stands of different compositions, size classes, and densities, and then to display the results of adjusting the balance of management activities and timing, producing graphical and tabular views of outcomes. The ability to develop, analyze, and compare multiple silvicultural pathways or management alternatives is a significant benefit of this system. Analysis of uncertainty is effectively unavailable within the system at present. Although the user interface is not as friendly as it might be, help systems and training are available for users who need assistance.

The landscape management system has been applied in diverse situations, varying from the development of a management plan for a small, private forest (Townsend 2002) to wildlife habitat evaluation of the Satsop Forest in Washington State (Ceder 2002) to assessment of fire risk on the Colville National Forest (Ceder 2005).

LMS provides significant advantages over similar software packages by its incorporation of, or links to, many different previously developed models and systems. These links allow a user to perform a variety of analyses on differing potential scenarios quickly. The primary interface of the system does not provide a great deal of guidance to a novice user, necessitating considerable training for the system to be effective, but ongoing development is improving this aspect. The speed of simulation and the flexibility of analyses through tools such as Toggle are strong assets of this system. The modularity of linkages to third-party models and tools allows LMS to be improved as new tools become available.

## 2.8 NED

NED is a set of computer-based tools for forest ecosystem management designed to allow the analysis of the trade-offs required when managing for multiple benefits. Development has been led by the USDA Forest Service's Northeastern Research Station, but includes many collaborators from other federal agencies, universities, state governments, and private consulting foresters throughout the eastern United States. The name NED was originally an acronym for the northeast decision model; however, since 1995 when development was expanded to include other regions of North America, the reference to the northeastern United States was dropped, and the name is now simply NED. The primary tool is designed as a DSS for professional forest managers to evaluate current and future conditions of their forests under alternative scenarios (Twery et al. 2005). Additional tools developed by the NED team are usable by the general public, school children, and forest landowners. These tools include the forest stewardship planning guide (Alban et al. 1995), NEWILD (Thomasma et al. 1998), StewPlan (Knopp and Twery 2003), and NEDLite (Knopp and Twery 2006), and are available free of charge from http://www.fs.fed.us/ne/burlington/ned.

NED has been developed as a goal-driven system with the intent of providing useful and scientifically credible information for project-level planning to natural resource managers. The resource goals addressed by NED include timber production, visual qualities, water quality and quantity, wildlife habitat, forest health, and ecology. The knowledge bases were developed over several years using committees of resource experts who identified potential specific goals that silvicultural treatments could affect within their fields. For example, the visual goals include variety (forest type or size class) at small (within stand) or large (among stands) scales, and timber goals include managing for maximum cubic volume production, high-value timber, or regular periodic income. These goals were then analyzed and broken into measurable desired conditions that could be evaluated within the system. The main NED DSS (the current version is NED 2) requires a fairly detailed inventory of a forested property, usually including plot data from trees, shrubs, ground flora, and down woody material. These data are needed to enable analyses for the full variety of resources, but NED will run with minimal data sets if the user only wants timber inventory summaries, for example. NED provides analysis of a variety of goals under the conditions produced by user-specified alternative management scenarios, but leaves the decision entirely to the user. Rather than have the program follow a predetermined decision process, the users of NED identify the need for detailed analysis by the computer and the desire to retain the final evaluation and decision for themselves.

The system design is based on a data file that includes inventories from multiple stands within a property or management unit. The data file is in the format of a Microsoft Access database, though Access is not required to run NED. The software interface is written in C++ and it uses Prolog components (Nute et al. 2005) to manage the knowledge bases and the handling of third-party external models, such as the FVS growth simulator (Dixon 2002), the SVS data visualization package (McGaughey 2002), and ArcGIS™. The NED analysis itself is not spatially explicit, but it does include an export function to ArcMap™ (Environmental Systems Research Institute, Redlands, CA) of summarized data as attribute layers. There is an import facility to allow the conversion of data files generated elsewhere that have been converted to formatted text to be imported into NED 2.

The primary application of NED software is among private consulting foresters in the eastern United States, where regular users number in the hundreds. The software is also used extensively in forestry classrooms in colleges and universities. The largest field applications to date include the development of management plans for the Baltimore City (Maryland) reservoir properties (Twery and Northrop 2004), a forest management plan for Fort Campbell, Kentucky, and the adoption of NED software for all forest inventories on State Forest lands in Vermont.

The most significant benefits of the NED system have proven to be associated with the accessibility of the system and its flexibility. Traditional foresters who simply want to summarize a timber inventory in preparation for a timber sale do not need to learn the rest of the system, nor do they need to collect extra data. However, as their interest expands, or other goals are identified by new land owners or policy makers, the system allows the use of additional tools to create stewardship plans, analyze wildlife and other resources, and draws users into a broader concept of forest management. The goal-driven approach to the analysis of inventory data and simulated plans distinguishes NED-2 from other available DSS or inventory processing tools.

## 2.9 SADfLOR

SADfLOR is a DSS developed under Portuguese Research and Technological Development projects coordinated by the Forest Research Center at the Institute of Agronomy (http://www.isa.utl.pt/cef). Its aim is to demonstrate and apply the potential of current decision support tools to enhance planning for forest management. The research and development teams included the Forest Service, the forest industry, the Conservation Agency, forest landowner associations, and other local nongovernmental organizations.

The prototype system architecture implements a multicriteria spatial DSS. All potential end-users from participating institutions were involved. Key aspects in its development were: (a) database design and interaction, (b) linkage to growth and yield models, (c) interactive silviculture modeling, (d) design and linkage to a management model base (mathematical representations of scheduling problems in ecosystem management), and (e) techniques for reporting solutions (e. g., Falcão and Borges 2005). The modular structure of the system includes a management information system (MIS), a prescription simulator, a scenario-design and solution module, and a report writer.

The MIS, INfLOR, stores bioecological, technical, and economic data in about 40 related tables. The identification of entities, attributes, and relationships between entities, to consider in the data model provides a simple, complete, and accurate model of the users' interests (Miragaia et al. 1998). Data are associated with geographical entities such as the area of project impact, homogeneous forest stands, and inventory plots and transects. The MIS stores topological data in a geographic information system. The data model was implemented in INfLOR using Microsoft® Access™ and MapObject LT™ (Environmental Systems Research Institute). Both spatial and aspatial data on forest ecosystems stored in INfLOR are made available to the second module, the prescription simulator.

The set of programs that define the prescription simulator, SAGfLOR, were developed using Microsoft Visual Basic™ 6.0 and MapObject LT. Growth projections are based on routines that implement both stand-level and individual tree growth and yield models for the most important Portuguese forest species (Falcão et al. 1999). Currently, SAGfLOR integrates GLOBULUS (Tomé 1998) for eucalyptus (*Eucalyptus globulus,* Labill) plantations, DUNAS (Falcão 1999) for maritime pine (*Pinus pinaster*, Ait) stands on the northern coastal region, and another model for the latter species for inland mountainous regions (Oliveira 1985). The SUBER model (Tomé 1999) is an individual tree model used for cork oak (*Quercus suber, L.*).

Generation of multiple prescriptions requires an interface with management models that select an adequate option for each management unit (Borges et al. 2003). For this interaction to be effective, additional information for model building, other than data on management alternatives, is needed (e. g., target product flows and spatial relationships). The scenario design and solution module, DECfLOR, supports this interaction. It enables the user to build the model that best represents the management problem and how to solve it. The set of programs that define DECfLOR were developed using Visual Basic™ 6.0 and MapObject LT. These programs may be used to address both stand- and forest-level management problems. The former are represented and solved using dynamic programming models that optimize stand management for maritime pine and eucalyptus. The latter may consist of unconstrained maximization of net present value of timber (cork), net present value of timber (cork) subject to demand-level constraints or subject to adjacency constraints, and, finally, net present value of timber (cork) subject both to demand-level constraints and patch-size constraints. The latter may include constraints on the maximum and minimum size of openings and constraints on the minimum size of old forest patches (Borges et al. 2003). The user may select a specific model to solve the management problem. For example, in the case of net present value of timber (cork) subject to demand-level constraints, the user may trigger the solution by linear programming (LP), by using LP Lagrangian relaxation (Hoganson and Rose 1984), or by selecting other combinatorial optimization heuristics that ensure location-specific cultural treatment schedules such as simulated annealing, evolution programs, or taboo search (e. g., Borges et al. 2002). The adjacency problem in scheduling forest management activities is solved using a dynamic programming heuristic (e. g., Hoganson and Borges 1998, Borges et al. 1999).

The heuristics programmed within DECfLOR produce integer solutions that may be displayed in a map by the solution reporter. Examples of geographic reports are distribution of stand age in each period over the planning horizon, forest operations in each period (e. g., harvests, coppice cuts, cork debarking, thinnings). Other descriptive reports (e. g., characterization of each management alternative assigned to each stand) may also be produced (Borges et al. 2003). Recently, three-dimensional (3D) visualization capabilities have been developed that may enhance solution reporting (Falcão et al. 2006).

The SADfLOR prototype was completed in 1999 and has been used successfully in the context of several outreach efforts. Emphasis has been on the demonstration of its potential to address management planning for National Forests, community forests, industrial forests and non-industrial private forests. This prototype has evolved and been adapted to assist management planning in Brazil (e. g., Miragaia et al. 1999) and in plantation forests in eastern and southern Africa (e. g., Ribeiro et al. 2000). It has also been developed to assist with strategic management planning for the major pulp and paper industry groups (Portucel, Silvicaima, and Celbi Stora Enso) in Portugal (Borges and Falcão 1998, 1999 and 2000) and Mediterranean forest ecosystem management (e. g., Ribeiro et al. 2004, Falcão and Borges 2005). A client-server architecture was developed in the context of projects aimed at developing an integrated planning system for the pulp and paper industry (Grupo Portucel Soporcel) (Ribeiro et al. 2005). Recently, the programming of process-based models added capabilities to address climate change scenarios in forest management. Current research and development efforts focus on evolving of better capabilities to support group decision making and sustainability assessments.

## 2.10 Woodstock

The Remsoft spatial planning system (RSPS™) is a commercial software suite for long-term forest management planning (Remsoft 2005). The system integrates four separate components that work together to help forest managers formulate strategic management plans that are feasible both tactically and operationally. In contrast to the first three general DSSs discussed in this section, all of which at least tend toward more-ecological applications, the RSPS suite provides capabilities for very explicit support of commercial business operations in forest management.

Woodstock™ is the strategic model-building component of RSPS, and provides the core functionality upon which the other components build. Woodstock provides a generic modeling framework within which user-defined models can be specified to address almost any type of land management problem. Modeling solutions are obtained by simulation, optimization, or a combination of the two methods. Typical applications might include any of the following objectives:

- Sustainable management of wood supply, habitat, biodiversity, watershed management, and other forest values
- Management to meet forest certification criteria
- Design and evaluation of harvest schedules and treatment regimes
- Evaluation of economic efficiencies such as present net value

The allocation optimizer component provides resource planners and managers with a tool to develop and assess strategies that allocate wood products to markets by considering wood supply origins, product transportation costs, delivered wood product prices, destination demands, and inventory capacity. Typical applications of this component include:

- Assessing multiple strategies for allocating wood fiber
- Assessing open-market wood purchase strategies
- Maximizing total revenue by allocating products to destinations
- Minimizing haul costs by associating treatment decisions with transportation costs
- Identifying wood production bottlenecks
- Identifying future wood supply problems for existing mills
- Exploring the consequences of adding or closing a mill

The spatial Woodstock™ component supports management and analysis of spatial data. It functions as a map viewer and data manager for viewing, reporting, and analyzing results from the other three system components. A basic objective underlying this component is the ability to represent knowledge about spatial relationships that can help assess the operational feasibility of plans. For example, insights gained from mapping the locations of current and future management activities can be fed back into Woodstock and Stanley™ (discussed next) to develop more operationally feasible plans.

The final RSPS component, Stanley™, is used to build and schedule spatial harvest units, conditioned by specifications in the strategic Woodstock plan. Stanley provides a transition to the operational level by automatically blocking and spatially scheduling all aspects of a management plan. Blocking and scheduling is accomplished by aggregating forest polygons into harvest units subject to minimum and maximum constraints on block size and other spatial constraints and decision criteria established in the Woodstock strategic management plan.

# 3 General Classes of Systems

In this section, we briefly summarize the application of some of the general classes of DSS as used in natural resource management. We omit detailed discussions of their principles and methods, and instead refer the reader to other chapters of this work for the relevant background.

## 3.1 Multicriteria Decision Models

Worldwide, forests are a key resource, providing a multitude of functions and services, and this situation poses considerable challenges to forest managers, who thus have to consider multiple and often conflicting ecological and non-timber objectives on a variety of spatial and temporal scales. Multicriteria decision models help to structure complex decisions in forest management by decomposing multiple objectives to relatively simple, measurable criteria. Different management alternatives are compared in qualitative and quantitative terms in a rational, transparent, and comprehensive way. These benefits are especially important in DSS approaches with public participation. Multicriteria decision-making techniques have been classified into two groups (Ballestero and Romero 1998): multiobjective decision-making methods that include mathematical programming and some combinatorial optimization heuristics (Chapters 12 and 13), and multi-attribute decision-making approaches such as the analytical hierarchy process, analytical network process, or Promethee (Chapter 15). Both groups have been successfully integrated into the framework of multi-criteria DSSs (Mathews et al. 1999, Varma et al. 2000, Kangas et al. 2000, Borges et al. 2003). They enable decision makers to model tradeoffs between multiple and conflicting objectives in multipurpose management implicitly or explicitly (Lexer et al. 2005, Vacik et al. 2006). Borges et al. (2002) have presented a review of the use of heuristic techniques in multiobjective forest management and of its integration within multicriteria spatial DSSs.

## 3.2 Artificial Neural Networks

Multifunctional decision-making processes for forest management are often highly unstructured, and require a combination of quantitative and qualitative analysis

(Rauscher 1999). Artificial neural networks (ANNs) and knowledge-based systems are decision support tools that have commonly been used to facilitate the formal analysis of the more-qualitative aspects of decision-making processes.

ANNs are data-driven systems that use inductive reasoning to generate conclusions. Knowledge representation is implicit in the architecture and in the way data are processed. Zahedi (1993) and Turban and Aronson (2004) give a detailed discussion of alternative ANN architectures and learning methods. Most ANN applications for forest management have dealt with problems such as pattern recognition, forecasting, and classification (Blackard and Dean 1999, Arrue et al. 2000, Liu et al. 2003, del Barrioa et al. 2006). Peng and Wen (1999) and Schmoldt (2001) reviewed ANN applications in forest management, dealing with modeling of growth and yield, plant disease dynamics, and climate change. ANN applications in forest management have some limitations. The accuracy of ANNs is highly dependent on the availability of large data sets for network training and testing purposes, and these often do not exist in forest sciences. Further, it is not trivial to determine an adequate system architecture, information processing and learning methods, so ANN design can often become too complex for application to natural resource management. Because ANNs represent knowledge in an implicit form, the knowledge base is often a black box to the user, so the lack of explanation capabilities in this form of DSS is another important limitation.

## 3.3 Knowledge-Based Systems

The knowledge-based system (KBS) architecture (e. g., knowledge base, inference engine, and explanatory interfaces) has perhaps been the most successful AI approach to addressing forest management issues. Many problem areas in forestry are suited to an approach that models the process used by people to make decisions about a system rather than try to represent the system itself (Reynolds et al. 2005). Storage of domain knowledge in the knowledge base involves the selection of an explicit approach to knowledge representation. The inference engine searches the knowledge base to select, harmonize, and extrapolate information and rules pertinent to the decision process. Explanatory interfaces in this form of DSS make these types of systems a white box to the user. That is, the derivation of conclusions typically is presented in relatively simple, intuitive terms, making these DSS relatively popular in the natural resource arena, in which potentially many managers, scientists, and stakeholders may be involved in a decision process.

Mills (1985) presented one of the earliest overviews of KBS applications in forest management. Other authors have further discussed issues involved in the development of KBS to address multifunctional forest management:

- Knowledge acquisition by elicitation from human experts or by machine learning (Gunn et al. 1999, Reynolds 1999, Reynolds et al. 2003)
- Type of knowledge representation (Thomson et al. 1998, Nute et al. 2000)

- Automation of knowledge base development (Loh et al. 1998, Roberts et al. 2002)
- Use of inference engines to cope with risk and uncertainty (Bellamy and Lowes 1999, Stoms et al. 2002, Tattari et al. 2003)
- Interfaces to support KBS use (Schröder et al. 1994, Nute et al. 1995, Zhu 1996), and
- Integration with other decision support tools (Twery et al. 2005, Sugumaran 2002)

# 4 Decision Support for Conserving Biodiversity

Some of the major systems already discussed (section 2) have been used to implement solutions specifically for conserving biodiversity, or solutions for conservation biology more generally. For example, Bourgeron et al. (2003) describe an application for design of biodiversity reserves in the interior Columbia basin (Pacific Northwest U.S.), and Girvetz and Shilling (2003) describe a sophisticated analysis of road systems on the Tahoe National Forest (California) designed to reduce habitat fragmentation as much as possible while maintaining as much access as possible for other management objectives. In the U.K., the GIS-based cost distance buffer model within BEETLE (biological and environmental evaluation tools for landscape ecology) (Watts et al., 2005), has been used to assess, map, and develop forest and open habitat networks to reduce the extreme fragmentation of woodland habitat in parts of the U.K. (see http://www.forestresearch.gov.uk/habitatnetworks for a discussion of this work). In addition, a decision support and information system has been developed in the U.K. (Ray and Broome, in press), to help forest practitioners understand the ecology of rare and protected species of forests, to help plan operations which avoid their disturbance, and manage woodland habitat so as to encourage their colonization.

Finally, a large number of more-special-purpose systems have been designed to support decisions on biodiversity and conservation biology, many of which have been reviewed in some depth by Johnson and Lachman (2001) and more recently Gordon et al. (2005).

# 5 Discussion and Conclusions

Lessons learned from this discussion are that:

- Integration with GIS can be expensive and difficult but provides substantial benefits.
- DSSs need to focus on targeted audiences
- We need to provide better ways to do what the user already needs to accomplish
- Transparency is an important issue

The complexity of natural resource management does not stop with the intricate details of the biological system found in a forest. Because all management is by people to meet goals or objectives desired by people, resource management is at its core a social activity. As such, the decision-making process for natural resource management demands that we understand the relationships among land owners, professional forest managers, forest-dependent communities, and other stakeholders. The availability of DSSs enables the analysis of a variety of options and the implications of alternative management approaches for all components of the system. The variety of tools described herein, and the approaches taken by the different systems, provide a sampling of the possible methods that can be used to help stakeholders and decision makers arrive at a reasoned and reasonable decision.

There are a number of lessons that can be learnt from the successes and failures of decision support system development efforts to date. Among the most important is that a clear focus on the target audience is crucial. If a system attempts to do everything for everyone, it is likely to be too complex to use and is unlikely to be adopted. The target audience can be identified best by determining the tasks or problems that are necessary but difficult to accomplish and that technology can make easier. The most successful DSSs provide better ways to accomplish tasks that must be done anyway. Use of the DSS need not be easier than the old way, but if it is not, it needs to accomplish more and provide better information. Such systems can often induce potential users to change the way they make decisions, but only if they can see the benefit in making the extra effort. Another lesson to be learned from past development is the need for transparency. A variety of DSSs using black-box computational techniques may produce good information, but if stakeholders cannot follow the reasoning used by the system, they are unlikely to accept its recommendations, no matter what the merits may be.

Clearly, not all decisions are made using a rational, reasoned process. People often base decisions on emotions, impulses, or other factors than rationality. Developers can make DSSs most useful if the systems address questions that potential users are already trying to answer, and for which they need help organizing information. Many managers have not found DSSs helpful in their daily activities, probably due to a mismatch between their needs and the information provided by the DSS, plus the difficulty of learning how to use the complex, integrated systems. Increased development focus on creating simple, stand-alone systems that can be learned and used easily to address single issues would likely increase the use of DSSs. If developers followed the creation of simple systems with integrated ones that link the stand-alone pieces, users might be more inclined to see that making the effort to learn the complex system would be worthwhile.

Some of the most promising lines of development for current and future DSS efforts include the use of the Internet to enable easy access to public data that can be downloaded and incorporated into local DSS processes. For example, Google Earth™ can provide visual information to a user to improve their understanding of the context of a resource-management decision. The Internet can also be used to enhance the capability of participatory decision-making systems, enabling users to share information without needing to be in the same location. Other remotely sensed data are also available either publicly or commercially from a variety of sources to enhance the information available for decisions. Increased computing capabilities and connectivity through the Internet will allow integrated systems to become much more powerful in the near future. An important indicator of success for future integrated systems will be the transparency of their operation. Any system involving decisions on public lands will face greater challenges if those participating in, or affected by, the decisions do not have easy access to explanations of the decision process. Conversely, the creation of simple, focused systems designed to address a single issue will continue to be needed. Many problems in resource management, from questions about wildlife habitat management in a national park to pulpwood production on a small private holding can still be addressed successfully without a detailed analysis of the entire ecosystem. For these problems, simple knowledge-based systems can be used to meet an important need.

Whether a DSS is intended for use at the scale of an individual, private property, or a national policy decision, ease of use is a strong factor in its acceptance. Ease of use is a combination of the system's clarity of purpose, interface, and support. All three factors are crucial to the adoption and success of a DSS. The more general a system is intended to be, the more adaptable it must be on the programming side, because the developers will need to alter, add, and remove many features as they encounter new users in new situations. Thus, interoperability and modularity may be important features in the design of a system. On the other hand, modularity and adaptability increase complexity, so systems designed for limited uses can be developed much more quickly and are much easier to learn. There is plenty of room for new development of decision support systems targeted at different audiences from individual resource managers to national policy makers.

## Endnotes

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

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# CHAPTER 61
# DSS Experiences in South America

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The objective of this chapter is to describe DSS experiences in South America. The chapter describes the conception, modeling, and implementation of two DSSs. The first was designed to be applied for the operational planning of solid-waste collection. To develop the computer system, a combination of quantitative techniques was used: simulation of discrete events and algorithms/heuristics for vehicle allocation and routing. The system was validated using a field test in Porto Alegre, Rio Grande do Sul, Brazil. The second experience describes a DSS to optimize forest harvest scheduling. The computational system was implemented as a spreadsheet DSS, based on a linear programming model. Computational experiments were conducted using real-world data from a forest products company. Both experiences provide useful insight on how DSSs are being built in South America, and how real-world problems are being approached taken into consideration local peculiarities.

**Keywords**: Decision supports; South America; Applications; Forest planning; Waste management; Environment

## 1 Introduction

Systems to aid in decision making were introduced over 30 years ago. In South America, decision support systems (DSSs) started to have some impact from the 1990s. This delay can be attributed to the lack of awareness of the value of model-based DSSs by decision makers, and the lack of widespread knowledge of modeling techniques. However, the DSS field has recently received increasing attention in South America, both in academic and non-academic environments, and several DSS applications have been described in the literature (Borenstein 2005).

It is possible to find several DSS applications described in the literature by South American researchers, including *corporate areas*, using Eom et al.'s (1998) classification, such as operations and operations management (Caixeta et al. 2002, Gasmuri and Maturana 2001), and *non-corporate areas*, including agriculture (Batista et al. 2006), natural resources (Braga 2000), health/health care (Oritz et al. 1995), and energy (Schirru et al. 1999).

Currently, the most challenging problem faced by South American countries is how to enhance their economies while minimizing as much as possible the resulting environmental impacts. The richness of the natural resources in South America and the social problems related with uneven economic development are receiving a lot of attention from various economic areas in both private and public sectors. The number of research papers in both areas has increased substantially since the mid 1990s, reflecting the growing concern with how economic activity is affecting the environment in this region. Pollution and the destruction of natural environments are increasing exponentially as countries become more industrialized. Thus, both the corporate and public sector are becoming interested in the development of computational systems to design and control the use of natural resources, such as water, forests, and waste. DSS applications in South America are found in water management (Braga 2000, de Azevedo 2000, Dolling et al. 2005, Scheer 1993, Striess et al. 2003), pollution control (Mondschein and Schilkrut 1997), forest management (Tarp et al. 1997), and climatic change (Maytin et al. 1995). Due to the importance of this non-corporate area for the region, sections 2 and 3 will describe DSS applications developed for various decision problems, but with the common interest of increasing the efficiency of the operations, given strong social, financial, and environmental constraints.

This paper presents two practical experiences with DSSs in South America related to natural resources management. The first aims to improve the planning of solid-waste management in urban areas, a very important problem in the populated cities of South America. This DSS was applied to a public-sector company responsible for collecting and transporting recyclable solid waste in one of the most important cities in Brazil. The second experience is aimed at improving the planning process of a forest products company. The main role of the computational system was to design optimal plans for harvest scheduling under different scenarios. The main criteria for the selection of these two DSS experiences are the relevance of the problems and their potential to be customized to other locations. These experiences illustrate how DSSs can be applied to the management of natural resources, taking into consideration different, but complementary, decision-making contexts. The first application emphasizes the public sector, where the DSS results are measured by their cost/benefit impact over the operation of the system, while the second application is focused on profit maximization, taking into consideration environmental conditions and restrictions.

With this chapter, we hope to describe how DSSs are being built in South America, providing valuable insights of how real-world problems are being approached, taking into consideration local peculiarities, and how DSSs are applied to solve them. Both cases, although applied to different problems, exemplify useful practices adopted by DSS researchers and developers towards the real application of computational systems to support managerial decisions in South America, overcoming local difficulties such as the lack of structured data and processes, poor overall information technology infrastructure, and model-based support illiteracy.

# 2 A DSS for Solid-Waste Collection Operational Planning

This section describes a DSS aiming at supporting the operational decision-making process of solid-waste managers in the area of logistics, from the collection stage to waste delivery to sorting units (Simonetto 2004). The system was developed to be used in the city of Porto Alegre, the capital of the southernmost state of Brazil, Rio Grande do Sul. The problem consists of designing good daily truck schedules over a set of previously defined collection trips, on which the trucks collect solid waste along fixed routes and empty loads at one of the several operational recycling facilities in the system.

## 2.1 Problem Description

Solid-waste collection in Porto Alegre involves 150 neighborhoods, with a population of more than 1.3 million. More than 60 tons of solid waste are collected per day and distributed to eight recycling facilities. The collection and distribution of the solid waste are performed by DMLU (from the Portuguese Departamento Municipal de Limpeza Urbana), while the recycling facilities are managed by cooperatives, whose members are mostly poor and not part of the mainstream economy. In these facilities, the solid waste is separated, appraised, stored, and commercialized. The profit remains with the cooperatives, making it an important income source for more than 450 workers. As a consequence, the DMLU solid-waste management program has successfully balanced social and ecological benefits (http://www.lixo.com.br accessed 9 September 2004).

Collection is performed weekly on each city street from Monday through Friday. The solid-waste collection teams are composed of one driver and two garbage collectors, who are specially trained for handling this kind of waste. A fleet of 24 specially designed trucks, each with a capacity of 1,600 kg, is used for the collection. The maximum amount of solid waste collected in one trip is 1,000 kg. The routes are designed to avoid any capacity-related problem. One truck is always used as a backup, in case severe disruption occurs. Every day, trucks leave the depot at 08:00 and start on a collection route. The routes are defined by the DMLU managers based on the divisions of the municipality neighborhoods. The idea is to conduct the collection of all streets within the same neighborhood. If a certain neighborhood is too large or has a dense population, the collection can be divided into more than one collection shift. The current routes, although not optimal in terms of operation costs, are well defined and known by the city residents. DMLU managers are not interested in changing the routes, since it would cause a major disturbance in the modus operandis of the system.

The choice of which facility will be used by each truck is based on several criteria, such as the distance from the collection end point to the facilities, the current available capacity of the facilities and so forth. Since there are currently eight recycling facilities located at different sites within the city limits, and the collection in a shift is conducted in distant neighborhoods simultaneously, the DMLU managers have decided to send the trucks directly to the recycling facilities, instead of consolidating the cargo in a larger truck. When a truck arrives at the recycling facility, it is weighed and unloaded. After unloading, the truck returns to the depot. Then, time permitting, it continues to collect waste in another neighborhood.

## 2.2 DSS Overview

SCOLDSS supports the following tasks: (i) reducing the amount of solid waste destined for the landfill, (ii) assuring a waste input percentage at each sorting unit, (iii) assigning vehicles to collection trips, (iv) defining their route, and (v) estimating the work capacity (productivity) of sorting units, in relation to the waste arrival and processing (separation). The system basically aids the solid-waste collection operational management through the generation, analysis, and assessment of

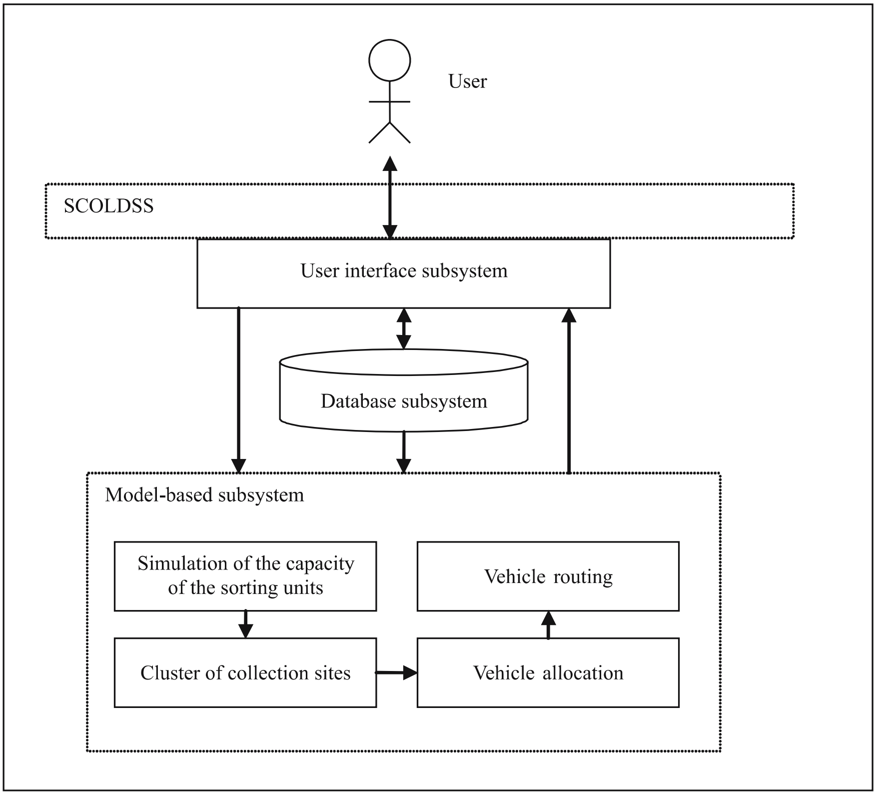


**Figure 1.** SCOLDSS architecture

possible operational scenarios for this type of collection. It is assumed that the solid-waste collection system (in terms of defining the equipment, human resources, areas, and separate collection frequency) has already been defined. To develop SCOLDSS, the decision support systems architecture proposed by Sprague and Watson (1991) was used; it is composed of the three following subsystems: database subsystem, model-based subsystem, and user interface subsystem, and is shown in in Figure 1.

### 2.2.1 Model-Based System

The model-based subsystem was created using various quantitative modeling techniques: the computational simulation of discrete events and the development of algorithms/heuristics for vehicle allocation and routing problems. Simulation is used to determine the sorting unit demands, since it presents a quite dynamic behavior profile, basically attributed to seasonal variations and the population consumption profile.

The use of these techniques is justified by the distinct nature of the problems being addressed. Firstly, the determination of the waste processing capacity is defined by the simulation model; secondly, the determination of solid-waste flow (vehicles and routes), as a consequence of simulation results, is solved using heuristic methods for the multi-depot vehicle routing problem (VRP). Based on the interaction of the waste processing simulation at sorting units and the execution of the multi-depot VRP with a heterogeneous fleet, the waste collection vehicle routing, as well as the final destination of the waste carried by them is determined in order to calculate the waste processing capacity for one day.

The simulation model mainly aims at estimating the solid-waste processing capacity at sorting units. The determination of the processing capacity is specific to recyclable wastes and has its origin in the input and output flows of this type of waste at the sorting units. This is not the case for solid waste destined to the landfill, as there is no solid-waste output (only input) in this type of disposal. The main information generated by the simulation model is the solid-waste demand that each sorting unit is able to process during a certain day of work, obtained as the average of $n$ simulation runs. The commercial software ARENA (Kelton et al. 2004) was used for the simulation.

The subsequent stage of using the model-based subsystem is characterized by having $n$ sorting units (with demand already having been defined by the simulation model) and $m$ collection sites with recyclable solid waste to be collected by the vehicles. Such a description clearly identifies the multi-depot VRP (Bodin and Golden 1981). The approach proposed by Gillet and Johnson (1974) was used for modeling and solving this problem, implemented in the form of the grouping or later routing heuristic. In this approach, collection sites must first be associated to specific sorting units, through assignments such as: solid waste from collection site $x$ will be sent to sorting unit $y$. As a result of this step, collection sites are clustered in accordance with the sorting unit in which the solid waste collected will be unloaded. Also, in this stage the minimum percentage of solid-waste input is assured in each of the sorting units, according to the maximum processing capacity provided by the simulation model. The main objective is to avoid unbalanced trip assignments to sorting units, where some facilities may be allocated excessive collection trips, and other facilities may be idle. Such solutions should be rejected when the social benefit of the solid-waste program is considered.

Finally, at the last stage, the collection routes to be covered are generated and the vehicles that will cover each route are assigned. The output of this subproblem has the following structure: vehicle *v* will cover collection sites *a*, *b*, and *c* (in this order) and unload its cargo in sorting unit *x*. For the solution development, a heuristic developed by Renaud and Boctor (2002) was used. This heuristic was specifically developed to solve the VRP with a heterogeneous fleet, in case there are vehicles with distinct load capacities. The basic processing stages of the heuristic are: the determination of the distance order in relation to each sorting unit, route generation using the different types of vehicles available, and the selection of the lowest-cost combination among the several generated routes.

### 2.2.2 User-Interface Subsystem (Dialogue)

The user interface subsystem in SCOLDSS is responsible for the definition of the solid-waste collection operational scenarios. This module has graphical and interactive facilities, and menu-data-driven dialogues that offer a friendly environment for the user to define all needed data to run the models in the DSS. This module is also responsible for the overall control of the DSS, accessing and exchanging

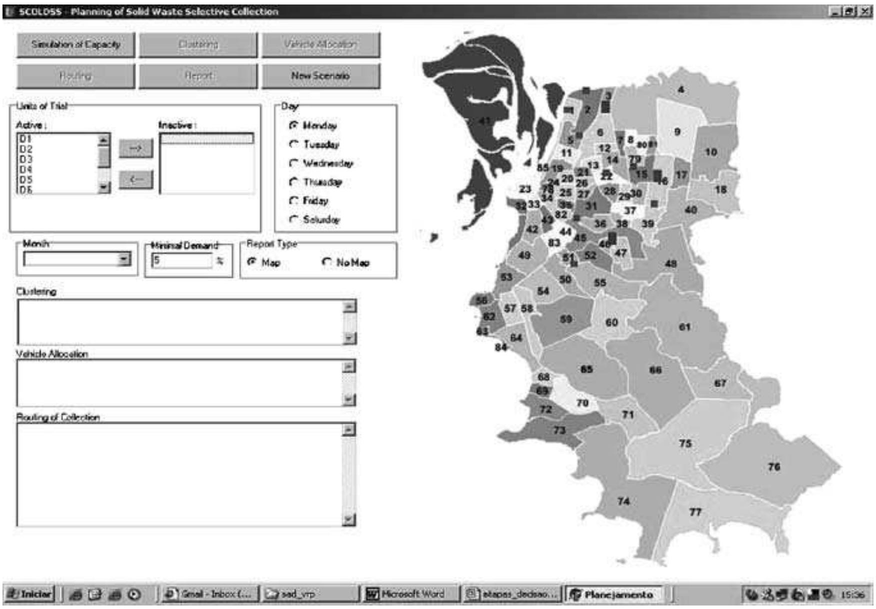


Figure 2. Main SCOLDSS interface screen

information with other subsystems within the DSS. The main SCOLDSS interface screen is presented in Figure 2.

The DSS can be used in the following way: the user chooses the weekday on which the separate collection planning will be made, the month (in order to consider the occasional seasonal variations in the process), and the operational waste sorting units. Next, the simulation can be performed to determine the amount of waste that each operating unit is able to process each day. Afterwards, the user executes the functionalities of the system step by step: vehicle allocation, collection route generation, and reports with main results.

The interface for SCOLDSS was validated with the participation of potential system users (academics and professionals), who, after receiving instructions on its functioning, used it to verify whether it was user-friendly and adequate. The main goal of this interface validation was to achieve consistency between the visions of the system analyst/modeler and the potential user of the model, in a way that was both appropriate and cost effective.

## 2.3 DSS Validation

In the first stage of validation, known as the conceptual stage, data from scientific articles and technical manuals related to solid-waste collection were used, in association with interviews with researchers and managers. Furthermore, in loco observations of the solid-waste collection process was required.

In order to verify the internal system structure and to guarantee subsystem accuracy, a subsystem verification and validation (V&V) was carried out for each model module in the system. This validation process took place in parallel to the development of each model within the SCOLDSS development cycle. As soon as the model was sufficiently developed to be considered an input-output device, this validation took place. After being satisfactorily verified and validated, the model was integrated into SCOLDSS.

The subdivision of the DSS into modules was immediate since its architecture was highly modular. Four basic modules were identified for subsystem V&V, as follows: simulation model, grouping of collection sites and vehicle allocation heuristics, and solid-waste collection-route heuristics. The verification and/or validation procedures used varied with the nature and objectives of each module. For the simulation module a paired *t*-test was applied. For the remaining two modules predictive tests were used.

Real data from a sorting unit were used to validate the simulation module, responsible for the estimation of the daily waste processing capacity at sorting units. The simulator behaved correctly during this validation, with a standard deviation of 1.01% compared to to collected real data, which does not compromise the system performance considering that the simulation deals with the maximum processing capacity.

The computational implementation of the heuristics was verified – that is, the system was checked to see if it was built correctly – by running test cases and comparing their output with the output provided for classical examples in the operations research (OR) library (Beasley 1990) for VRP problems. So far, only very minor discrepancies have been identified (less than 1%), and are probably a consequence of using different solvers and central processing units (CPUs). In addition, for each heuristic, sensitivity analysis was performed by systematically changing the input variable values and parameters over a large range of interest and observing the effect upon the heuristics output. This analysis led to a better understanding of the model-based subsystem with respect to real systems.

## 2.4 DSS Application

The main purpose of our experiment was to investigate the operational planning of solid-waste collection in Porto Alegre for each working day during a week (three months were considered to avoid seasonal variations). The results are compared with the operational strategy defined by DMLU. Two main criteria are selected in our study to compare the results by manual planning with the results obtained by SCOLDSS: the distances traveled in a collection shift and the number of trips, reflecting the main operational and fixed costs involved in the solid-waste collection performed by DMLU.

The experiments were performed for 15 distinct dates (five in March, five in April, and five in May). The results obtained are presented in Tables 1 and 2.

**Table 1.** Comparison of distances between the current system and SCOLDSS

| | Current distance | SCOLDSS distance | Reduction percentage |
|---|---|---|---|
| Monday | 546.5 km | 500.7 km | 8.39% |
| Tuesday | 522.8 km | 478.4 km | 8.49% |
| Wednesday | 442.8 km | 400.4 km | 9.58% |
| Thursday | 591.8 km | 537.2 km | 9.23% |
| Friday | 374.9 km | 343.1 km | 8.57% |
| Mean | 495.76 km | 451.95 km | 8.82% |

**Table 2.** Comparison concerning trips between the current system and SCOLDSS

| | Number of current trips | Number of SCOLDSS trips | Reduction percentage |
|---|---|---|---|
| Monday | 29 | 23 | 20.71% |
| Tuesday | 27.5 | 24 | 12.7% |
| Wednesday | 24 | 19 | 20.83% |
| Thursday | 33 | 27 | 18.18% |
| Friday | 23 | 19.3 | 17.05% |
| Mean | 27.36 | 22.53 | 17.89% |

An important aspect concerns the use of the collection vehicles. DMLU currently selects one vehicle for each trip. If the site has a high rate of waste generation that is able to fill a vehicle (above 85% of its capacity), such a strategy is valid. However, there is no justification for allocating a trip to collect 400 kg, considering that the vehicle's transportation capacity is approximately 1,600 kg. This fact is quite common in DMLU operational planning. SCOLDSS attempts to find ways to visit two or three different collection sites in a single trip, aiming to reduce the number of trips and the distance to be covered by the collection vehicles. By using this system, it is possible to obtain a mean reduction of 8.82% in the distance covered by the collection vehicles and a reduction of 17.89% in the weekly number of trips. Considering that the mean distance covered by the vehicles is currently 494.43 km/day, the reduction with the use of SCOLDSS is very significant, estimated at 43.8 km. The distances covered weekly would suffer a mean reduction of 262.8 km, leading to an annual reduction estimated at 13,665 km. This reduction represents savings of around 10% of the DMLU annual budget for solid-waste collection per year, considering the operational and maintenance costs. Note that this saving rate could be higher. Although the number of vehicles required is less than in the present operation, these vehicles are fully depreciated. As a consequence, the fixed cost of vehicle deployment is low in relation to the variable operating costs. However, in the case of new vehicles with high depreciation value, the savings are expected to be more significant. This result is very significant to DMLU, as it needs to renew almost half of its fleet.

Concerning the number of trips, the current mean is 27.3 trips per day (163.8 per week). Using SCOLDSS, the average number of trips would be 134.9 weekly trips (a reduction of 17.89%), which would result in an annual reduction by 1502 trips. Note that this reduction is obtained even when considering that the mean cost of a trip increases from U.S. $6.65 to $7.37, since the trips become longer. It should also be noted that the decrease in the total number of trucks can lead to a reduction in the total numbers of crew members needed for solid-waste collection. Therefore, it is possible to estimate the savings in labor cost. Considering that the monthly wage for a collection team in each truck is $2,600 and the DMLU needs to keep a maximum of 28 teams (based on the results presented in Table 2), instead of the current 33, the use of the heuristic method can lead to savings of around $156,000 annually, which is approximately 6.2% of the budget assigned to the solid-waste collection program.

As a whole, the human schedulers responded positively to the prototype. The human schedulers were very impressed with the results and were willing to implement the schedules provided by the heuristic approach. The main advantage of the use of the DSS was to offer an objective analysis tool, avoiding basing the analysis and evaluation of scheduling options either on empirical factors or exclusively taking into consideration operational and financial aspects that were easily measurable. Analysis and evaluation of the possible scheduling alternatives, through modeling, provided the means to study the results for each alternative, and sufficient knowledge to make comparisons among them.

# 3 A Decision Support System for Forest Planning in Southern Brazil

## 3.1 Forest Industry Context

Brazil has an important forest and wood industry that is responsible for 4% of its gross domestic product (GDP) and directly employs more than 1 million people, exporting U.S. $4.2 billion annually (Remade 2005). The forest area extends from the northern Amazon region, which concentrates on tropical wood exploration, to the southern states of the country, where commercial plantations of exotic species provide raw materials for furniture, wood manufacturing, and pulp companies.

Our study was focused on plantations, where the production chain starts with forestry activities followed by harvesting. The harvesting intensity can be of two basic types: thinning, which removes about 40% of the standing trees and leaves the rest for further growth, or clear-cut, removing all standing trees. The plantation rotation age is usually 18–25 years in southern Brazil, and thinning can be made after 10–15 years. It is important to note that these rotation periods are extremely short compared to northern-hemisphere plantations due to the very favorable weather and soil conditions found in Brazil. All clear-cut harvests are followed by planting of new trees.

The forests are usually composed of several stands that vary in age, species, and production potential, and are integrated with industrial plants [sawmills, medium-density fibreboard (MDF) and plywood, pulp and paper, power plants] to use logs of different diameters fully. The wider-diameter logs have greater value and are used for plywood or solid-wood products, while the lower-diameter logs are used at pulp mills, MDF manufacturing firms, or power plants. Transportation costs represent a significant value of the total costs of delivering the logs to the mills, thus establishing some restrictions on the possible use of the logs depending on the forest location.

The forest management planning process consists of defining which locations (stands) are to be cut or thinned in each period (year or season), what the expected volumes to be extracted of every type of log are, and the expected revenue of selling this product mix. This process typically considers an 18–20-year planning horizon. The choice of the optimal forest policy will depend on: (i) the current forest inventory (volumes, ages, and species of trees in every land stand), (ii) current and expected operational costs, (iii) legal, environmental, and operational restrictions, (iv) expected market prices and demand for the product mix, and (v) the discount rate. The discount rate exerts a very significant influence on the forest policy – the greater the discount rate, the sooner the trees are cut. In Brazil, this issue is of even greater importance because the current basic interest rates for government bonds are extremely high in comparison with the annual inflation rate.

Most of the large forest plantations in southern Brazil are owned by pulp and paper or MDF manufacturing firms. In such cases, most of the log volume produced (small-diameter logs) is aimed directly at their own industrial processes, and the larger-diameter logs are sold to third-party sawmills and solid-wood manufacturing firms, usually through long-term supply contracts. Other players include medium-sized forest companies that have their own manufacturing facilities – for plywood or solid-wood products, and a large number of smaller sawmills and forest owners that are integrated into the production chain.

In the last few years, because of an increase in the local and global demand for paper and wood-related products, the Brazilian forest industry has been experiencing a shortage of raw materials – especially of plantation-type logs. This concern is frequently referred to as the forest blackout, and the shortage is predicted to last until the year 2012 due to the natural delay in establishing new sources of supply. The situation is a consequence of the lack of investment in new plantations that occurred earlier (at the beginning of the 1990s) and an unawareness of this growing demand. This circumstance reinforces the strategic importance of forest assets, as processing and manufacturing companies further down the supply chain have less bargaining power, a weaker position, and are subject to constant price increases on raw materials (logs).

## 3.2 The Role of OR Models

Operations research applications have been developed for forest management problems since the 1960s (Weintraub et al. 2000). Models have been formulated to address various problems such as short-term timber harvest scheduling operations and forest-level planning, in both private and public forests (Haight and Weintraub 2003).

The harvest scheduling problem involves the planning and timing of management activities such as planting and harvesting, and determining their locations, usually in a forest composed of several stands that vary in age, species composition, and production potential (Hokans 1984, Haight and Weintraub 2003). In commercial private forests the objective is typically to maximize global earnings, considering operational costs and the expected product prices and demands. The operations can be restricted by resource availability (roads, equipment, and staff) and are subject to legal and institutional measures aimed at the protection of the natural environment, wildlife, water quality, soil, and scenic beauty (Caro et al. 2003).

## 3.3 Organizational Context and Decision Problem

Our work was developed for a forest and wood manufacturing company, ForestBR (for the sake of confidentiality this is a fictitious name), which is focused on export-type solid-wood products for house building and refurbishment (items used for moldings, doors, and window parts). ForestBR's main business unit sells about U.S. $50 million/year of solid-wood products, mainly to the U.S. and Canada. The logs are supplied by the firm's own forest plantation or can be bought from external suppliers – according to the production volumes planned. The products' final destination are home center stores, distribution centers, and small amounts of construction material, as well as factories specializing in making doors, windows, and furniture. The company accounts for around 15% of the Brazilian finger-joint molding exports, processing 229 million board-feet of sawn timber every year. The market for this kind of products is subject to significant and cyclic price oscillations in a commodity-like behavior, since demand depend heavily on the housing starts rate and the economic activity of the main markets. For example, the housing starts rate shows a seasonal variance – being high in spring and summer and low in autumn and winter, and a strong sensitivity to the basic mortgage rate. Additionally, the firm is exposed to exchange fluctuation risks of the Brazilian currency and faces fierce competition from other international companies.

ForestBR owns a 15,000 hectare forest plantation located in the south of Brazil, populated with native *Parana* pine (also know as Aruacária) and exotic *Taeda* pine species. The main industrial unit – composed of sawmill and drying facilities, and moldings and panels manufacturing line – is located near the forest. There is a common understanding that the goal should be to maximize earnings for both forest and industry investments.

We have identified the following management concerns regarding forest planning and operations, translated here as some important decisions faced by the management team:

1. Which harvest activity (clear-cut, thinning, or none) to select for each stand in each period for a fixed log demand (e. g., 20,000 $m^3$/month)?
2. How log demand variation affects operations, forest profitability, and sustainability?
3. How to balance forest and manufacturing activities (e. g., product mix, external suppliers of logs) to achieve better global profitability?
4. How to consider uncertainties such as product prices, exchange rates (U.S.$ versus R$), cost variations, and different discount rates?

The problem dealt with in this research work is complex due to the need to balance the harvesting of two coexistent species, presenting different growing patterns and demand characteristics, simultaneously. Besides that, the lack of a well-defined harvest and plantation planning leads to a scarcity of mature logs in some future periods due to the irregular plantation intensity in the past.

## 3.4 DSS Description

Figure 3 presents the decision support system architecture. A forest inventory control system has been in use for many years by the forest department of the company. It has a comprehensive database that controls the actual volume and diameter distribution of the trees in each of the stands, based on field data. Using SISPINUS (Oliveira et al. 1998), a forest yield simulation system, the

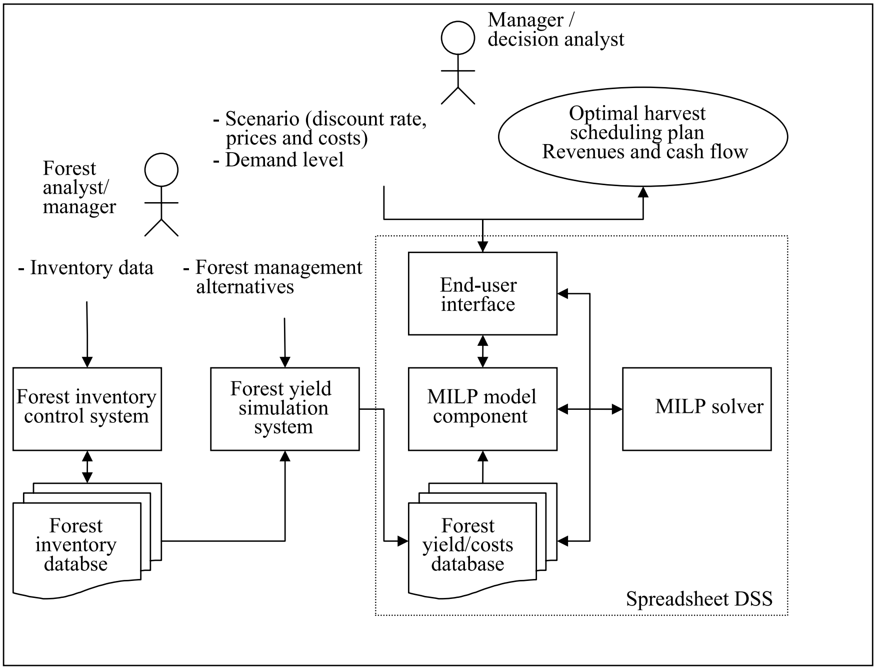


**Figure 3.** DSS architecture

analyst/manager is able to predict the volumes to be extracted in the present or in a future period for a given set of activities to be performed (thinning and clear-cutting). The system runs a deterministic simulation with an exponential smoothing yield function. SISPINUS is able to analyze a large set of possible forest management alternatives for each stand, in which the most important parameter is the harvest activity in each period. The SISPINUS output represents the volume produced for each diameter class for each stand, considering different time periods.

Figure 4 shows an example of the results obtained by SISPINUS, for a given stand. The variable *n* represents the number of trees per area of the stand, while the variable *vol* represents the total wood volume per area of the stand. A typical pine species stand can withstand one or two thinning activities in its lifecycle. These are usually undertaken between the ages of 12–16 years, while clear-cutting will not occur before the stand reaches 18 years old. In the example shown in Figure 4, two thinnings were simulated. The first one is undertaken when the stand reached the age of nine years, with a second thinning four years later. A significant decrease in the number of trees per area of stand can be observed after each thinning, while the decrease in volume per area is less intense. Based on this harvest activity, a total volume of 680 $m^3$ is obtained if a clear-cut is carried out when the stand reaches 25 years. For a clear-cut at 21 years, the volume is reduced to 550 $m^3$.

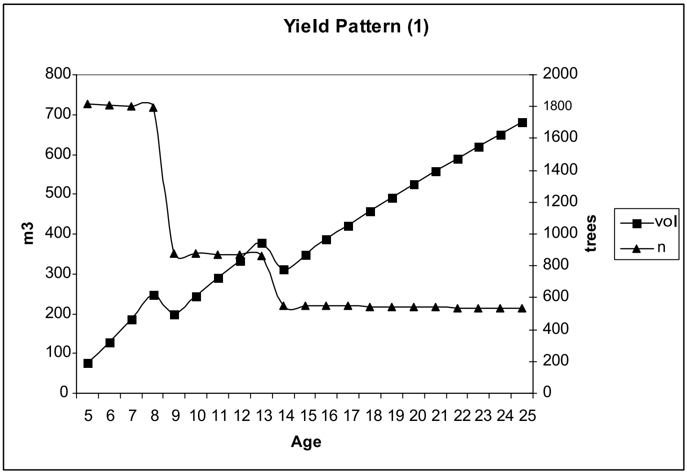


**Figure 4.** Yield pattern for a pine stand

The actual harvesting timing will depend on the demand for logs and on some operational restrictions (equipment availability, road capacities, bad weather in winter, etc.), for instance, the harvesting can be delayed until the age of 25 years or more. By repeating the forest simulation procedure interactively for all forest stands, the manager can design an operational plan that satisfies the main objective, which is usually expressed as a minimum timber volume to be delivered to the sawmill subject to some basic operational restrictions. It is important to note that the quality of the operational plans obtained depends heavily on previous knowledge and the experience of the management team, and also on the patterns of activities simulated. Besides, the procedure is very time consuming and a mathematically optimal solution is rarely obtained. Due to these effects, the management team was unable to carry out this procedure in an effective and efficient way.

The spreadsheet DSS consisted of four modules: the forest yield/costs database, the mixed integer linear programming (MILP) model component, the MILP solver; and the end-user interface. The forest yield/costs database was designed to store, for every forest stand, the expected productivity (timber volume per hectare) of management alternatives considered in each future period of the planning horizon. The management alternatives are thinning and clear-cut harvesting. All data is obtained by running several simulations in the forest yield simulation system. Some sample data are shown in Table 3. For example, stand 3 can be harvested (clear-cut) in 2006 with a productivity of 376.3 $m^3$/h, or in the following years at a much better rate (more than 400 $m^3$/h); thinning is not considered in any of these cases. On the other hand, stand 16 presents diverse options. The first is thinning in 2006 (age 15 years) to produce 2248 $m^3$/h, followed by clear-cut harvesting between 2007–2009 (with 381,3 to 455,6 $m^3$/h). The second option is thinning in 2007 at 238 $m^3$/h, and clear-cut harvesting after 2008. The database also stores other stand information such as plantation year, species, area, distances to mill, expected transportation, and harvesting costs.

**Table 3.** Forest yield/costs database samples

| | | | | | | Productivity ($m^3$/h) | | | |
|---|---|---|---|---|---|---|---|---|---|
| **i** | **Project** | **Plan-tation year** | **Area (h)** | **Distance to mill (km)** | **Transp cost (R$)** | **2006** | **2007** | **2008** | **2009** |
| 3 | PT-13B | 1985 | 103 | 22 | 6,96 | 376,3 | 400,4 | 424,1 | 447,6 |
| 4 | PT-13C | 1985 | 71.1 | 28 | 7.81 | 575.3 | 608.7 | 641.4 | 673.3 |
| 5 | PT-13DE | 1986 | 178.9 | 36 | 8.97 | 355.9 | 381.6 | 406.8 | 431.6 |
| 6 | PT-13DT | 1986 | 364.2 | 36 | 8.97 | 373.2 | 400.3 | 427 | 453.2 |
| 7 | PT-13DT-85 | 1986 | 88.3 | 36 | 8.97 | 444.5 | 476 | 506.7 | 536.8 |
| 8 | PT-14D | 1987 | 531.6 | 23 | 7.14 | 330.3 | 356.3 | 382 | 407.4 |
| 10 | 89A | 1989 | 288 | 18 | 6.38 | 404.6 | 437.6 | 469.9 | 501.6 |
| 16 | 91B | 1991 | 210.1 | 32 | 8.43 | 224.8 | *thinning* | | |
| | 91B | 1991 | 210.1 | 32 | 8.43 | | 381.3 | 419.1 | 455.6 |
| | 91B | 1991 | 210.1 | 32 | 8.43 | | 238 | *thinning* | |
| | 91B | 1991 | 210.1 | 32 | 8.43 | | | 409.2 | 446.1 |

The forest yield/costs database provides input to the MILP model component. This is where each instance of the developed optimization model, formulated as a linear programming model (see Appendix A), are created and solved. The What's Best software is used as the MILP solver within the Excel spreadsheet environment.

The spreadsheet DSS was designed for two basic types of users: the firm management team – executives, directors, or forest managers who have no previous knowledge about the structure of the underlying optimization models, and decision analysts, who have the ability to alter the model specifications and parameters.

In order to initiate the planning process, the decision maker must provide the following inputs to the DSS: discount rate, reforestation costs, estimated selling prices for each species, and estimated minimum and maximum demand for each species. The harvesting and transportation costs are already defined in the forest yield/costs database. After solving the MILP model, the DSS provides an optimal harvesting plan with the following information for each year on the planning horizon: (i) expected total revenues (net present value) for each forest stand, (ii) the area to be thinned/harvested, and (iii) the total volumes of timber produced per species and per stand. By interactively repeating the planning process, the decision maker is able to analyze different scenarios (varying discount rates, costs, and product prices), to evaluate the result of different demand levels on the forest management and profitability, and to obtain optimal plans for thinning and clear-cut harvesting. Figure 5 outlines the DSS user interface.

During the initial phase of system testing and evaluation, it was observed that the Excel interface was appreciated by end-users who were familiar with its look and feel, thus facilitating system acceptance. On the other hand, there were some difficulties on the development of data management and integration features.

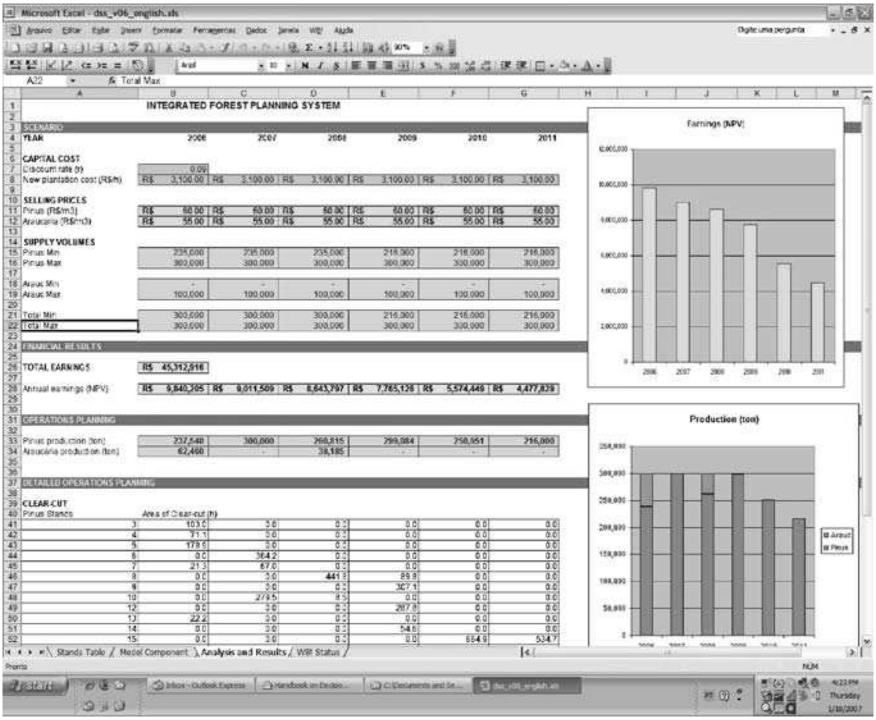


**Figure 5.** Spreadsheet DSS user interface

## 3.5 Computational Experiments

In this section, we present the results of some experiments conducted using the DSS application. For the sake of simplicity, a subset of the data was used in the experiments and the process was conducted for a planning horizon of six years. All the data were obtained from original databases of ForestBR, with the consent and collaboration of the company. Our aim was to evaluate the DSS in terms of its validity and usefulness, and provide some criteria that would enable the management team of ForestBR to make a decision to invest in a full-scale deployment of the system.

A set of 15 stands were analyzed, covering an area of 4,036 hectares, which represent 26.9% of the total plantation area (52 stands). The individual stand sizes varied from 22.2 to 1,200 hectares, with an average of 269.06. The average stand age was 18.5 years, varying from 15 to 21 years. This means that most of the stands would reach an appropriate age for clear-cut harvesting during the planning horizon of six years.

**Table 4.** Comparison of productivity parameters obtained in SISPINUS versus data provided by the company's annual plan

| | | | **Expected productivity ($m^3$/h)** | | |
|---|---|---|---|---|---|
| **Stand** | **Year** | **Activity** | **ForestBR** | **Yield simulator** | **Difference** |
| 8 | 2007 | Harvesting (clear-cut) | 320 | 356.3 | 10% |
| 9 | 2010 | Harvesting (clear-cut) | 300 | 403.8 | 26% |
| 14 | 2011 | Harvesting (clear-cut) | 320 | 406 | 21% |

The first task was to calculate the yield data for every stand using the forest yield simulation system. The data obtained using the developed DSS presented some relevant difference from those provided by the company's forest management team (see Table 4). It seems that the forest managers were too conservative, avoiding any risks of overestimating production. At this time, it is impossible to compare our harvest planning schedule approach with the manual approach due to these large differences. It would be necessary to validate the forest parameters of productivity with further data collection, a very time-consuming task that is beyond the scope of this work. However, this issue does not invalidate the results of the further experiments presented below.

The first round of experiments aimed at analyzing the influence of the discount rate on the harvest scheduling plan. Table 5 presents the harvesting scheduling plan for each analyzed discount rate, using a maximum demand of 25,000 $m^3$/month and a minimum demand of 19,583 $m^3$/month. In this table, Ar refers to *Parana* pine and Pi to *Taeda* pine. The results demonstrate that high values of discount rates lead to

**Table 5.** Timber volumes (in $m^3$) to be harvested per species under different discount rates

| **Disc rate** | **Species** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** |
|---|---|---|---|---|---|---|---|
| 9.0% | Pi | 19,795 | 25,000 | 21,735 | 23,311 | 19,583 | 19,583 |
| | Ar | 5,205 | – | 3,265 | – | – | – |
| 8.5% | Pi | 19,583 | 21,056 | 21,735 | 25,000 | 19,583 | 23,100 |
| | Ar | 5,205 | – | 3,265 | – | – | – |
| 7.5% | Pi | 19,583 | 19,583 | 19,583 | 22,234 | 25,000 | 25,000 |
| | Ar | 5,205 | – | 3,265 | – | – | – |
| 7.0% | Pi | 19,583 | 19,583 | 19,583 | 22,330 | 25,000 | 25,000 |
| | Ar | 5,205 | – | 724 | 2,670 | – | – |
| 4.0% | Pi | 19,583 | 19,583 | 19,583 | 22,642 | 25,000 | 25,000 |
| | Ar | – | 5,365 | 1,021 | 2,358 | – | – |
| 3.0% | Pi | 19,583 | 19,583 | 19,583 | 22,642 | 25,000 | 25,000 |
| | Ar | – | 1,075 | 5,417 | 2,358 | – | – |

an anticipation of the harvest activities. The quantification of the influence of this rate is a very important result for the company managers, resulting in much better long-term planning. These results were not obvious for the managers and very difficult to obtain by the usual manual process.

The second round of experiments analyzes a typical management decision (see Table 6). The problem was to identify the optimal volumes of logs to be consumed by the sawmill in the following years to maximize revenues and maintain forest sustainability. Naturally, all logs considered are to be obtained through the harvesting of the company's forest. We used a fixed discount rate of 9%, which

**Table 6.** Revenues (R$/year) and volumes produced ($m^3$/month) under different scenarios for demand levels

| **Scenario** | | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** |
|---|---|---|---|---|---|---|---|
| A | Max demand | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 |
| | Min demand | 23,416.7 | 23,416.7 | 23,416.7 | 23,416.7 | 23,416.7 | 23,416.7 |
| | Revenues | 9,333,752 | 7,927,288 | 8,122,096 | 7,345,117 | 6,360,304 | 5,825,323 |
| | Vol produced | 23,417 | 23,417 | 23,417 | 23,417 | 23,417 | 23,417 |
| B | Max demand | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 |
| | Min demand | 25,000 | 25,000 | 25,000 | 18,000 | 18,000 | 18,000 |
| | Revenues | 9,840,205 | 9,011,509 | 8,643,797 | 7,765,126 | 5,574,449 | 4,477,829 |
| | Vol produced | 25,000 | 25,000 | 25,000 | 24,924 | 20,913 | 18,000 |
| C | Max demand | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 | 25,000 |
| | Min demand | 25,000 | 25,000 | 25,000 | 25,000 | 18,000 | 18,000 |
| | Revenues | 9,462,074 | 9,357,301 | 8,131,531 | 5,197,290 | 7,696,554 | 4,871,712 |
| | Vol produced | 25,000 | 25,000 | 25,000 | 25,000 | 19,937 | 19,583 |
| D | Max demand | 30,000 | 30,000 | 30,000 | 30,000 | 30,000 | 30,000 |
| | Min demand | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 | 20,000 |
| | Revenues | 10,795,215 | 8,238,704 | 9,731,146 | 6,239,272 | 5,343,769 | 4,975,365 |
| | Vol produced | 27,483 | 22,820 | 28,265 | 20,000 | 20,000 | 20,000 |

was defined by one of the company executives. Table 6 presents the results of four different scenarios. The decision variable is the *volume produced* for each scenario per year. The log demands and volumes produced are shown in $m^3$/month, while the revenues are expressed in R$/year. The first row of Table 6 represents scenario A, the base case scenario, where the production level is constant for all six years. The production level stays at 23,416 $m^3$/month and total revenues for the period are R$ 44,913,880. Scenario B estimates the influence of increasing production for the first three years of the period. Here, we sup pose a minimum demand of 25,000 $m^3$/month from 2006–2008 and the total revenues expected are R$ 45,312,916. Although we can observe a slight increase in total revenues, there is a drawback in this scenario, a decrease in the production levels in the last two years, which could heavily impact on the sawmill future operations. Scenario C analyzes the result of extending the period of producing 25,000 $m^3$/month until 2009. In this case, the total revenues decrease to R$ 44,716,462. Finally, scenario D is based on more-flexible production levels, varying from 20,000 to 30,000 $m^3$/month for the entire period. Naturally, the revenues are higher than previous scenarios, totaling R$ 45,323,472. With this kind of sensitivity analysis it is possible to evaluate different operational strategies for the wood manufacturing process and forest sustainability.

Preliminary results demonstrate that DSS can be a very powerful tool to support long-term forest and operations planning for vertical companies. In the opinion of the company's managers the system can be used towards better balancing of species demand and better integration between the forest and wood manufacturing operations, considering multiple harvesting methods (thinning and clear-cut).

# 4 Conclusion

To exemplify how DSSs are being developed, implemented, and applied in South America, this chapter describes the conception and development of two experiences related to natural resource management. These applications were selected due to the importance of this theme for developing nations, and their potential to be generalized to a global scale. Furthermore, the experiences are complementary, describing the development and application of DSSs for the support of decision-making processes related to a common theme, but under different perspectives and objectives. One of the examples focuses on decision makers from the public sector, in which social and environmental aspects are considered as important as financial ones. In the second example, the main users of the DSS system are managers from the private sector, where the main objective is to maximize profitability, with the environmental aspects considered as restrictions.

The first example relates to the development of a DSS for the operational planning of solid-waste collection. The DSS supports the main operational stages of the solid-waste collection process, namely the collection by trucks and solid-waste unloading at sorting units. The major contribution of this research is the DSS's capacity to incorporate the control of the storage and processing capacity of the material at sorting units, a fact which was neglected by previous studies in this area. The possible benefits to be obtained by using SCOLDSS include: (a) a reduction of the distances to be covered by collection vehicles, (b) a reduction in the number of trips, and (c) balance in the distribution of waste collected among the sorting units.

The second example refers to a forest planning DSS, in which the main objective is to optimize the harvest scheduling, taking into consideration various factors such as financial discount rates, forest yields, and harvesting costs. The initial application of the computational system has demonstrated very good potential. The system was used to evaluate forest plans for a six-year period using data from a subset of the forest from a real company. The limitations of this work are related to its theoretical approach. As the model was not yet been applied to large business cases, the results are preliminary. There may be some difficulties concerning the large number of variables that the linear programming model will have to process as the number of forest stands increases and the planning period is extended to 20–25 years.

Both DSSs have been developed and are running. Notwithstanding the short experimentation time, the tests carried out clearly demonstrate that both computational systems have enormous potential as effective prescriptive tools. Further tests using quantitative techniques are being undertaken to assess the range of their capabilities.

Overall, the DSS systems considered were successful. In both examples, the DSSs outperformed the managers' expectations in terms of results and capabilities. The DSSs' ability to carry out sensitivity analysis on several input parameters and the highly interactive graphical user interfaces were highly appreciated by the decision makers involved in the computational experiments. The decision makers were also very impressed with the quality of the DSSs' outputs and were willing to implement the results provided by them. However, both implementations were not straightforward tasks. The complete data acquisition to run the DSSs may call for a systematic and organized approach. Since many South American organizations do not record some of the required data, this process can involve additional costs, mainly due to information technology equipment and training. Moreover, given the natural complexity of some of the techniques used in both systems, a relatively long period of experimentation is required by the users before the DSSs can be applied effectively to real problems. However, it must be noted that this time cannot be considered a waste of resources, but as a learning experience that will increase the knowledge of managers about the operations of solid-waste collection and forest harvesting scheduling, respectively.

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# Appendix A. The Forest Harvest Scheduling Model Formulation

We propose the following model formulations for the harvest scheduling problem:

$$\text{Max} \sum_{i \in I} \sum_{j \in P_i} \sum_{t \in T} v_{ijt} r_{ijt} x_{ijt}$$

such that

$$\sum_{j \in P_i} \sum_{t \in T} x_{ijt} \leq A_i \qquad i \in I \tag{1}$$

$$d_{lt} \leq \sum_{i \in I_a} \sum_{j \in P_i} v_{ijt} x_{ijt} \leq D_{lt} \quad t \in T, l \in L \tag{2}$$

$$td_t \leq \sum_{i \in I} \sum_{j \in P_i} v_{ijt} x_{ijt} \leq TD_t \quad t \in T \tag{3}$$

Where:

$I$ = set of forest stands.
$P_i$ = set of possible interventions (thinning 1, thinning 2, harvesting) in stand $i$
$T$ = planning horizon
$L$ = set of log diameter classes
$d_{lt}$ = minimum demand in period $t$ for log class $l$
$D_{lt}$ = maximum demand in period $t$ for log class $l$
$td_t$ = total minimum demand of logs in period $t$
$TD_t$ = total maximum demand of logs in period $t$
$v_{ijt}$ = productivity ($m^3$/h) of area $i$ under prescription $j$ in the each period $t$
$r_{ijt}$ = $p_{lt} - c_{ijt}$, where:
$c_{ijt}$ = harvesting/$m^3$ and transportation costs/$m^3$ (from the stand $i$ to the sawmill) in period $t$
$p_{lt}$ = unitary price of selling log class $l$ in period $t$
$x_{ijt}$ = is the decision variable meaning the area allocated in stand $i$ under prescription $j$ in period $t$

Constraint (1) guarantees that the maximum available plantation area for each stand is respected. Constraint (2) guarantees that both the maximum and minimum demands are fulfilled for each class/species. Constraint (3) guarantees that both total maximum and minimum demands for logs are fulfilled.

# CHAPTER 62
# DSS Experience in Africa – Cases from Egypt

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Decision support systems (DSSs) emerged in the 1970s and have gradually, in different dimensions and through various channels based on emerging information and communication technology (ICT), affected the decision-making process at the individual, organizational, and societal levels. Competition, convergence, globalization, business, and socioeconomic pressures as well as market needs have all contributed to the deployment of cutting-edge mechanisms for rational and effective decision-making processes for government, private, and public-sector organizations alike. This chapter describes the experience of the government of Egypt in spreading the awareness of ICT and its use in managing socioeconomic development since the mid 1980s, through building multiple DSS platforms for governmental decision making with a variety of lessons learnt in the design and delivery of DSS under complex conditions common to developing nations. The experience offers insights into a variety of problems for information system designers, implementers, users, practitioners, and researchers. The chapter focuses on the use of DSSs for development through the experience of a government think tank, the Information and Decision Support Center (IDSC), while demonstrating a number of cases showing the implementation and institutionalization of DSSs for a variety of issues such as debt management, foreign exchange policy, custom tariff policy formulation, and development planning.

**Keywords:** Decision support systems; Decision making; Decision analysis; Crisis management; Information technology transfer; Information and communication technology; Developing nations; Africa; Egypt

## 1 Introduction

The importance of information technology has been greatly emphasized in most developing nations (Goodman 1991, Lind 1991) where the government has played a vital role in its diffusion (Moussa and Schware 1992). These governments, through their policies, laws, and regulations, still exert significant influence throughout various organizations and entities (Nidumolu and Goodman 1993). Recently, the extensive benefits of information collection, analysis, and dissemination, supported by computer-based technologies have been investigated to enable decision makers and development planners to accelerate their socioeconomic development programs. Thus, many developing nations have embarked on medium- and large-scale information technology and computerization projects with a focus on public-private partnership models to ensure diffusion and sustainability (Kamel 2005). In practice, most of these projects have sought to introduce computing and telecommunication technologies for business and socioeconomic development purposes. However, frequently, they have concentrated more on large-scale capital expenditures rather than human capital investment such as training and human resource development (UNESCO 1989). Therefore, many of these schemes failed to achieve their goals, resulting in a generally negative conventional wisdom that defined information technology as inappropriate to developing nations. However, it is important to note that such a statement should not be generalized to all developing nations, because some projects have actually managed to make a difference to their own environments and have contributed to socioeconomic development for their own communities, such as in the cases of telecenters and community development associations (Kamel 2004). These projects have managed to close the digital divide in many communities in developing nations and have contributed to supporting the formulation of the knowledge society.

Developing nations, over the past two decades and gaining from the experiences of the past, have invested extensively in training and human capacity development, consultancy, and the establishment of a strong and efficient technological infrastructure that could move them into a state of self-sufficiency and help build an information infrastructure (infostructure) to help boost their socioeconomic development efforts. Moreover, many developing nations have embarked on the development of long-term, detailed strategy plans for the diffusion of information and communication technology (ICT). The majority of these nations have assigned a high-level policy maker, often at the cabinet level, to be responsible for ICT and to formulate projects and activities that can capitalize on such technologies to boost the developmental process. However, to realize concrete benefits from the implementation of information technology and to benefit from the opportunities enabled by emerging technologies, there is a constant and urgent need to apply appropriate technology that fits with the nation's values, social conditions, and culture. Additionally, there is a need to identify information technology needs and related policies and regulations to provide the proper environment for its implementation. Some of these policies need to be created to enable the appropriate environment for growth while other policies in many ways need to be amended to cater for the market transformations caused by emerging technologies.

Technology transfer and more importantly introduction, adoption, diffusion, and adaptation are important components for successful implementation and institutionalization of ICT and represent a building block on the path to the realization of effective benefits for the community. This chapter focuses on one of the applications of information technology, decision support systems (DSSs), and demonstrates how they can be deployed to rationalize the decision-making process at the policy-making level given the limited or scarce resources in developing nations, such as is the case in Egypt, and in supporting the development process across various sectors in the economy.

DSSs are defined as advanced computer-aided information technology that can be used to support complex decision making, problem solving, policy testing, scenario simulation, and strategic planning with more reliance on mathematical models, simulation techniques, and quantitative tools (Shim et al. 2002). DSS models are important mainly because they are specifically designed to evaluate alternative decisions, test policy measures, assess the impact of different operational rules, and project the future performance of complicated systems. DSSs can therefore provide efficient support for strategic decision making and development planning (Khorshid 2003, Kamel 1994, El Sherif and El Sawy 1988) especially when using model-driven approaches (Morton et al. 2003, Belton and Ackermann 1997) with optimal interaction between the technology and the decision maker. Moreover, the complexity of real problem situations motivates decision makers to explore the applicability of various existing methods for solving problems and crisis management situations in their organizations (Jackson 2003, Kamel 2001).

With respect to socioeconomic issues, decision situations generally include structured, semistructured, and unstructured elements. While a computer system could be developed to solve the structured portion of a DSS problem, the judgment of the decision maker is brought to bear on the unstructured part, thus constituting a human-machine problem-solving system (Shim et al. 2002, Turban 1998). It is important to note that, since the development of DSSs in the early 1970s, many of their tools have benefited from the evolution of information technology infrastructure across the three eras of growth in the industry: data processing, microcomputers, and networking (Khorshid 2003). Recent developments in emerging communications technology and the trend towards information technology and media convergence also promise many opportunities for policy makers to benefit from online and timely access to electronic services through a variety of platforms including mobile and wireless devices, as well as more-conventional devices.

## 2 Government Decision-Making Processes

In the context of developing nations, the government decision-making process has a set of specific characteristics given the challenges faced in terms of planning and socioeconomic development. In that context, Table 1 demonstrates (Khorshid, 2003), these characteristics and the related challenges.

Government decision making targets the optimum allocation of scarce resources by the delivery of public services in the most efficient and effective way, whether deployed by conventional methods or newly emerging electronic channels such as electronic government (Kamel 1993, 1997). Government decision making over the last couple of decades has been greatly affected by the emergence of ICT in that decision-making processes have been transformed to capitalize on the opportunities enabled by such technologies with a focus on socioeconomic development (Kamel 1994). It is important to note that ICT should be looked on as a platform and vehicle for development, which can be realized through the delivery of different services to the community that aim to make citizens' lives

**Table 1.** Government decision-making characteristics in developing nations

- A government decision or policy maker is usually faced with semistructured or unstructured problems that cannot be handled by innovative, intelligent, and flexible problem-solving capabilities and decision-making techniques and tools alone.
- Government decisions are strategic in nature and have considerable implications for the future performance of the socioeconomic system of the country.
- Socioeconomic data to support government decisions generally vary in quality, are sometimes incomplete and are rarely consistent, and the multiplicity of sources and differences in the methods of collection usually give rise to errors.
- Most strategic decisions made by a government include an increasing level of uncertainty and risk due to the complexity of problems and the large number of variables analyzed.
- Socioeconomic systems are characterized by the existence of complex interactions and linkages among issues, problems, policies and decisions known as multiplier effects, which can only be captured by complex and advanced decision support tools and techniques.
- Government decision making involves the evaluation of alternative socioeconomic options, policy measures, and decisions with respect to their impact on development objectives, which sometimes results in conflicting effects on different development priorities.
- When adopting appropriate computer-based tools to support government tactical and strategic decisions, one needs to handle the expected difference in response among government staff.

more efficient and effective by helping to raise their standards of living through more-rational and effective decision-making processes. In the context of developing nations, such processes are more complicated due to the scarcity of resources including the information infrastructure, which represents a major building block in the government decision-making process (Kamel 2005). The process is mainly strategic in nature and has considerable repercussions and impacts on the future performance of the socioeconomic system (Khorshid 2003, El Sherif and El Sawy 1988).

Socioeconomic data to support government decisions usually vary in quality, are incomplete and rarely consistent, and come from a multiplicity of sources with different data-collection methods (Khorshid 2003, Kamel 1997). Other elements related to strategic decisions at the highest policy and government levels include: high levels of uncertainty and risk, complex interactions between various elements, and multiple effects within a larger developmental framework, leading to conflicting effects (El Sherif and El Sawy 1988). Accordingly, a computer-based DSS should be viewed as a tool to support the decision-making process within a government by enhancing the productivity of decision makers and increasing the effectiveness of public decisions (Khorshid 2003). Respectively, DSSs should be equipped with a comprehensive set of analytical tools that includes information systems relevant to the decision-making environment to provide multidimensional ad hoc dynamic reporting. Moreover, to ensure effective communication using decision makers via intelligent man-machine interaction systems to assess the decision's related socioeconomic implications, given the semistructured and unstructured nature of the problems faced (Khorshid 2003, Lind 1991, Keen and Scott Morton 1978). Additionally, for DSSs to be effectively and efficiently implemented and institutionalized to yield the expected outcomes, there is a need for a set of building blocks to be enabled. This includes building awareness and commitment, leadership and strategic thinking capabilities, legislative and institutional infrastructures, human resource capacities, and infostructure and a state-of-the art technological infrastructure (Kamel 2005, Khorshid 2003, El Sherif 1990). Below, we summarize experiences in the design and delivery of decision support centers and systems in Africa, using the example of the Cabinet of Egypt Information and Decision Support Center (IDSC) and present some of the decision support cases implemented since its inception in 1985.

## 3 Information and Decision Support Center (IDSC)

Realizing the enormous impact of information technology and its important role in socioeconomic development, during the 1980s the government of Egypt strived to implement a nationwide strategy to support the realization of its targeted objectives. Therefore, it adopted a supply-push strategy to improve Egypt's managerial and technological infrastructure (Kamel 1997). The objective was to introduce and diffuse information technology into all ministries, governorates, and government organizations, which necessitated the development of an infrastructure for informatics and decision support, a software service industry, and a high-tech industrial base in the electronics, computers, and communications sectors. Consequently, in late 1985 the government, established IDSC to support top policy makers in key business and socioeconomic issues through the formulation of information and decision support centers and projects (Kamel 1998). Such a strategy was boosted and complemented by the establishment of the Ministry for Communications and Information Technology (MCIT) in 1999 (www.mcit.gov.eg), and by a comprehensive plan called the Egypt Information Society Initiative (EISI) in 2001 (Kamel 2005). This growth path should be considered an adaptive learning curve for the introduction and diffusion of ICT in Egypt, while considering the process of development planning and the readiness of the community in terms of the resources available and the human capacities ready.

The cabinet decision-making process is usually seen in terms of its mission, objectives, and outcomes. However, extensive observations revealed that the decision-making process is better viewed by its stakeholders as a process of attention to sets of issues with varying and changing priorities. These issues circulate continuously and are liable to political maneuvering as situations change until they are managed over time. The issues are usually complex, ill-structured, interdependent, and multisectoral with strategic impacts at the national, regional, and international levels (Kamel 1998, El Sherif and El Sawy 1988). The decision-making environment at cabinet level is characterized by being data rich and information poor due to poor analysis, isolation of information experts from decision makers, the use of computer systems as ends rather than tools supporting in decision making, and the focus on technical issues rather than on decision outcomes (El Sherif and El Sawy 1988).

The mission of IDSC was to provide information and decision support services to the cabinet for socioeconomic development, with the aim of improving the nation's managerial and technological infrastructure by enhancing the decision-making process for the development of information and decision support systems for top policy makers. Moreover, it targeted support for the establishment of decision support systems and centers in different ministries, making more-efficient and effective use of the available information resources and initiating, encouraging, and supporting informatics projects to accelerate the managerial and technological development of various ministries, sectors, and governorates (Kamel 1997 and 1993). For data accessibility and information dissemination, IDSC interacted in three main directions with top policy makers: with ministers and governors, government, and public sector organizations; with academic institutions and research centers; and through international channels, accessing major databases and organizations worldwide through state-of-the-art computing, information, and communications facilities (Kamel 1997, 2001).

The scope of IDSC activities extends to four levels: the cabinet, various sectors, national, and international levels. At the cabinet level, it provides information and decision support, crisis management support, data modeling and analysis, multisectoral information handling, and database development. At the sectoral level, it provides technical and managerial assistance for the establishment and development of decision support centers and systems, advisory and consultancy services, and sectoral information systems development. At the national level, it provides assistance in policy formulation and drafting, legislative reform support and for the development of a technological infrastructure. At the international level, it supports the transfer of state-of-the-art information technology to Egypt, establishes DSS models for developing nations, and formulates cooperation links and communication channels with international information technology (IT) organizations (Kamel 1997). Recently, it is jointly implementing projects with various units in the government for information technology diffusion and for the assessment of information technology penetration and its implications at the local level in cooperation with the MCIT (www.idsc.gov.eg). It is important to note that the role of IDSC has been transformed and adapted to serve its stakeholders and constituencies in light of its evolving role, which was articulated after the establishment of the MCIT. The accumulated learning and experience of IDSC in Egypt was transformed to support the government in decision making as well as in helping to create new generations of ICT-literate communities that are electronically ready and capable of working in an environment governed by emerging and changing ICT tools and applications.

DSSs imply the use of computers to assist managers in their decision processes in semi- and ill-structured tasks, to support rather than replace managerial judgment, and to improve the effectiveness of decision making rather than its efficiency (Keen and Scott Morton 1978). DSSs were mainly developed and applied in profit-oriented organizations, which are managed through market constraints and trends (Kamel 1994). However, IDSC experience suggests new areas of applications for DSS-based on developmental objectives for socioeconomic improvement, governed by countrywide laws and regulations and regarded as systems, which ought to fit within developmental contexts, policy decision making, and supporting management problem solving (Kamel 1997, 1998). While there are examples of successful DSSs used for strategic decision making by top management in such decision contexts as mergers and acquisitions, plant location, and capital expenditures, these DSSs tend to focus on limited and well-structured phases of specific decisions. However, when supporting the comprehensive strategic decision-making process over a longer period of time with competing and changing strategic and socioeconomic development issues, multiple decisions, and changing participants, much less progress has been made (Kamel 1998).

DSS challenges come mainly from the complex nature of the strategic decision-making process and the related issues that this entails for the design, development, and implementation of DSS. This could be attributed to the nature of strategic decision making, which is usually indistinct, ill-structured, and drawn out over a long period due to the requirement for rapid responses in crises (El Sherif and El Sawy 1988). It is usually a group rather than an individual effort involving cooperative problem solving, crisis management, consensus building, and conflict resolution (Gray 1988). It involves multiple stakeholders with different assumptions (Mason and Mitroff 1981). The information used is mostly qualitative, verbal, and poorly recorded (El Sherif and El Sawy 1988), and its continuous flow causes not only information overload with multiple and conflicting interpretations but also the absence of relevant information (Zmud 1986). Finally, the formation of strategic decisions is more of an evolving and emerging process where the supporting requirements are difficult to forecast. There are also some challenges associated with the nature of the decision maker at such high-level policy making such as communication difficulties due to scarcity of time, unwillingness to spend time learning, preference to rely more on personal experience and intuition rather than on information technology tools and techniques, and resistance to change (Kamel 1998).

In the case of Egypt, strategic decision making at the cabinet level provides an opportunity for the design and delivery of information and decision support systems that differ from other conventional and traditional settings. The inadequate reliability of the information infrastructure, coupled with the need for crisis response, led to the prototyping of an issue-based design and delivery processes rather than an organizational decision-based approach to fit the decision-making environment. Many similarities could be mapped between the cabinet and organizational decision making where the use of issues management is not alien to corporations (King 1981) and was applied to planning of various management

**Table 2.** Conventional versus issue-based decision support systems approach

| | Conventional | Issue-based |
|---|---|---|
| **Focus** | Decision maker<br>Single decision<br>Decision making<br>Alternative generation | Issue<br>Groups of interacting issues<br>Attention focusing<br>Agenda setting |
| **Favored domains** | Tactical and operational decisions<br>One-shot decisions<br>Functional applications<br>Departmental applications | Strategic decisions<br>Recurring strategic decisions<br>Cross-functional applications<br>Trans-organizational applications |
| **Design and delivery** | Promotes customization to individual decision maker<br>Interaction between decisions not incorporated<br>Prototyping design<br>Design approach becomes the system | Promotes consensuses around group issue<br>Integration and consensus drives process<br>Prototyping design and delivery<br>Delivery approach becomes the system |
| **Executive information systems readiness** | No tracking component<br>Emphasis convergent structuring<br>Major transformation | Incorporates tracking component<br>Balance divergent exploration and convergent structuring<br>Easy transition to executive information systems |
| **Emerging leveraging technologies** | Expert systems<br>Artificial intelligence | Idea processing and associative aids<br>Multimedia connectivity platforms |

information systems organizations (Dansker et al. 1987). Table 2 provides a comparison of the conventional decision-based approach and the issue-based approach to DSSs as identified by IDSC, which has been successfully implemented during the period 1985–1988 in response to the need to support strategic decision making at the cabinet level. The table is useful for information systems researchers and practitioners in determining the advantages and constraints of the issue-based approach to various organizational and decision-making environments (El Sherif and El Sawy 1988).

The decision-making process at the cabinet level addresses a variety of socio-economic issues such as balance-of-payment deficit, a high illiteracy rate, housing, health, public sector reform, administrative reform, debt management, privatization, and unemployment. The decision-making process involves much debate, group discussions, and the development of studies, and is subject to public accountability and media attention (El Sherif and El Sawy 1988). It is important to note that, at this level, the successful use of DSSs requires that the user has a significant amount of independence and autonomy in the decision-making process. Moreover, the perceived usefulness of DSSs is reduced where there is lack of autonomy, a command and control culture, and little role in the decision-making process (Elbeltagi et al. 2005).

# 4 DSS Cases from Egypt

The following is a set of decision support cases designed, implemented, and institutionalized by the government and public-sector organizations for socioeconomic purposes in Egypt through IDSC. The cases cover priority developmental issues including debt management, foreign exchange-rate policy, custom tariff policy formulation, and local administration.

## 4.1 Debt Management

During the 1980s, economic rebuilding efforts required Egypt to accumulate a foreign debt of about 33 billion U.S. dollars covered by 5,000 loans. These loans needed to be monitored for debt service payments, term renegotiations, interest rate levels, and payment management and scheduling with a large number of creditor countries, banks, and international agencies. The magnitude of the debt burden led to the reform of the debt management program becoming a priority issue at cabinet level. To overcome these difficulties and provide effective support for the debt management problem, a joint team from IDSC and the Central Bank of Egypt (CBE) was formed. The project had two main purposes: to centralize and computerize all foreign debt data in the central bank, and to develop a computer-aided management tool supporting and facilitating the registration, control, analysis, reduction, and rescheduling of foreign debt. The system components included a complete debt-validation database for government loans, a transaction-processing system for debt management, and a DSS capability to investigate the impact of different scenarios.

The DSS was developed to provide a management tool to support and facilitate the registration, monitoring, control, and analysis of Egypt's debts. Over a period of 18 months, a comprehensive national database, located in the CBE, was developed by the IDSC's technical staff. The database included details of government debts and payments, linked to a debt payments transaction processing system. The database was provided with DSS capabilities, enabling the implications of different debt management scenarios to be tested (Kamel 1997). It is important to note that, prior to the development of the DSS, decision about and renegotiation of loan payments were done on a case-by-case basis. Data related to each loan was therefore fragmented, global debt management was not possible and accurate estimates of aggregate debt portfolio figures were not available (Khorshid 2003, El Sherif and El Sawy 1988). Throughout the development phase, a number of technical and cultural problems occurred, causing delays and frustration. The problems were mainly technical, and related to hardware requirements, software availability, and processing of operations. More importantly, some cultural challenges were faced, mainly related to the fact that most of the software was developed and interfaced in English, which represented a problem for many local users. It is important to note that the impact of the system, using decision support tools and generators, was the successful negotiation of debt rescheduling with 14 different countries. Negotiation was smoothly managed through the provision of grounded information support made available via the DSS. Moreover, loans have been viewed ever since as part of a comprehensive, integrated, and dynamic portfolio rather than being managed on an isolated case-by-case basis (Kamel 1997).

## 4.2 Foreign Exchange Rate Policy

Since the beginning of the 21st century, Egypt has faced a shortage of foreign exchange earnings, reflected in a prevailing external imbalance, and an increasing deficit in the current account of the balance of payments. To restore its external balance, the government of Egypt is adopting an economic policy directed towards promoting exports, rationalizing imports, and applying a flexible foreign exchange rate system, a policy that has been carried out over the last decade (Kamel and Tooma 2005). Since the result of export-oriented measures is only felt in the medium term, the Central Bank of Egypt needed to make short-term adjustments to the foreign exchange market via a devaluation of the Egyptian pound against the U.S. dollar, and to liquidate part of its foreign reserves to increase the supply of foreign currency. Early in 2003, the government of Egypt decided to apply a floating foreign exchange rate policy in order to bridge the gap between the price of the U.S. dollar in the official banking system, and that in the black market. In order to identify the macro-impact of this devaluation policy of the Egyptian pound, the minister of planning opted for the development of a decision support tool to address the issue, conduct various policy experiments, and assess their socioeconomic implications (Khorshid 2003). The DSS included a social accounting matrix for the fiscal year 2001/2002, capturing the cycle of income flows within the economy representing the database, and a model-base consisting of an economy-wide mathematical model designed to test the impact of changes in the foreign exchange rate on the short- and medium-term performance of the economy. Moreover, it included an advanced computer modeling language to implement the suggested mathematical model and provide the appropriate solver. The selected tool was the general algebraic modeling system (GAMS) software and a user-friendly interface system whose function was to make policy experiments and result generation as friendly and transparent as possible. This computer-based system, linked to the GAMS software, permitted the formulation of alternative scenarios related to the foreign exchange rate, and the generation of appropriate socioeconomic indicators in a simple manner (Khorshid 2003).

The DSS was successfully used to estimate the short- and medium-term impact of the devaluation policy on most macroeconomic indicators, including but not limited to the balance of payment, inflation rate, volume of exports, and demand for imports. The model-based DSS successfully supported the urgent request of policy makers to assess the direct and indirect impact of this foreign exchange rate policy on the economy. This economy-wide impact provides the necessary background to formulate appropriate complementary policy measures in order to reduce the negative effects of the adopted devaluation program. Despite the usefulness of this DSS in policy formulation and testing, it suffers from being a specific system to address a particular problem. It should be noted here that the loss of generality (or flexibility) in this system is nonetheless compensated by the low development and implementation costs compared with other, more-general DSSs (Khorshid 2003).

## 4.3 Customs Tariff Policy Formulation

For a long time, the government has been involved in the formulation of a complex customs tariff structure with three objectives: (a) developing a homogeneous and consistent tariff structure, (b) increasing revenue to the treasury, and (c) minimizing the impact on low-income groups. In 1986, a new customs program was announced. However, despite initial agreement and good intentions, interministerial debates and conflicts about policy forms and the perceived economy-wide impact grew. After long and exhaustive discussions among the different stakeholders, IDSC in collaboration with the ministry of finance developed a DSS model using the already announced tariff-reform proposal (Edelstein 1996, El Sherif 1990). Data was collected, with difficulty, from fragmented sources. During the duration of the project, the team in charge carried out continuous daily contacts and discussions with the most revelant ministries, and coordinated with senior policy makers to gather comments and feedback, and build consensus. Initially, conflicts were sharp, discussions were heated, and one-sided theories prevailed. It was a case of entities working together but acting as separate islands with no effective communication or collaboration. For example, the ministry of industry, wanting to encourage local manufacturing, sought to raise import tariffs on automotive spare parts, while the ministry of finance disagreed, because that would reduce a sizeable amount of customs revenues. However, as the model became more representative through the prototyping effort, the impacts of various what-if scenarios, reflecting alternative tariff rates, were demonstrated with numbers rather than abstract opinions. The focus gradually moved from objection to constructive input. After intensive deliberation, a consensus was reached, and a new customs tariff policy was put in place (Khorshid 2003).

The implications of the new model included the fact that the developed customs tariff policy DSS has proved to be an excellent negotiation tool to support the government decision-making process. In fact, the customs tariff DSS facilitated the group decision-making exercise by reducing conflict and promoting consensus by clarifying the trade-offs and potential impacts of alternative tariff structures on the whole economy and each sector. Furthermore, the DSS provided realistic quantitative estimates of the expected increase in government revenues due to the new customs tariff program. The original estimated U.S.$ 100 million increase in customs revenues (based on abstract opinion), was shown by the DSS what-if analysis to be unlikely, and that any realistic scenarios would generate about U.S.$ 10 million, which was proven correct a year later. To conclude, the customized DSS was an effective tool to address specific problems and support particular decisions at a senior policy-making level. Since these DSS tools generally concentrated on relatively small problems, they were found to be less expensive, but more time consuming, compared with general-purpose DSSs. However, they have a number of limitations that relate to their lack of adaptability and generalizability and being influenced by the interests of the DSS developer or decision maker (Khorshid 2003).

## 4.4 Local Administration

Egypt is divided into 27 governorates (including the city of Luxor). Each governorate has a governor who collectively constitutes the council of governors. The decision-making process at the governorate level addresses a variety of national socioeconomic development issues such as health, education, food security, the high illiteracy rate, housing, poor technological infrastructure, and unemployment. In 1981, a presidential decree was issued, requiring all of Egypt's governorates and central government agencies to streamline their information collection, analysis, and dissemination methodologies and techniques through the development of an Information and Documentation Center (IDC) (Kamel 1993). However, until 1987 no significance impact was felt. Throughout the period 1981–1987, there were no systematic procedures implemented for the collection of information because it was viewed as personal property and that sharing it would mean loss of power and authority. However, each governor was allowed to access the information available at the local administration offices on a selective basis. These conditions prevailed because every local administration director owed his loyalty to his federal minister who had sole authority to review his performance, assess his outcome, and make promotions despite the fact that the governor paid their salaries. Based on the lack of coordination among the local administrations, the bias of the directors to the ministers, and the lack of communication and coordination between the director and the governor, governors frequently based their decisions on their own intuition rather than on the use of information (Kamel 1997).

The role of IDC was insignificant for the development program as well as for the decision-making process at the governorate level. Moreover, on various occasions data access from different local administrations lacked smoothness, relevance, timeliness, and accuracy. IDC did not provide support to improve the follow-up and evaluation mechanisms within the governorates nor did it introduce changes to the administrative systems. The failing role of IDC and the need for administrative and technological development, in addition to the need to make better use of the available resources, mainly information aimed at the rationalization of the decision-making process, necessitated a move towards a better solution and concrete action.

The decision-making process in Egypt's governorates has passed through a number of phases due to various political, social, and economic reasons. In general, this was based on ad hoc decisions and intuition. Previously, there were some attempts to rationalize the decision-making process but these attempts failed for a number of reasons related to the laws of local administration and the relationship between the federal government and the local administrations. With the diffusion of information technology adopted by the government as a part of the nationwide structural adjustment program, there were trends to make use of relevant, timely, and accurate information collection and handling techniques to rationalize the decision-making process to support socioeconomic development (Kamel 1997).

The government of Egypt has traditionally been hierarchical, with crucial socioeconomic development decisions being taken at the federal level, leading to centralization of power, authority, and responsibilities. Thus, each governor has little control over critical decisions, although he has discretion over tactical and operational decisions. However, in the late 1980s, the government sought to promote greater decentralization of decision making; therefore, it considered empowering each governor, holding him responsible and accountable for developmental decisions. The government sought to improve the decision-making skills of the governors and the directors of the local administrators with state-of-the-art information technology. Correspondingly, the government realized in 1987 the importance of establishing a comprehensive information-base network that could provide support for the cabinet and top policy and decision makers at the governorate level.

The Governorates Information and Decision Support Centers (GIDSCs) project was launched with the objective of providing computer-based information and decision support to the governors of Egypt's 27 governorates. Over the following five years, IDSC established an information and decision support center in each governorate with the main mission of reconceptualizing the role of local governorates in the areas of socioeconomic development and growth. The project had a two-tier strategy: firstly, the development of an infrastructure for informatics and decision support systems, and secondly the development of human capabilities in the areas of information, computers, and communications (Kamel 1993).

The conceptual design of GIDSC was based on a criterion that includes five main elements. Firstly, it was important to have an output-driven process in which the implementation was guided by the timely, accurate, and relevant delivery of information on socioeconomic indicators in specific areas such as housing, food supply, agriculture, industry, tourism, and education. Secondly, there was a need to introduce an impact-driven process where each GIDSC should contribute to improving the standard of living, quality of education, business, and socioeconomic development. Thirdly, it was vital to formulate a partnership with the governor to provide local support for the GIDSC. Fourthly, there was a need to implement a phased implementation given the limited human, financial, and technical resources and lack of prior experience in implementing similar projects. Finally, there was growing interest in portability of -solutions, where similarity of the basic needs across the governorates and the limited resources necessitated that the solutions developed for one GIDSC could be transferable to the others (Kamel 1999).

The development of GIDSC project, given the limited financial and technical resources, necessitated a phased implementation approach that was developed over four phases: initiation, base building, institutionalization, and sustained growth. Table 3 demonstrates the strategies and impact of each of these phases. In the initiation phase, the project team focused on studying the decision-making environment in all the governorates, assessing the available resources for the establishment of GIDSC. One GIDSC location was selected in the governorate of Suez as the pilot project because of the belief of the governor in using IT for socioeconomic transformation, the rural-urban societal mix of the governorate of Suez, its proximity to the governorate of Cairo for follow-up and maintenance purposes, and Suez's economical and political status.

In the base-building phase, six more GIDSCs were established in the governorates of Sharkeya, Port Said, South Sinai, North Sinai, Ismailia, and the Red Sea. These governorates were selected because they shared the same socioeconomic issues. This phase was characterized by having the governorates more aware of the GIDSC project and anxious to follow and replicate the experience. The project team became more aware of the methods and techniques to use while dealing with the staff of the governorates. Adding account executives to conduct periodic visits to the GIDSC and respond to technical and administrative inquiries altered the structure of the project team and led to effective adaptation to all project-related issues.

Moreover, the inclusion of training and human-resource development programs with boarder topics and areas of applications related to management and information technology was introduced, together with a prize presented for the best achievements in the programs in the form of a monetary reward. In the institutionalization phase, the remaining governors were jealous and eager to establish their own GIDSC after the remarkable, although initial and growing, success of the existing GIDSCs. Therefore, a plan was developed to expand the project based on a parallel strategy to inaugurate the remaining 19 GIDSC within one year. During the fourth phase, the focus was on sustainability and growth, which included more attention on training and human resources and better formulation of communication links between various data sources and local administrations, in addition to focusing on the career development of the GIDSC staff and ensuring the diffusion of GIDSC services and deliverables to different users in the governorate.

To conclude, it is important to note that the GIDSC project was important within the context of Egypt's socioeconomic development. While political and societal influence played crucial roles in introducing the early phases of the project (initiation and base building), the role of the functional perspective increased in the latter phases of the project (institutionalization and sustained growth). This

**Table 3.** Strategies and impacts of the GIDCS implementation phases

| | **Strategies** | **Impacts** |
|---|---|---|
| Initiation | Use of a supply-push strategy to demonstrate GIDSC benefits, priority development issues (education and health)<br>Portability of the sectoral database to transfer the model across different GIDSC and establish standards<br>Use of simple, user-friendly applications to bridge the technological gap | Changes in the decision-making process (mechanisms and structure for data collection, analysis, information handling, and dissemination) |
| Base-building | Increasing the variety and frequency of training programs for GIDSC staff<br>Capitalizing on the lessons learnt from the Suez experience<br>More organizational visibility for the GIDSC | Standardized identification and collection of data<br>Increasing appreciation of the role of GIDSC by implementing governors |
| Institution-alization | Selection of GIDSC staff with minimum levels of managerial and technical skills for recruitment<br>Extensive training programs were enforced<br>Cross-fertilization was taking place through the organization of brainstorming sessions between staff of different GIDSC<br>Documentation of DSS cases<br>Issuing an incentive scheme for GIDSC staff to encourage them and enhance their motivation | Increasing support from different governors to the GIDSC model<br>Creation of a competitive environment among governors on the use of IT in socioeconomic development<br>Producing a newsletter addressing the DSS cases that were implemented across the nation<br>Development of local cultures that accept the deployment of IT in decision making |
| Sustained growth | Massive penetration and diffusion of IT across the 26 governorates<br>Implementation of DSS to meet local needs reflecting adaptation (cultural interface)<br>Diffusion of IT knowledge and DSS at various organizational levels to overcome resistance to change (organizational interface)<br>Adoption of users and the use of decision support tools (user interface)<br>Value assessment and evaluation | Organization of a GIDSC conference to demonstrate the DSS cases implemented to the public and potential users<br>Emergence of new ideas and projects from the local level |

is in contrast with previous research, where the functional perspective was crucial during the early phases (Cooper and Zmud 1990, Laudon 1985). There are a number of lessons accumulated from the GIDSC experience in Egypt. These lessons could be replicated in other developing nations with similar socioeconomic conditions including, but not limited to, African nations. This includes the importance of understanding the underlying motivations for using IT innovation and placing these motivations in the economic and political context of the adopters. Moreover, emphasizing that the social group has an important role in influencing attitudes towards IT innovation, the governors were highly susceptible to the attitudes of their peers and superiors. Finally, the GIDSC project offered a direct challenge to the conventional wisdom that large-scale information technology projects managed by governments in developing economies are usually badly managed and lead to a waste of money and resources. A distinctive characteristic of the GIDSC project is that it has been financed entirely by Egyptian funds, and was planned and executed completely by Egyptian managerial and technical professionals who have localized and customized the various solutions made available by different information and decision support systems to the local situations and conditions (Kamel 1993, 1997).

## 5 Lessons Learnt

Developing nations represent a challenging domain for information and decision support systems. The characteristics of the nation, the problems faced, and the opportunities are among the challenges. Examples of these challenges include the lack of informatics infrastructure, the limited availability of information, the lack of technical expertise, and the widening application gap between existing information and decision support systems. The IDSC experience in Egypt shows that challenges relate to strategic decision making, DSSs, implementation of DSSs, and their institutionalization. In strategic decision making, the challenges relate to the ill-structured nature of processes extending over long periods of time, the involvement of many stakeholders, the need for conflict resolution, consensus building, and crisis management, the efficient and effective use of scarce resources, and the turbulent and dynamic environment in which the decision-making process occurs. In DSSs, the challenges relate to managing the development of multiple information and decision support systems, their institutionalization within the context of each application, the development of appropriate interfaces, the availability of tools and generators relevant to different industries, supporting rather than replacing managerial judgments, fast response, and prototyping the design and delivery phases. In implementation, the challenges relate to the lack of user involvement, the inadequacy of model evaluation, the lack of a problem definition, resistance to change, and the difficulty to diffuse new model-based systems. It also included untimely, unresponsive and inadequate information and non-responsiveness to user needs, lack of top management support, lack of vital continuous communication, poor documentation, and language problems (Gass 1987). In terms of institutionalization, the challenges include overcoming resistance to change, adapting model-based systems to the context of work and formulating documented procedures, managing the process of change, information technology diffusion and adoption, and their impact on the individual and the organization.

Managing the implementation and institutionalization of DSSs requires all these challenges to be faced. Strategic decision-making aimed at realizing socioeconomic development objectives is one of the most difficult and challenging contexts in this regard due to the messy, ill-structured, dynamic, and turbulent environments involved. Based on the decision support cases demonstrated in

**Table 4.** Recommendations for DSS implementations in developing nations

- Structuring of issues is an integral part of the design and implementation of DSSs dealing with socioeconomic development.
- Providing DSSs for development planning is often coupled with both urgency and criticality of the issue. Therefore, DSS design should allow for crisis management to be able to respond to crisis requests, which entails the preparation of crisis teams with their managerial and technical support capable to operate in such situations.
- Providing DSSs requires much time and effort in building and integrating databases from multiple data sources and sectors.
- Developing a DSS for one socioeconomic issue might affect other issues, which should be considered during the design phase to save time and effort, and avoid duplication of activities.
- An effective DSS depends on the availability and accessibility of timely, relevant, and accurate information.
- Successful implementation of a DSS is a necessary but not sufficient condition for successful institutionalization; both processes should be well integrated.
- Prototype DSSs should be considered during the design, development and delivery phases.
- Providing DSSs requires textual and document-based information sources capabilities, which should be reflected in the organizational design.
- Recurring decisions related to certain issues need to be monitored through a management system to track changes in the critical parameters of these issues.
- Successful design and delivery of DSSs is based on top management support during implementation and organizational support during institutionalization.
- Evaluation and assessment of DSSs is a vital process that should accompany all phases of implementation and institutionalization to realize online response to changes occurring in the environment.
- Continuous multilevel training of human resources leads to the adaptation, diffusion, and adoption of decision support systems within various organizations.

a range of sectors and on the experience of IDSC, Table 4 includes a set of lessons learnt that could be generalized to the design and implementation of DSSs in similar developing nations. These lessons are relevant for future research with the continuing emergence of innovative ICT platforms, leading to the emergence of a variety of electronic decision support systems for private- and public-sector issues and projects.

## 6 Conclusion

To conclude, the experience of this new form of information-based organization in Egypt led to the improvement of the decision-making process at the cabinet level, supported the socioeconomic development programs, and helped better allocate the available resources. IDSC has been a catalyst for ICT transfer, introduction, use, adoption, diffusion, and adaptation over the last two decades in Egypt. It has enabled an environment that facilitates the transformation of Egypt towards a digitally ready society. Moreover, it has helped raise awareness at the highest policy levels of the importance of ICT as a platform for business and socioeconomic development, which not only led to the improvement of the decision-making process but also to better resource allocation. More importantly, the process highlighted the growing importance of ICT to the growth of the economy, which led to the establishment of MCIT to help position Egypt in the global information society map. The base-building phase of the IDSC during the 1980s and 1990s involved moving to a new phase of spreading the use of ICT throughout the community at large during the 21st century and not just to policy makers. This role was carried out by MCIT based on the work and achievements of IDSC in the earlier phases. The benefits of the learning experience and the development of the phases was felt through the spread of ICT awareness and use among rural and underprivileged groups in Egypt, which again was based on the prior work done as part of the GIDSC project.

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## Terms

**Building blocks:** the critical success factors of the information technology industry and that include hardware, software, human resources humanware, networking and information.

**Crisis management:** situations where policy makers at the government and public sector level are required to take decisions given scare resources and provided with limited time to formulate and make decisions regarding specific socioeconomic issues.

**Diffusion of information technology:** reflects the spreading of information technology concepts among the society of implementation whether within an organization or the community at large.

**Government-private sector partnership:** explains the teaming of different entities in the government and the private sector to realize a change or transformation in the development of information technology at large and specifically in the software industry.

**Governorate:** Egypt has 27 governorates which represent the local administrations on the nation,. Like provinces, each governorate has a capital and consists of a number of towns and hundreds of villages.

**GIDSC:** the model governorate information and decision support center located in each of Egypt's governorates to support the governors in his decision-making process through the provision of timely and accurate information support.

**Humanware:** the most important aspect and building block in the information and communication technology infrastructure: human resources.

**IDC:** the information and documentation center located in each governorate and responsible for the streamlining of information collection, analysis, and dissemination methodologies and techniques.

**Informatics projects:** projects that involve in any way the use, design, delivery, implementation, and management of information technology irrespective of the element involved, including software, hardware, etc.

**IDSC:** the federal information and decision support center located at the cabinet level to support top policy makers in their decision-making processes through the provision of timely and accurate macro-level information compiled through the inputs of various model GIDSC.

**Issue-based DSS:** the decision-making process that relates to complex, ill-structured, interdependent and multisectoral issues with strategic impacts at the national, regiona,l and international levels.

**MCIT:** the ministry of communications and information technology, the government organization responsible for the introduction and diffusion of state-of-the-art information and communication technology as well as setting the policies and procedures needed to render the community in Egypt digitally ready to benefit from the global information society.

# CHAPTER 63
# Evolution of Knowledge Management Towards Enterprise Decision Support: The Case of KPMG

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Realizing that knowledge and its proper management are essential for effective decision support, this chapter traces the evolution of knowledge management within a major professional services firm – KPMG. By supporting decision making, computer-based systems for managing knowledge can impact organizational performance and the very nature of the organization itself. Here, we examine a progression of knowledge management systems at KPMG, beginning with the 1997 condition of having disparate or no knowledge management systems and culminating with an enterprise-wide integrated system accommodating both locally and globally managed knowledge. This chapter investigates why KPMG pursued the development and implementation of a global knowledge management system. Strategically, knowledge-management advances were used to transform the firm from a confederation of local enterprises to a global enterprise. In addition, it summarizes some of the key capabilities and technologies of the resulting knowledge management system, K-World. This chapter also examines some key implementation issues. Finally, the chapter investigates two key problems emerging from the use of the system after its introduction: search and client confidentiality, plus some of the emerging extensions for K-World.

**Keywords:** Enterprise decision support; Knowledge management system; K-World; KPMG; Professional services; Evolution; Global Knowledge Management; Global DSS

"We are at the vanguard and will leap our competition." Michael Turillo

## 1 Introduction

In the early to mid 1980s, KPMG developed a unique vision of knowledge management captured in their concept of a shadow partner (Gladstone and Eccles 1995). Supporting clients was not just a job for people but one that required integration of human and computer activity. KPMG needed to integrate and evolve their knowledge management system to support their decision needs.

Unfortunately, that vision was not executed at the time, and KPMG went from one limited knowledge management system (K-Man) to 64 country-specific disparate systems (e. g., K-Web), until they finally developed an integrated system with locally and globally managed knowledge. Called K-World, its implementation was so successful at integrating the system into their professionals' work that, shortly after its implementation, there was an interest in taking K-World public as its own company: Cering. However, the initial public offering environment changed, and this did not occur. Although ultimately the implementation went well, there were some emerging potential issues associated with client confidentiality and search, plus some system implementation issues.

This chapter is a case study of the evolution of knowledge management within a professional services firm (KPMG) and some of the problems that it faced, including designing, implementing, and using a system for supporting decision making of their professionals. We examine how knowledge management technology has been used within KPMG to facilitate the transformation from localized collaboration to global collaboration capabilities, and why such a system might be spun off to be its own company. In so doing, we analyze the key capabilities of such systems and some potential problems. KPMG knowledge management efforts are reviewed across the time period of roughly 1986 to 2006, with a detailed focus on 1997 to 2006.

This chapter brings up-to-date the well known case "KPMG Peat Marwick: The Shadow Partner," (Gladstone and Eccles 1991) and "KPMG Peat Marwick U.S.: One Giant Brain" (Alavi 1997). The later case study stops in 1997, just before KPMG dropped Netscape's browser from its design. This chapter includes some additional background information relating to both of the earlier cases and progress towards the current knowledge management system, K-World, and the firm's analysis of spinning off K-World as an initial public offering (IPO).

This case is a longitudinal study examining a single professional services firm, KPMG, using two methodologies: a field study and archival research. KPMG's ultimate use of knowledge management is traced through multiple technologies across time and organizational issues. The field study was unstructured, involving interviews to gather and detail information from KPMG knowledge management personnel, including Robert Elliott (a partner who developed original vision of the shadow partner), Robert Zeibig (principal in charge of global knowledge management), Bernard Avishai (international director of intellectual capital), and Michael Turillo (managing partner, knowledge management, international chief knowledge officer). Additional information was gathered from users of the KPMG knowledge management systems. Archival information was gathered from published and Internet sources, including a speech by Bill Gates, KPMG presentations, various publications, news releases, and press articles.

Evolution of decision support and knowledge management systems is an emerging area that is gathering increased attention. O'Leary (2007a) provides a survey of issues that relate to predicting, facilitating, and managing the evolution of knowledge management systems. O'Leary (2007b) provides an empirical investigation of the evolution of a knowledge management taxonomy over time. This paper provides a detailed example of the evolution of a system to illustrate and provide specificity to some of the concepts discussed in those and other papers.

The chapter is organized as follows. Section 2 discusses the importance of knowledge management to professional services firms, including an analysis of the pre-1997 knowledge management efforts of both KPMG and other large professional services firms. Section 3 investigates KPMG's initial efforts into web-based knowledge management in 1997 and the resulting disparate systems. Section 4 summarizes the reasons KPMG needed to have a global knowledge management system, including the potential loss of whole countries of offices. Section 5 describes capabilities of K-World, a knowledge management system built in response to the needs discussed in section 4. Section 5 also lays out the basic capabilities and architecture of K-World. Section 6 discusses the proposed spin-off of the knowledge management group and the capabilities of the new firm, while Section 7 briefly summarizes the new company and its product. Section 8 analyzes the decision to drop the notion of an IPO. Section 9 investigates important emerging issues, those of search and client confidentiality, and system extensions. Section 10 briefly summarizes the chapter.

## 2 How Important is Knowledge Management for Professional Service Firms?

Knowledge management and the corresponding collaboration that it facilitates are critical, and provide a core value for professional services firms. For example, as noted in Foley (1996), Allen Frank, former chief technology officer for KPMG who left KPMG in May 1997, explained,

> "We're basically a giant brain. For us the knowledge management environment is the core system to achieve competitive advantage."

Similarly, as noted by Ellen Knapp, former vice chairman at Coopers and Lybrand, "all our assets are knowledge assets." Further, as noted by Frank (Netscape 1997), "At KPMG, our best asset is the knowledge that resides with each of our professionals. With 18,000 employees in the U.S. alone, distributed across 120 offices, it's imperative that we share this knowledge to provide the best service possible to our clients."

Although the notion of a professional services firm being a giant brain is arguable, it is clear that professional services firms see the importance of knowledge management: *the need to be able to share knowledge to support professionals' decision making*; *and the fact that the primary asset professional services firms have is in the knowledge they can bring to clients*. We might view the function of such a firm as being a joint human-computer system ultimately supporting their clients. For it to be successful at this, KPMG went through an evolution toward providing integrated decision support system for its professionals in support of their clients. At the outset, KPMG had limited systems ability to facilitate knowledge distribution across the firm. Instead, knowledge was locked into pockets limited by geographical boundaries, personal relationships, and limited system capabilities and integration.

## 2.1 KPMG's Early Knowledge Management Efforts

KPMG is a professional services firm, one of the so-called Big Four – formerly the Big Six and then the Big Five (the largest professional services firms now also include Ernst and Young, Deloitte and Touche and PriceWaterhouseCoopers – formerly Price Waterhouse and Coopers and Lybrand). KPMG was one of the first of the professional services firms to explore using technology to facilitate knowledge management in the classic case study "KPMG Peat Marwick: Shadow Partner" (Gladstone and Eccles 1995).

In the early 1980s Robert Elliott, a partner with KPMG, developed the vision of a shadow partner. This computer version of a partner would provide decision, knowledge, and administrative support to KPMG partners. As discussed in Gladstone and Eccles (1995), the shadow partner could have a range of capabilities designed to support their professionals, including;

- monitor news feeds for information relevant to clients, and then notify the partner of the activity
- provide access to libraries of previous engagements and proposals
- provide access to information about staff that perform particular types of engagements
- allow access to mailing lists of experts within particular areas
- provide access to project information for those projects where the partner is in-charge
- provide calendaring
- provide online training
- provide access to information about various key client personnel, and who knows them.

In 1986 a committee was formed at KPMG to advise on the adoption of a system to facilitate communication, coordination, and collaboration. In 1989, proposals for the shadow partner knowledge management system were presented to KPMG partners at meetings in both the U.S. and Europe.

In October 1990, Jon Madonna was elected chief executive officer (CEO). It was not until April 1991 that Madonna met with Elliott about the shadow partner concept, possibly suggesting a limited interest in the concept. In 1991, KPMG was faced with potentially implementing the system at different levels of costs ranging from $30 million to $100 million. However, rather than implement the shadow partner concept, from 1989 to 1991, a specific department, KPMG Consulting, implemented a system referred to as K-Man using First Class (Siboni 1997). From 1994 to 1995, K-Man was diffused throughout the rest of the firm (Siboni 1997). At the time of implementation, First Class provided relatively limited capabilities beyond proprietary e-mail. Although information could be stored in folders, there were limited search capabilities. For example, the primary means of categorizing information for search was through eight-character folder and file names. As a result, rather than having a shadow partner by the beginning of 1996, KPMG had K-Man, an instantiation of First Class, a commercial e-mail package that would provide only limited support for their professionals.

Madonna remained CEO until October 1996, when Colin Sharmin replaced him. Steve Butler was elected KPMG LLP USA CEO and Roger Siboni was elected as the new USA chief operating officer (COO) in October 1996. In 1999 Butler replaced Sharmin as Chairman. Paul Reilly was CEO at the international firm from October 1998 to May 2001. In May 2002 Michael Rake took over has chairman. 2002 Eugene O'Kelly took over as CEO of KPMG LLP USA, until 2004. It would be after October 1996 that extensive knowledge management support would be built at KPMG.

## 2.2 Knowledge Management at the Rest of the Professional Services Firms

By 1996, virtually all of the other Big Six professional services firms had substantial knowledge management systems, typically implemented using Lotus Notes, but increasingly implemented in an Internet and Web environment. Price Waterhouse had been the first in 1989 (Mehler 1992). Arthur Andersen followed closely behind and was the first to move onto the Internet with Knowledgespace.com. Shortly after, Ernst and Young focused heavily on knowledge management, ultimately developing one of the more-sophisticated systems among the professional services firms (Svary and Chard 1997). Coopers and Lybrand implemented Lotus Notes in 1994 (Lotus Press Release, January 4, 1994). Furthermore, Coopers and Lybrand's had been rated one of the most 25 innovative intranets (Information Week 1997). Price Waterhouse and Coopers and Lybrand later merged to create PriceWaterhouseCoopers. Deloitte and Touche implemented Lotus Notes in 1995. In late 1996, Banks (1996) singled out Ernst and Young, Coopers and Lybrand, and Arthur Andersen as being the leading professional services firms in terms of knowledge management. During the period 1998–2000, Andersen, Ernst and Young, and PriceWaterhouseCoopers each finished in the top 20 of the most admired knowledge enterprises in a survey of the leading knowledge management firms in the world (Chase 2001). However, KPMG was not in the top 20 in any of those years.

Research into knowledge management at professional service firms has continued with a number of case studies. KPMG was the focus of two studies, one involving the original vision (Gladstone and Eccles 1995) and the other looking at an early version of their knowledge management system (Alavi 1997). Andersen Consulting, which became known as Accenture, was also the focus of three case studies about their knowledge management system (Savary and Chard 1997, Davenport and Hansen 2002, Meister and Davenport 2005). Ernst and Young, and then later Cap Gemini Ernst and Young, were also a focus of later case studies (Lara et al. 2004).

## 3 K-Web, D-Web, U-Know, …

In the United States, according to Roger Siboni (1997), the notion of a web-based collaborative knowledge management system at KPMG, dubbed K-Web, was introduced in 1994 as a concept and piloted in 1996 using Netscape as the basis for the system. Elliott (1997) dubbed Siboni's (1997) presentation as the solution to the classic shadow partner case (Gladstone and Eccles 1995). After Siboni took over as COO in October 1996, KPMG began the implementation of web-based technology for knowledge management purposes.

In January of 1997, KPMG in the U.S. decided to build K-Web using Netscape's Communicator and Suitespot (Netscape 1997), "… to increase internal collaboration as part of an enhanced knowledge sharing environment." As originally designed (Netscape 1997),

> "… K-Web, project team members will be able to work on shared documents as well as send and receive Web-based mail messages, extend discussions to their partners and clients, and ultimately automate business processes. KPMG is planning to use K-Web to hold town hall meetings over the Intranet, engage in sophisticated chat sessions and to make it easier for KPMG professionals to locate colleagues. K-Web will also serve as the front end for accessing information in legacy databases internally about particular KPMG clients and projects."

However, during the middle of their knowledge management system implementation, in July 1997, KPMG chose to drop Netscape and adopt Microsoft products at the same time that an alliance with Microsoft was announced. This action apparently ended up as part of a legal case against Microsoft (U.S. Department of Justice 1998).

This delay stalled KPMG knowledge management efforts, but also made the point that choosing Microsoft technology had additional benefits beyond the knowledge management system. As noted in KPMG (1999b) by Charles Stevens, vice president of the application developers' customer unit at Microsoft, "KPMG will be able to assist their clients in developing and implementing their own knowledge management system based on the Microsoft platform." As a result, the choice of knowledge management technology is more than meeting internal requirements and supporting professionals' decisions. It can be a function of alliances with other purposes.

As it turns out, in addition to forming an alliance with Microsoft, KPMG (1999b) was one of the first five firms to "… embark on its fast track program to fully exploit the power of the Web browser, integrate Microsoft-based messaging, collaboration and knowledge-sharing applications …"

At roughly this time, KPMG Germany began developing D-Web (D for Deutsch), and KPMG in the U.K. was developing U-Know (U for United Kingdom). Similar efforts took place in KPMG offices in other countries, including, Canada, The Netherlands, Australia, and South Africa. As with K-Web in the

United States, each of these efforts was designed to leverage web technology into knowledge management. However, users in one country were generally unable to access the knowledge management systems in other countries. For example, KPMG users in Canada were unable to use K-Web in the United States. KPMG had a disparate set of knowledge management systems. In still other countries there was no digital knowledge management. Systems could not communicate or there were no systems available. Accordingly, at the time, KPMG did not have a true global knowledge management system. Systems met some support needs but did not integrate systems. Effectively, decision support was still geographically limited.

# 4 Was There a Need for a Globally Integrated Knowledge Management System?

Accordingly, by the end of 1997, KPMG did not have a globally integrated knowledge management system. Instead, different countries were pursuing their own systems. According to Boom (2004) there were 64 different intranets scattered throughout the company. In addition, at this time the decision-making focus of professionals and support of those decisions was largely local. For example, Boom (2000) noted the following quotes from KPMG interviews at the time:

- “I only work with local clients”
- “Why change, we already have a legacy system”
- “There are too many cultures in KPMG” (for a global system)

This raises the question: Was there a need for a globally integrated knowledge management system? Starting at the end of 1997, at least four factors appeared to drive the need for KPMG to pursue a globally integrated knowledge management system to support professionals’ decisions: competition, a need to collaborate for the larger engagements and more-profitable engagements, keeping the firm together, and decreasing costs.

## 4.1 Competition

In October 1997, a merger was announced between KPMG and Ernst and Young (Ernst and Young and KPMG 1997), although it never took place. Zeibig (2000) indicated that, as part of the merger activities, KPMG and Ernst and Young were made aware of each other’s knowledge management systems. In February 1998, after the failed merger between KPMG and Ernst and Young, KPMG’s international chairman noted (MacDonald and Lublin 1998), “Going into the merger our perception of Ernst and Young was that they were ahead of us in knowledge-management systems and communications. Our discussions confirmed that.” Human-system integration and decision support for professionals lagged at KPMG compared to Ernst and Young.

## 4.2 Globalization: Larger, More-Profitable Engagements

One of the driving forces for K-World implementation was the need to globalize and move to larger engagements. According to Zeibig (2000), the largest engagements were global and these had the highest profit margin. These engagements required coordination of collaboration across multiple countries using knowledge management. Unfortunately, during 1998 and the beginning of 1999 (Turillo 2001), KPMG was global in appearance, but not in reality. Different cultures, business cultures, and languages stood in the way of being a global firm. Competing for a large audit client forced KPMG to realize that their knowledge management system needed to have global support capabilities.

Decision support for professionals needed to be integrated across geographic boundaries. Unfortunately, the independent knowledge management systems in each country did not facilitate the ability to mobilize resources on a global basis. In fact, disparate systems stood in the way. Although KPMG had offices around the world, the independent knowledge management systems made it impossible for their professionals to fully collaborate. However, competing for the high-margin engagements required a knowledge management system that would allow the firm to collaborate globally across its many offices.

## 4.3 Keeping the Firm Together

More than just profitability was at stake. Collaborating on engagements influenced the ability to keep clients and firm members. As noted in the Wall Street Journal (May 27, 1999), "Last month, top partners at KPMG Canada threatened to defect to Arthur Andersen, citing as one of their reasons the difficulty in serving multinational clients due to KPMG's unintegrated systems." The future of KPMG was dependent on globally linking the firm's different offices and their knowledge management systems. Without an integrated system the future of the firm as a single, independent entity was threatened.

## 4.4 Redundant Information and Systems, and Extra Costs

Furthermore, according to Bill Gates (1999a), during 1998 there were substantial knowledge resources and software redundancies, resulting in extra costs. For example, dozens of offices were buying the same information and there were three e-mail systems. Further, according to Turillo (Grzanka 1999), KPMG used 13 different messaging systems, six different knowledge management systems, and multiple human resources, finance, and payroll systems on at least six different operating systems. Driving down costs would require system integration and the elimination of redundancy.

## 4.5 Local Materials and Control

Although there was a need for a global system, there remained tensions for the ability of different countries to add and control their own materials. For example, because accounting and audit principles differ from country to country, auditors in one country are likely to need daily access to different materials than auditors in other countries. Some decision support needs varied. Furthermore, the rate of change of those materials is likely to differ. Accordingly, there was tension between the need for a global system and global resources, versus a local system and local resources. As a result, individual countries and other organizational units maintained the ability to add materials and servers to K-World.

# 5 K-World

In the middle of 1998, Siboni left KPMG (Abate 1998). That also seemed to be the end of K-Web as the solution to the shadow partner case. However, it was also becoming clear that it was important for KPMG to mobilize resources on a global basis to meet the competition and procure the more-profitable engagements. Integrated decision support for professionals was necessary for more-profitable engagements.

As a result, in part of an announcement indicating that KPMG would be combining firms in the Americas and Europe to form regions as a basis to serve global clients in a worldwide consolidation, Stephen Butler, former CEO and chairperson, also announced the advent of K-World, indicating that (KPMG 1998)

> "Being global means being capable of accessing the same information at the same time, regardless of whether you're in New York or New Delhi … This knowledge management system is transforming KPMG's embedded intellectual capital into a global strategic asset – and it's enhancing KPMG's ability to collaborate with other organizations, irrespective of their messaging environments. A single knowledge repository allows us to access global sources of information, limit redundant information searches, and streamline the development of client deliverables anywhere."

K-World was seen as more than just knowledge management. Its global decision support would be an enabler for a new organization structure, and it would allow the firm to be able to compete for the more-profitable engagements. As a result, K-World led to a change in the priorities of the firm. Former chief executive Paul Reilly called K-World (Cone 1999) "the No. 1 priority of the global firm."

On June 9, 1999, KPMG began the roll out of K-World to the United States, United Kingdom, Germany, and The Netherlands (KPMG 1999b). It also announced that K-World would be deployed to Canada, Australia, Sweden, and Switzerland. By August 2000, all KPMG users had been brought into the system. By 2001 many of the disparate legacy systems had been shut down (Boom 2004).

## 5.1 Capabilities

The vision of a shadow partner was being actualized in K-World. According to Gates (1999a), K-World was designed to connect and support KPMG's 93,000 people worldwide, in order to provide a corporate memory for collaboration (Gates 1999a):

> "The consulting companies have really seen that this is a key area for them to try to jump onto first, because they have a variety of engagements all over the world with different kinds of industries. … [T]hey'd like to share the learning that has gone on."

One of the key themes to illustrate the concepts associated with the original shadow partner case was how the system could be used to facilitate the merger of a client. In order to test K-World, this scenario was used to examine the existence of time economies associated with using the system (Management Consultancy 2000). As noted by Gates 1999b

> "… the ability to pull together all key members of the global team in order to make decisions and recommendations. What would have taken 80 hours in the past took only one hour in a test and resulted in a smarter firm with a deeper understanding of customer needs."

K-World's design was aimed at facilitating collaborative communities of practice. As noted by Michael Turillo, KPMG's chief knowledge officer,

> "Knowledge is content in context and our global communities of practice – who marry knowledge about complex services to specific industries – determine K-World's contextual frames. K-World brings qualified internal content and filtered external content to each community …"

Ultimately, K-World has been designed with a wide range of resources to support the professional's efforts. For example, as noted by Trotman (2003), K-World resources include access to company financial statements, audit engagement tools (such as financial disclosure checklists), and training materials. Professionals can employ those materials to support their own and collaborative decision making.

### Interaction with Clients

K-World was designed for internal KPMG use. However, there also was a need to integrate decision support with clients. KPMG professionals and clients needed to generate and access some of the same materials. Thus, KPMG needed a collaboration tool through the internet.

Accordingly, in 2000 K-Client was deployed (Boom 2000). K-Client was designed to facilitate communication and collaboration within globally deployed KPMG teams and with clients. K-Client provides workflow management capabilities, and the ability to gather and organize large amounts of information from a wide range of sources. While K-World was designed for internal use, K-Client was designed for internal and client interaction.

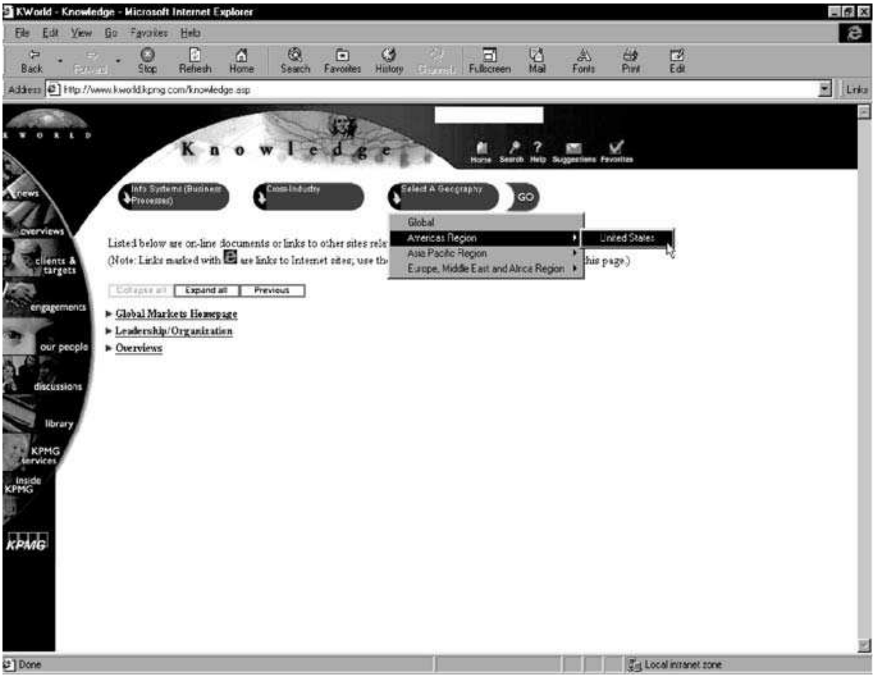


**Figure 1.** Sample screen

### Knowledge Architecture

Information in K-World is categorized based on a hierarchical taxonomy to support professionals' decision making. According to Boom (2000) the design was aimed to "let people use the Global Taxonomy to find solutions from other cultures." See Figure 1 for a sample screen.

The taxonomy had three dimensions: product, industry segment, and geography, mirroring the firm's organization structure. For example, at the highest level there is product information, industry segment information, or geography information. Under "product", the user might choose "assurance," and under assurance, the user might choose "advisory services," and so forth. Under industry, the user might select "global industry groups." Information also is categorized by news, clients, library, and other categories.

## 5.2 Technology for K-World

The importance of the underlying technology for K-World was echoed by Turillo, in a statement that ended up generating some controversy in the knowledge management community (Hildebrand 1999): "Knowledge management cannot be done without technology." White (1999) describes a design of the global network infrastructure for K-World, labeled K-Net.

KPMG had decided to use Netscape during Allen Frank's tenure as chief technology officer. However, although KPMG had been using Netscape prior to the time of K-World's development, K-World was based on Microsoft products (Kane 1997), which linked countries together using the Internet (KPMG 1998). Shortly after that decision, Netscape was criticized for failing to make inroads among the Fortune 1000 (Bowman 1997).

On the other hand, some questioned Microsoft's ability to provide the software and the know-how for knowledge management (Johnston and Davis 1999). As noted by an analyst at Meta Group, David Yockelson, (Johnson and Davis 1999), "While there is not one platform to tackle knowledge management, Lotus (Notes) does have many of the piece-parts you might desire, and Microsoft doesn't. Microsoft has things on an agenda, which is to come up with those piece-parts and also be a platform provider to third parties who will come up with piece-parts."

KPMG used a number of third-party products to piece together the technology for K-World. For example, in addition to Windows NT Server, SQL Server, Exchange, Site Server, Outlook, Office, and Internet Explorer, KPMG also include collaboration software from Silknet Software, portal software from Sageware, other software and services from Razorfish, and NewsEdge news solutions (NewsEdge 2000).

As noted by Yokelson (Johnston and Davis 1999), "One could argue that having to put the pieces together isn't the best thing." However, that piecing together process is where additional value was created by KPMG's knowledge management group.

## 5.3 People and Costs

Knowledge management with a system like K-World can require substantial human resources. As a result, knowledge management efforts resulted in a shift of personnel from other functions in order to facilitate the system introduction. With K-World, there was a shift in the function of personnel from a library department to a knowledge management department (e. g., Boom 2000).

Boom (2000, 2004) notes that there was a knowledge management staff in The Netherlands throughout the time frame 2000–2004. In 2002, after K-World was largely implemented there were about 40 people in the U.K. knowledge management group (Autonomy 2002). Ultimately, Turillo's development and implementation of K-World with a team of 55 developers (Flash 2001a) took place in the Boston office, over a period of two and a half years. At the same time, there also were 15 full-time knowledge editors in the New York office, charged with capturing knowledge from published papers, books, speeches, and magazine articles (Glasser 1999).

The capabilities provided by K-World did not come inexpensively, and probably not surprisingly apparently exceeded the original shadow partner estimates. Ultimately, in just the first five months of 1998, KPMG spent over $40 million on the knowledge management initiative (Glasser 1999). Further, as noted in the Wall Street Journal (May 27, 1999),

> "Worried about partner defections, Big Five accounting and consulting firm KPMG International said it will spend $100 million to more fully tie together its world-wide computer systems.
> … KPMG's attempt to develop a new global "digital nervous system" marks the first time that the firm has devoted such a large amount of money to a computer overhaul.
> KPMG typically spends $50 million a year on upgrading its computers."

KPMG indicated that they planned to spend more than $400 million on K-World through 2002 (Cone 1999). The first $10 million was for designing the technical architecture. $100 million was for the first year, and $115 million was for the second year. Yearly expenditures were planned to level out to about $80 million per year by 2002. External content purchases were planned at roughly $20 million per year.

## 5.4 Implementation

One of the first implementation concerns was the notion that K-World was focused too much on or about the United States. For example, as noted in Boom (2000) at the time of the implementation some typical comments included:

- "There is only U.S.-based information on K-World."
- "K-World is U.S. driven."

This was a potential problem because of cultural differences between offices in different countries summarized in Figure 2 (generated by KPMG, Boom 2000).

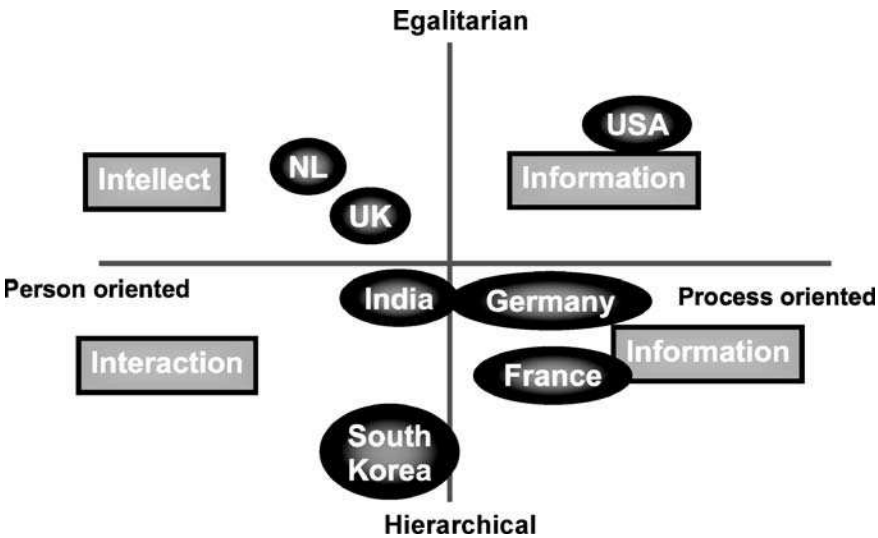


**Figure 2.** Country dimensions of knowledge (Boom 2000)

When cast along two dimensions of equalitarian versus hierarchical and person versus process, countries laid out in different quadrants. Based on this two-dimensional diagram, the complaint against a U.S.-driven system would result in a system that was more focused on processes than people, and less hierarchical than other settings. A K-World that was focused on one quadrant potentially would not be well-received in a global firm. Somehow implementation would need to accommodate or mitigate potential differences.

## Cultural Transformation

Accordingly, a number of steps were taken to transform the culture and facilitate system evolution (Boom 2000). First, the technological structure allowed professionals to communicate with each other and learn about corresponding views. Second, professionals were trained to use, and trained in the benefits of, globally used best practices, but adapted to meet local needs. In addition, there also was training in other-culture awareness. Third, the system allowed knowledge capture in each different geographic area. This allowed professionals to find solutions from other countries and cultures. Fourth, the system was built to allow multiple languages. As a result, they could put solutions in their own context. Finally, an international content acquisition workgroup was found to try to ensure that appropriate international resources were built into the system to support decision making (Bloom 2004).

Ultimately, a three-phase cultural transformation model was planned (Figure 3), which included adoption, loyalty, and collaboration phases (Boom 2000). The

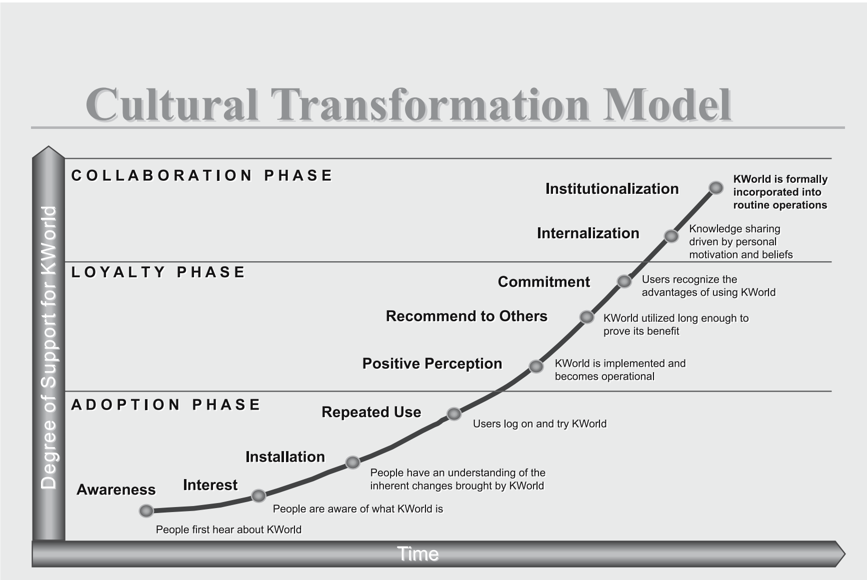


**Figure 3.** K-World cultural transformation (Boom 2000)

planned cultural transformation for K-World, started with awareness, moved to loyalty, and finished with institutionalization.

The cultural transformation model paralleled the system development and evolution. At the awareness and interest states in the *adoption phase* only basic design information, and possibly a prototype, is necessary. In order to progress to the installation and repeated use states, an existing system with sufficient resources to draw the users back is necessary. In the *loyalty phase*, in order to obtain positive perception, the implemented system must be operational, providing integration across multiple countries in order to obtain global benefits. For users to recommend to others, there generally needs to be greater benefits than the existing legacy systems. In the *collaboration phase*, links to multiple countries and client capabilities need to be established to realize global capabilities that ultimately would facilitate internalization, and ultimately institutionalization, where K-World becomes integrated into the fabric of the firm.

### Technology-Enabled Implementation

KPMG apparently also used a technology-enabled (e. g., O'Leary 2000) approach to facilitate change. As noted by Colin Sharman, former chairman of KPMG (White 1999), "KPMG is globalizing and K-World … is both the product and the catalyst for this transformation." Technology was being used to drive the implementation across multiple geographic locations. Technology-enabled approaches are often used to drive change in global organizations, in part, because the focus is on the need for technology similarities rather than cultural differences. The focus on technologies appears to minimize the apparent impact of some of the cultural differences.

### Local Differences

Further, each individual country's systems (e. g., U-Know) and office systems (e. g., specific cities) still held local information. English is used at the global level; however, a country's specific language could be used at the local and office level. In addition, individual business units can have their own servers, which facilitate capture and presentation of unit specific knowledge. Both the individual and business-specific servers were connected to the same infrastructure that was K-World.

Local knowledge remains outside the control of K-World. It is administered and created locally. Online countries appoint local content managers who are responsible for adding knowledge (Power 2000a). Local knowledge is not necessarily globally indexed within the K-World taxonomy. However, as noted by one user, "in general, the first place I look is (locally)." Further, as noted by another user, "With our (business-specific server) we have all the knowledge I use, plus we have links to all the important K-World knowledge." K-World provides the infrastructure and link point to a wide range of other knowledge sources. As a result, knowledge could remain local, but was globally accessible.

### 5.5 Quality of K-World (Chase 2001)

By 2001, the quality of K-World had become apparent. In June 2001, a poll of knowledge management experts was made to determine the most admired knowledge enterprises. Four of the Big Five were named among the 37 finalists: Andersen, Ernst and Young, PriceWaterhouseCoopers, and KPMG. KPMG finished 13th, behind Ernst and Young at 12th and Andersen at 11th. At the time KPMG's global chief knowledge officer noted that "Knowledge sharing is a core value in KPMG and underpins our current and future ability to serve our clients worldwide."

## 6 Spinning Off K-World (Turillo 2001)

In November 2000, Merrill Lynch put together a report on a potential new firm, Cering, whereby KPMG would spin-off K-World. K-World had a number of investors, including Microsoft, that were providing venture capital to support the spin-off. Michael Turillo, Partner-in-Charge of knowledge management (and K-World), would be the new CEO of the emerging company (Flash 2001a). Why was KPMG going to spin-off K-World? Turillo explained that it was a function of costs, client interests, Securities and Exchange Commission (SEC) constraints, emerging technology capabilities, a desire for return on investment, and a lack of fit with KPMG Consulting Incorporated (KCI).

### 6.1 Costs

The K-World cost per user had been higher than was expected. Further, because all users were now on the system, there were no other users to drive down the cost per user. In addition, maintaining the position of the system on the technology curve required additional spending and maintenance. Otherwise, there would be the unintended consequence of slipping back to where the firm had been prior to K-World. As a result, another way of generating additional funding was required.

### 6.2 Clients Wanted It

After Bill Gates (1999a and 1999b) mentioned the system at the CEO Summit in 1999, a number of KPMG clients became interested in the system and wanted to have the system capabilities. They recognized that the system offered more than they had in their own knowledge management systems. In addition, Flash (2001b) noted that after KPMG started using K-World internally, they had hooked some clients to the portal. KPMG had created an asset.

The director of knowledge technologies at International Data Corporation felt that K-World could provide links to clients (Grzanka 1999): “Today it is an internal capability with potential for leveraging out to customers. Over the long term, it can form the basis of an electronic umbilical cord.”

However, because of KPMG’s work in assurance, the SEC limited the work that KPMG could do to implement knowledge management systems, and their ability to provide knowledge management to clients.

## 6.3 A Way to Further Exploit Emerging Technology

K-World was built to meet the current requirements of KPMG, which did not include mobile computing capabilities. However, recent developments in technology suggested that mobile computing be built into the system and more fully leveraged. Breaking away from KPMG would provide resources that would allow the knowledge management group the ability to provide mobile computing-based knowledge management as part of a continued evolution of K-World.

## 6.4 After Spending Millions, KPMG Asked “Can We Get a Return on Investment (ROI)?”

KPMG had put millions of dollars into this system. Unfortunately, knowledge management is often seen as an overhead. Costs can be readily seen, but it may be hard to trace specific revenues generated by using the system. One approach to potentially realizing return on investment was to spin it off as its own company, particularly in the IPO environment of the times. As an IPO, K-World could generate substantial additional funds and not increase costs.

## 6.5 Why Not Make It Part of KCI (KPMG Consulting)?

An alternative approach was to make the knowledge management group and K-World part of KCI. However, there were at least three reasons for not making it a part of KCI:

- KCI defined its space as the systems integrator and e-business spaces. Knowledge management is not even in the top 10 of KCI business issues.
- In 2000, KCI was spun off as part of an IPO (KPMG 2000a). KPMG did not want there to be any distractions for the spin-off. In any IPO, there is a need for focus. Worrying about K-World would detract from that focus.
- Finally, KPMG knowledge management used an approach that minimizes the need for consulting, so there was no real need for KCI.

In addition, KPMG spent two years taking KCI public, an experience that could be used to take the knowledge management group public. Ultimately, KCI went public under the name BearingPoint (http://www.bearingpoint.com/), but it did not include the knowledge management group.

# 7 The New Company and Product (Avishai 2001)

Cering, the new company, would focus on providing a system that consisted of products from 20 vendors, and devote its attention to knowledge management across four basic dimensions, including an enterprise portal, collaboration/messaging, business intelligence, and knowledge management consulting.

The target customer would be a company that wanted a solution to its knowledge management problems, but is either unwilling or unable to integrate the products to get that solution. As noted by Avishai, "We are like a 'fund manager,' we look for the best vendor, and swap technologies in and out. We deliver a Rolls Royce off the shelf. Alternatively, if a company is interested, we could take a role as an application service provider."

## 7.1 Taxonomy

One of the key knowledge management issues is the taxonomy used to categorize knowledge in the system as a basis for search and other purposes. KPMG's knowledge management group found that about 30% of a company's taxonomy may take customization, and 70% is part of the emerging general language of business. For a given business, it can take two to three months to construct the taxonomy. In addition, the taxonomy needs to be revisited every three to five months to bring the taxonomy up-to-date. As a result, development time, costs and maintenance can be substantial.

Ultimately, the K-World taxonomy reflects the organization structure and view of the world in which KPMG does business. As noted by Power (2000b), the taxonomy is managed by KPMG's director of intellectual capital and is based on an agreed view of the business, its locations, and the functions and industries in which it operates. The importance of the taxonomy is that it forms the basis of search in K-World, rather than using single-search, single-request enquiries (Power 2000b). The issue of the taxonomy and search is discussed further in section 9.

## 7.2 Merrill Lynch Report

According to Flash (2001b), Merrill Lynch, praised the potential leadership of Cering in a November 2000 report saying, "[Cering] has the strongest management team we have seen, and in the end the story is the same. People, not technology, win the software game based on execution. We believe that Cering is well positioned to leverage its KPMG heritage to assume an early leadership role in the (enterprise portal) space."

## 8 Planned IPO for Cering Dropped

Knowledge management at professional services firms is expensive. The costs of being an early mover in 1991 with shadow partner were between $30 million and $100 million. The yearly costs of K-World were reportedly $100 million (or more), $50 million more than the normal level of expenses. The technology curve had moved and it would continue to move. As noted above, realizing the change in technology, KPMG sought to find a return on this overhead function, and planned to spin it off to be its own company.

In August 2000 (Southworth 2000), Rod McKay was named KPMG's chief knowledge officer. Later (Shoesmith 2001), McKay was quoted as being the global chief knowledge officer, an offshoot of his role as KPMG Canada's chief technology officer and chief knowledge officer. At the time of his appointment, McKay noted "Knowledge sharing is a core value within KPMG."

During the summer of 2001, KPMG decided not to pursue the Cering IPO plan. The environment for IPOs was substantially different than it had been earlier in 2000. Both Bernie Avishai and Michael Turillo left the firm. Robert Zeibig joined another part of KPMG.

In late August 2001, as part of a realignment of priorities within the organization, McKay announced that KPMG was laying off 50 members of the knowledge management group in the Boston office (Goodison 2001). As further noted by McKay (Goodison 2001), "The people affected are or were in the knowledge management activities of our firm, maintaining and developing informational databases – the application content that really supports our businesses throughout KPMG globally."

## 9 Emerging Issues

By 2002, after K-World's implementation and roll-out continued, the system was well received and largely complete, including shutting down some local legacy systems (e. g., Boom 2004). However, there were still some emerging issues and system extensions.

## 9.1 Search

Initially, searching was designed so that users would locate K-World resources by establishing a context using the taxonomy that would provide them with a list of items (KPMG 1999c). Context was set by three main parameters: product, business segment, and geography. By setting the context using those parameters, the basic matrix organizational structure of the firm would be built into the knowledge management system. Then, given specified parameters, there were additional content selectors that provided greater detail: news, overviews, clients and targets, engagements (active and completed), discussions, library, KPMG services, and inside KPMG (see Figure 4).

In a short period of time, the number of knowledge resources (document lists) became substantial, making searching difficult. For example, within the context established in Figure 4, how much material might be in technical resources or in tools and templates, and how might we search those resources? As a result, just as search was a defining issue in KPMG's K-Man system, where only documents in text format could be searched, searching emerged as a critical issue in K-World. Finding knowledge was difficult, unless you knew where to look and what to look for. At least four other reasons were behind emerging difficulties with search.

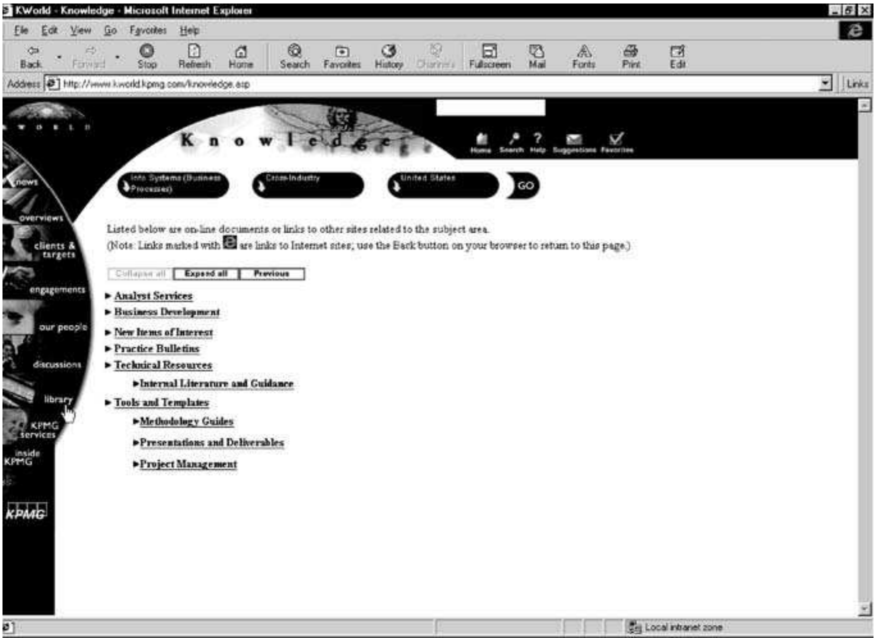


**Figure 4.** Search example

First, the existence of K-World increased the number and document types of postings. Now, it was not difficult technically to post materials. For example, as noted in Felt (2004), "there was a day when the U.K. intranet had a quarter of a million Web pages … (then) the business went into overdrive and anything that could go online went online — without any discipline." This had at least two consequences: The number and type of documents exploded. As a result, this complicated searching efforts, making the selection of knowledge from that set of resources even more difficult, leading to the next issue.

Second, the chief knowledge officer in the U.K. noted (Felt 2004) "Our users suffer from the same malaise that many Internet users suffer from — they are lazy in constructing queries. … They neither have the patience nor the time to sift through long result lists in order to find the information they need." Although searching was possible, it was not easy.

Third, if searching within a single country such as the U.K. was difficult, imagine when that search needed to broadened to multiple countries. As Turillo once noted (Glasser 1999) "KPMG was not so much a global company as it was a collection of geographically identified franchises." Unfortunately, this resulted in knowledge silos at KPMG (Raghavan 2001). The existence of those knowledge silos, coupled with decentralized resources and architecture, also made finding knowledge resources difficult.

Fourth, when KPMG initially adopted Microsoft Exchange, the K-World architecture called for the use of tagging documents for searching capabilities (e. g., KPMG 2000c). Further, as noted in Felt (2004) "We believe that you can't just automatically go around and auto-classify and auto-search and auto-understand everything without any effort at all … Having the ability to use domain expertise to instill discipline in our information environment yields enormous benefits." Unfortunately, manual tagging is costly and time consuming, and because it is manual, the quality is inevitably uneven.

Accordingly, because of the limited search capabilities, some countries in the KPMG federation of offices tried to develop solutions to improve the search of K-World. Because of the decentralized structure, different countries were in a position to pursue their own solutions. According to Felt (2004), the U.K. adopted its own technology solution to search – going with Verity. Autonomy (2002) indicated that KPMG in the U.K. was also pursuing the use of a recommendation engine that recognized the social networks that exist within a corporate online environment and automatically suggests documents and identifies the experts who have used them.

However, apparently other countries were free to try alternative approaches. Accordingly, global search still faced a number of limitations.

## 9.2 Client Information

One of the key potential problems associated with knowledge management systems in professional services firms is the potential lack of client confidentiality, and resulting misuse of client information. Ian McBride, KPMG Australia's chief knowledge officer at the time of the K-World introduction noted (Power 2000a),

> "We have to assure our clients that we will not be putting their confidential information on K-World and that there is no logical link between K-World and that data. Rather, what is there are experiences, best practices and proposals without client names or fees."

Further, according to ETW (2003) "Client names and confidential information are removed from stored documents which are used as examples of best practices." In addition, KPMG has a code of conduct that includes many references to client confidentiality (KPMG 2006). As a result, according to McBride, K-World does not currently contain client-sensitive knowledge.

Unfortunately, some of the key advantages of the original design and story of the shadow partner included knowledge about which clients that specific work had been done for, and what was charged for that work (Gladstone and Eccles 1995). For example, if work is done for similar companies in the same industry, that industry knowledge could be very useful in guiding the design of proposed work for others with similar problems in the same industries, or choosing who should work on the engagement, or knowing what to charge. Without company names, finding and choosing relevant resources can become substantially more difficult. Instead of being built into the system, client name information would only be available in the memories of the particular users. Accordingly, over time such information would be lost. As a result, it is important to note that it was anticipated that the next release of K-World would have a security model built around it that would enable KPMG to publish more-specific information that would facilitate searching, but which would still not be client-identifiable (Power 2000b).

## 9.3 System Extensions

A number of system extensions were planned for K-World to further support professionals' decision making, facilitating K-World evolution, including (e.g., Boom 2004)

- Newsletters on industry sectors
- Personal portals
- Knowledge maps
- Alacra

As librarians were shifted into knowledge management, adding research to K-World became more feasible. Librarians could be active contributors to K-World by adding knowledge that they generated from an analysis of various data sources. Proposed newsletters about particular industry sectors could include researched emerging developments, such as the impact of new technologies or other emerging developments.

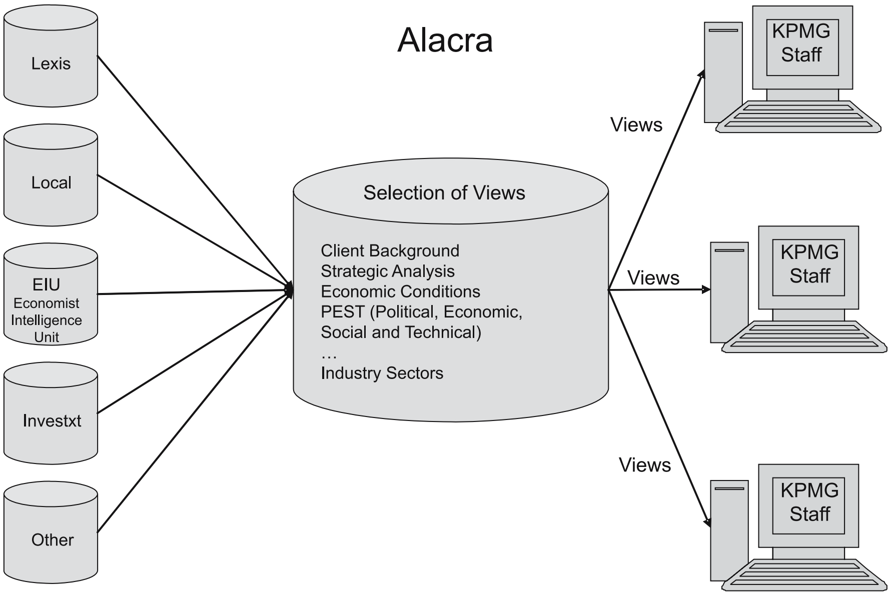


**Figure 5.** Alacra integration of multiple data sources (Boom 2004)

Yahoo! was among the first to come up with the well-received concept of allowing personal portals, such as My Yahoo! Accordingly, as a potential extension, it is not surprising that K-World was also focused on potentially providing its users with personal portals that they could customize to meet particular client and decision support needs. Personal portals could help users rapidly use the resources that they found the most helpful and insightful.

Knowledge maps show who has knowledge and who uses or needs that knowledge. They can be used to facilitate understanding processes or flows of knowledge, or built to support group processes. There are ultimately several approaches used to construct these maps. For example, one approach is to use e-mail message maps to understand flows of knowledge. Alternatively, such maps can be hand-built or customized to meet the requirements of particular processes. In any case, the development of knowledge maps can lead to changes in processes or understanding why processes operate as they do.

Alacra is a company that packages multiple sources of financial knowledge to support users. As a result, they provide a single point of departure for knowledge, allowing a company to outsource some of its knowledge management functions. Outsourcing would be a reversal from the build-it-internally mentality associated with K-World. As an example of the use of Alacra, see Figure 5.

## 10 Summary

It is not clear whether KPMG was able to leap the competition with K-World. However, they apparently were able to implement and evolve a system that allowed them to pull together disparate systems and facilitate collaboration and global decision support.

KPMG's knowledge management system has evolved over time. KPMG has gone from having a vision of a shadow partner that preceded virtually all professional service knowledge management efforts, to being behind the other major professional services firms in knowledge management, to having a knowledge management system so robust that apparently it could be spun off as its own firm in a competitive knowledge management environment. In addition, based on the survey of the most admired knowledge enterprises, the resulting knowledge management was competitive with the best in the world (Chase 2001). KPMG went from a firm that almost lost an entire country of offices to competitors because of its lack of global knowledge management capabilities, to a firm with a global network capable of sharing information and supporting decisions on the largest engagements.

Global sharing and integrated decision support became important for more-profitable global engagements. Accordingly, KPMG found it necessary to guide the system away from a potential U.S.-focused system to one that would accommodate multiple cultures. KPMG used a technology adoption model that tried to move users across the life cycle in parallel with system developments and evolution.

Two of the key emerging issues are client privacy and search. Ensuring that confidential knowledge is not included among knowledge management resources that can be freely selected is important for assuring client confidentiality. Further, as the number of documents, types of document, and sources of those documents has increased, searching has become more important and more challenging. Ironically, not including client information could ultimately hamper searching. Consistent with KPMG's organization structure and history, different countries have apparently pursued their own solutions to improve K-World's searching capabilities. Ultimately, K-World continues to evolve as new and emerging changes are considered.

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# PART X

# Decision Support Horizons

# CHAPTER 64
# Compositional Enterprise Modeling and Decision Support

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In this chapter, we present a conceptual model and a web-based architecture for implementing an enterprise-wide modeling system for decision support. It describes a framework and a method that is aimed at effectively organizing, integrating, and reusing knowledge and model components from various sources across an organization in order to provide better knowledge access to decision makers. It is a useful tool for operational and strategic corporate decision-making.

**Keywords**: Compositional modeling; Decision support systems; Enterprise modeling; Knowledge components; Model integration; Organizational knowledge base design

## 1 Introduction

It is widely observed that the society we live in has been gradually turning into a "knowledge society" (Drucker, 1968; Bell, 1973; Holsapple and Whinston, 1987; Toffler, 1990; Romer, 1990; Davenport and Prusak, 1998; Castells, 2000; David and Foray, 2002; Friedman, 2006). Knowledge plays a key role in the modern business world. Knowledge creation and effective management of organizational knowledge is recognized as a source for competitive advantage (Nonaka, 1991; Holsapple et al., 2007). Active knowledge management is increasingly practiced in some systematic form by mid- to large-size companies in all industries. More of an organization's core competencies are projected to center around creating and managing knowledge. This raises questions about how organizations discover or create knowledge, process knowledge, and how they apply knowledge to critical organizational decision making to turn knowledge into competitive advantage for the organization.

Much of the important knowledge in an organization is unstructured. Corporations routinely generate huge amounts of business data, spread across organizational units and departments, on a daily basis. While the concept of viewing knowledge as a critical resource has now been widely accepted in theory and practice (Davenport et al., 1998), it is not fully understood how to explore the available volume of corporate knowledge that is largely scattered across the enterprise in order to enhance decision-making and organizational performance. Advances in technology have enabled organizations to develop and deploy information management applications managing data on an unprecedented scale, but most of the knowledge management projects still struggle to find effective ways of creating enterprise-wide models and knowledge repositories and improving knowledge access (Grover and Davenport, 2001).

However, it is clear that certain basic knowledge management principles ought to be followed to achieve the general goal of building enterprise-wide organizational knowledge bases that can be effectively used as the basis to deliver relevant, model-based knowledge to the right person at the right time (Papows, 1998). Those principles include (i) reusing prior knowledge as much as possible to derive and create new, higher-level knowledge (Dykeman, 1998; Markus, 2001); (ii) sharing and integrating organizational knowledge to ensure that all departments have the ability to effectively access and utilize knowledge across the whole enterprise (Ruggles, 1998; Angus and Patel, 1998; Gray and Meister, 2003; Ipe 2003); and (iii) providing decision support systems (DSS) tools that transform scattered data into meaningful business information for supporting operational and strategic corporate decision-making (Doler, 1996; Holsapple and Whinston, 1996; Marshall et al., 1996).

Organizations have become increasingly distributed, with information sources dispersed in many locations, which makes effective model management and knowledge access more difficult. Moreover, getting a coherent set of knowledge for organizational decision making is made more challenging by the heterogeneity of the underlying knowledge representations, retrieval techniques, and end-user computing front-end interfaces. A big challenge for organizations today, particularly large organizations, has become finding ways to effectively organize knowledge (of diverse types and representations) across the enterprise (Brown and Duguid, 1998).

The need for effective model and knowledge management combined with the potential power of new information technology prompts us to develop an enterprise modeling and decision support system (EMDSS) that is based on a decentralized, knowledge-based architecture. Our approach goes beyond traditional enterprise integration which typically focuses on the integration of application systems across an organization. Our EMDSS aims at the automation of query-specific model-building, identifying relevant knowledge that is encoded in the form of model components and integrating those into an executable composite decision model. It contributes to solving the problem of organizing and integrating corporate knowledge that is dispersed across an organization.

This chapter presents an extension of an earlier system that was originally developed in a centralized model management environment (Ba et al., 1997). Our approach is based on the idea of an enterprise-wide knowledge network that is aimed at effectively organizing and integrating model-based knowledge components from various sources and providing better knowledge access to decision makers located across the entire organization. Conceptually, our framework applies to explicit knowledge that is expressed in a formalized representation, including data models, decisions models, and other structured knowledge documents. Tacit organizational knowledge cannot be incorporated into our approach and must be considered outside the EMDSS. In order to facilitate meaningful, automated integration of knowledge pieces from different sources, we limit our system to knowledge components that are represented in a few specific languages as discussed later. Nevertheless, our scheme recognizes the inherent heterogeneity and the distributed nature of organizational knowledge.

The remainder of this chapter is organized as follows. Section 2 summarizes some limitations of traditional knowledge management and processing approaches. In Section 3, we present a three-tier computing architecture for our EMDSS system. Then, in Section 4, we discuss in detail the knowledge representation issues. Section 5 discusses the organizational knowledge structure that is critical to the successful implementation of the knowledge network. Section 6 illustrates through an example how to use the system in practice.

## 2 Traditional Knowledge Management Approaches and Limitations

Over the years, more and more organizational knowledge has been stored in the form of corporate data, decision models, procedures, rules, and organizational documents. The term document has come to encompass a wide variety of explicit knowledge forms including text (reference volumes, books, journals, newspapers, etc.), illustrations, tables, mathematical equations, scientific data, scanned images, video, voice, hypertext links, and animation. Explicit knowledge refers to knowledge that is expressed in a form that can be transferred among people or automated systems and includes written records and formal model specifications. Tacit knowledge, on the other hand, resides in people's minds and is not directly accessible for processing. Tacit knowledge is often viewed as the primary source of organizational knowledge and the question of translating tacit into explicit knowledge is an important issue (Nonaka, 1991). In this paper, however, we consider only knowledge components that represent forms of explicit knowledge.

Relatively recent technology development of data warehousing and data marts offers organizations new ways of organizing large amounts of organizational data. Transactional data from operational systems, which normally are relational databases, is cleansed, consolidated, aggregated, and transformed into a data warehouse for online analytical processing and decision support purposes. While current data warehousing presents a powerful technology to supply data that can be processed to generate higher-level information, which can be used as inputs to knowledge-creation processes, its scope is limited to aggregating homogeneous sets of data (Ponniah, 2001). First, the data representation schemes in data warehousing reflect the traditional database technology that works well for structured data models but largely fails to represent less structured knowledge such as decision models or knowledge documents. Second, due to the lack of a flexible knowledge representation scheme that allows interoperability, data models in the data warehouse have to be pre-specified and tedious data transformation procedures have to be applied to data from every single operational system.

Current knowledge management systems (KMS) that organize unstructured knowledge representations as files and documents are gaining significance. However, they are not able to automatically build operational decision models from knowledge pieces included in the knowledge base (Alavi and Leidner, 2001).

## 3 Three-Tier Computing Structure for Enterprise Modeling and Decision Support

The idea of a centralized knowledge base that keeps every piece of information generated in the company in one place is unnecessarily limiting. Acknowledging the fact that knowledge generated in a company is inherently dispersed, we propose a three-tier computing architecture for our EMDSS system, where the organizational knowledge base is decentralized, where various organizational units contribute to and maintain their own specific knowledge. For example, the accounting department maintains its own server containing knowledge that is related to cash flow and other accounting models. The manufacturing department, on the other hand, will keep on their server the inventory planning and scheduling models. This decentralized model of an organizational knowledge base enables localized quality control on the knowledge provided, as well as a better support and interaction between knowledge providers and knowledge seekers. There still needs to be a single access point that leads to the right pieces of knowledge, no matter who the knowledge providers are and where the knowledge resides. In our EMDSS architecture, the knowledge broker provides this single point of access. It is a centralized intermediator that facilitates retrieval and integration of dispersed organizational knowledge. The architecture is based on a three-tier structure.

This computing architecture addresses the main issues surrounding knowledge processing. First, it allows heterogeneous computing platforms to co-exist within an organization. The client—a Web browser—is virtually universal. Every user from the organization can access knowledge from the organizational knowledge base without being constrained by the local computing platform.

The Web-based architecture allows access to distributed organizational knowledge while keeping the knowledge access process transparent to end users. Decision makers thus are freed from the formidable task of figuring out where the needed knowledge resides and what tool to use to access it. Lastly, and most

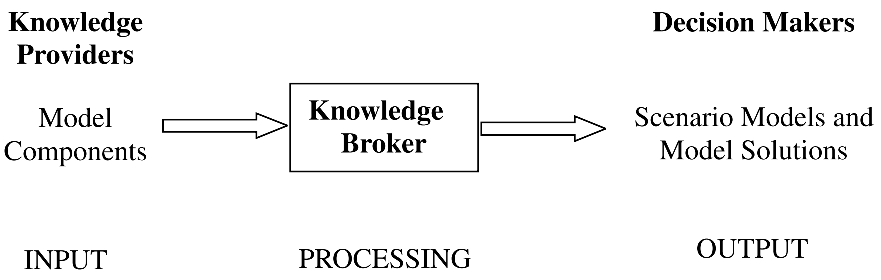


**Figure 1.** The knowledge broker as an intermediary

important, the architecture recognizes the heterogeneous nature of organizational knowledge by integrating models of various structures and forms in the knowledge base.

The most important concept in this three-tier architecture is the centralized knowledge broker. The knowledge broker serves as the intermediary between end users and knowledge that is scattered around the organization. In other words, it is a gateway to distributed knowledge bases on the enterprise knowledge network. It is a technological/organizational entity that generates value-added knowledge products by linking knowledge together with services as depicted in Figure 1. Knowledge sharing and integration is central to the broker effectiveness.

The knowledge broker maintains the enterprise knowledge structure that plays the role of a meta-directory for effective knowledge organization and access (Brown and Duguid, 1998; Lee, 2004). It contains information on what is available in the knowledge base, how knowledge is related to each other, and where knowledge resides. Each time a new piece of knowledge is added to the knowledge base, the knowledge structure is updated automatically. We explain the knowledge structure in detail in section five.

# 4 The Organizational Knowledge Base

The key to successful implementation of the enterprise knowledge network is the organization and operationalization of the knowledge base (Earl, 2001). In this section, we discuss the knowledge management principles of the organizational knowledge base (OKB) and put organizational knowledge into operational terms. We view the OKB as a special kind of organizational memory that collects and stores previously used pieces of knowledge that are specified as model components (Walsh and Ungson, 1991; Scheer, 1997; Annand et al., 1998; Wijnhoven, 1999). It is a repository of organizational knowledge whose purpose is to provide a resource of *sharable* and *reusable* knowledge components for helping to better understand, explain, and predict organizational phenomena in a variety of different situations (Stein and Zwass, 1995; Alavi and Leidner, 2001). Prior literature has pointed out that in order to achieve the necessary depth and versatility, the OKB needs to contain knowledge of different types: (i) relationships among organizational variables encoded as quantitative or qualitative constraints (Monge, 1990); (ii) their preconditions and associated assumptions that define the presuppositions under which they hold (Szulanski, 1996); and (iii) knowledge about knowledge expressed as metarules which relate knowledge components and/or assumptions to each other (Sen, 2004).

One of the main challenges in designing organizational knowledge bases is to decompose and modularize the vast body of knowledge available from different sources into semi-independent building blocks and to properly structure these building blocks to reflect the inherent relationships among them (Davenport et al., 1996). Merging knowledge components into an integrated, composite structure requires not only a careful approach of grouping relationships into independently meaningful units, but also an explicit treatment of the assumptions that describe when they apply (Blake and Gomaa, 2005). Falkenhainer and Forbus (1991) present a compositional modeling system in the engineering domain that most closely resembles our EMDSS approach. Their system organizes knowledge fragments that are represented as various kinds of formalized, qualitative relationships and constructs models to answer user-specific queries. Earlier cases of model integration examples in the business area include, for example, Dolk and Kotteman (1993) and Muhanna and Pick (1994). Those approaches, however, do not consider model-based reasoning capabilities or the incorporation of qualitative knowledge as a form of representing organizational knowledge in their model bases.

The observation that model-based organizational knowledge normally consists of more than just a set of relationships, because most knowledge holds only in a particular context, leads us for our purposes to a definition of a knowledge component where the underlying assumptions and conditions are explicitly and separately expressed from the actual relationships. We argue for different representation languages to represent the underlying assumptions of a knowledge component and its constituting relationships. Each knowledge component has two sections; one contains the specification of assumptions (the conditions section) and the other (the relations section) contains the actual constraints and relationships that apply if the assumptions hold. Knowledge components are of the following form:

**component** <NAME> *(input port)* (*output port*)
{verbal description of the functionality of the knowledge component}

**conditions**
*precondition-specifications*

**relations**
*relationship-specifications*

**end**

where <NAME> is an identifier of a particular knowledge component instance, *input port* is a list of the variables whose values need to be provided, either by computing them in other knowledge components or by importing them as exogenous quantities. *Output port* is a list of the variables that are computed internally, and which can be shared with other components. The conditions section contains precondition specifications, which define the assumptions that an instantiation of a knowledge component depends on. Lastly, the relations section contains relationship specifications, which would be constraints of a particular knowledge representation language. We only assume that internally, that is, within a single knowledge component, the relationships are of a homogeneous type. Using different knowledge representation languages permits heterogeneous relationship specifications across knowledge components.

Next, we describe in Section 4.1 the types of organizational relationships and how these relationships can be specified in the "relations" section of a knowledge component. In Section 4.2, we present a set of commonly used assumptions for knowledge representation. These assumptions define the context in which each knowledge component applies and are explicitly represented in the "conditions" section of a knowledge component. An example of an organizational knowledge base that contains many knowledge components is provided in Section 4.3 to illustrate the principles of the knowledge component concept.

## 4.1 Representation of Organizational Relationships

In this section, we describe how organizational knowledge is represented in our knowledge management system. A common limitation of many traditional DSS systems is their rigid and uniform representation of information, usually restricted to strictly quantitative information. But Monge (1990) and Weick (1989), for example, have observed that theoretical and especially empirical organizational research has been impeded by the lack of appropriate conceptual and computational tools to represent inexactly, vaguely, or (in other words) qualitatively specified knowledge. Comprehensive descriptions of domain knowledge require the use of different languages to formally represent various kinds of quantitative and qualitative knowledge. Reasoning with models that are expressed in different representations has been the subject of considerable research in the area of artificial intelligence (e. g., Davis, 1990; Kuipers, 1994). To accommodate the inherent heterogeneity of organizational knowledge in the business domain, four different, but (within limits) interoperable, representational forms are considered in our system to specify knowledge (Hinkkanen et al., 2003).

### 4.1.1 Quantitative Knowledge

Most decision support systems in organizations focus on computing with quantitative knowledge. For example, the accounting department may keep information in a spreadsheet system for number crunching. The marketing department may have a forecasting model, often quantitative, that needs numerical information on past sales. Quantitative knowledge could also be, in principle, all kinds of equational constraints that are commonly used in MS/OR-types of models (for example, a production scheduling model or a logistics model). This type of knowledge can yield important insights about an organization and is a very valuable component of any knowledge management system and DSS.

### 4.1.2 Purely Qualitative Knowledge

A large amount of organizational knowledge tends to be qualitative in nature. Theories in management and organizational science typically encompass general statements that apply to whole classes of organizations. Hence, management theories try to discover commonalities across all organizations with general validity, which can sometimes only tenuously be described as certain trends, influences, or tendencies. Qualitative descriptions are often used to formulate causal and functional relationships as general propositions. Statements, like "*Increasing the level of partnership among organizational units leads to an increase in the productivity of the entire organization*," that expresses a monotonic relationship between two variables (partnership and productivity) are actually very characteristic of organizational knowledge. An effective EMDSS system has to find a way of representing this type of knowledge in the knowledge base, such that it not only stores knowledge, but is also accompanied with a means to process and compute with this qualitative knowledge.

Research in the field of qualitative reasoning has produced several formal approaches of representing and computing with qualitative knowledge (Kuipers, 1994). For example, qualitative relationships of the above kind can very well be represented in the QSIM[1] modeling language as $M^+/M^-$ constraints, and then stored in the organizational knowledge base as:

$$\text{PRODUCTIVITY} = M^+(\text{PARTNERSHIP})$$

where $M^+$ means that there is a monotonically increasing (bi-directional) relationship between the variable PRODUCTIVITY and the variable PARTNERSHIP.

### 4.1.3 Semi-Qualitative Knowledge

Semi-qualitative knowledge refers to a hybrid form of representation that combines quantitative with qualitative information. Including semi-qualitative representations enables the integration of qualitative model components with

[1] Qualitative Simulation (QSIM), originally developed by (Kuipers, 1986), is perhaps the most widely known qualitative reasoning system. It consists of the QSIM modeling language and the QSIM solver. Besides allowing the representation of qualitative arithmetic constraints, QSIM particularly features the qualitative representation of monotonically increasing ($M^+$ constraints) and monotonically decreasing ($M^-$ constraints) functional relationships.

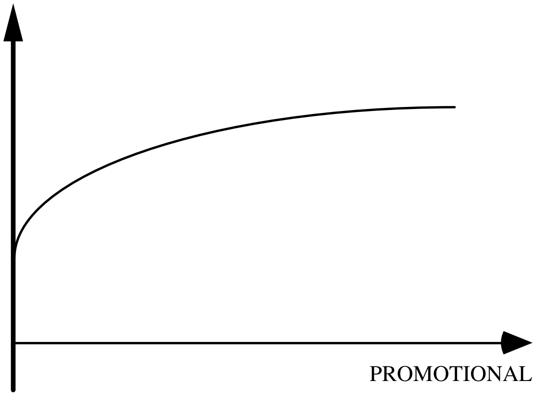


**Figure 2.** Purely qualitative relationship

quantitative model components when composite models are constructed as described later in the chapter. Functional relationships are often partially known. In addition to knowing purely qualitative properties such as monotonicity, we may have partial numerical information. In particular, some purely qualitative relationships obtained from qualitative management theory can actually be refined with respect to particular companies under consideration. An EMDSS system, therefore, should offer a representation language to capture the semi-qualitative knowledge.

For example, a possible depiction of the relationship "An *increase in promotional expenditure leads to an increase in sales volumes*," which is a purely qualitative relationship, could be specified in QSIM as:

$$\text{SALES} = \text{M}^{+}(\text{PROMOTIONAL\_EXP}).$$

It simply indicates that sales monotonically increase with higher promotional expenditures (see Figure 2). An $\text{M}^{+}$ relationship defines an entire class of monotonically increasing functions $f$ Let $s$denote SALES and $p$ denote PROMOTIONAL_EXP. Then we can say that the above relationship defines a functional relationship $s = f(p)$ up to the qualitative property $f'(p) > 0$, that is, it defines $f$ as a member of a particular class of functions $M$, namely $f \in M = \{g | g' > 0\}$ [2], a class which includes, for example, exponential curves, lines, and arbitrary monotonic wiggles. There may be a quantitative functional relationship between sales and promotional expenditure. However, the quantitative relationship may remain hidden to us for various reasons such as (i) limited

[2] Actually one can also define so called corresponding values which are, again in qualitative terms, specific points of an $\text{M}^{+}$ relationship. Thus we could specify a corresponding value (0,(0,inf)), meaning f(0)>0. That is we would restrict the class M further to M={g|g(0)>0,g'>0}, or in other words, even without any promotional expenditure we would still expect some sales.

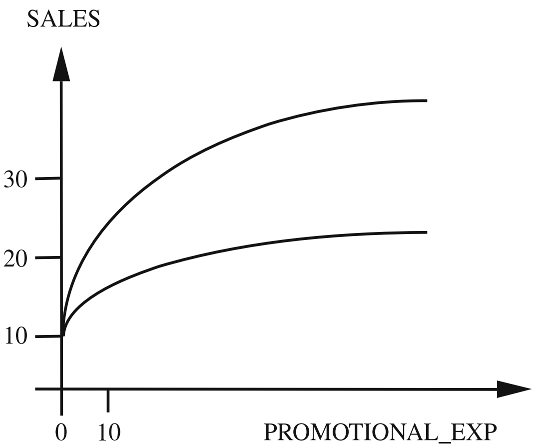


**Figure 3.** Range specifications by first expert

cognitive capabilities may prevent us from discovering it, (ii) complete knowledge discovery could be too expensive, or (iii) perhaps we are only interested in qualitative properties.

The above relationship could be specialized, if needed for better accuracy, to mirror the company's specific experiences and projections, and be restated more precisely by including specific ranges of the expected increase. In our EMDSS system we use the RCR[3] modeling language to represent semi-qualitative information, which is suitable in cases where the relationship of interest can be bounded by envelope functions. Then the above relationship could be restated in the knowledge base as

SALES = [lb(PROMOTIONAL_EXP), ub(PROMOTIONAL_EXP)]

where lb(PROMOTIONAL_EXP) denotes a lower bounding function, and ub(PROMOTIONAL_EXP) denotes an upper bounding function of the qualitative relationship between promotional expenditure and sales. More formally, we can say that the above relationship defines a class of functional relationships, $s = f(p)$, where $f \in M' = \{g \mid lb(p) \leq g(p) \leq ub(p)\}$. In order to get specific bounds on the relationship, competent experts could specify ranges for this relationship, as shown in Figures 3 and 4.

Using interval analysis it is straightforward to reconcile inconsistent range specifications by taking the union of intervals. In this case, we might get a compromise formulation, such as that shown in Figure 5, which would then be added to the organizational knowledge base as a new knowledge component.

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3 Rules-Constraint-Reasoning (RCR) is a semi-qualitative reasoning system introduced by Kiang et al (1994) and Hinkkanen et al. (1995). It uses an interval-based representation to hybridize qualitative and quantitative information. Kuipers and Berleant (1988), Williams (1991), and Berleant and Kuipers (1998), present alternative hybrid modeling languages.

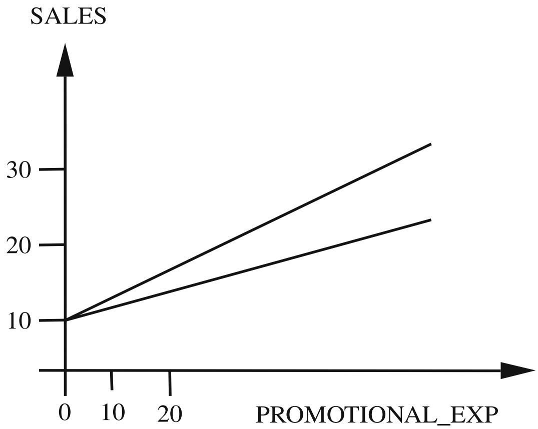


**Figure 4.** Range specifications by second expert

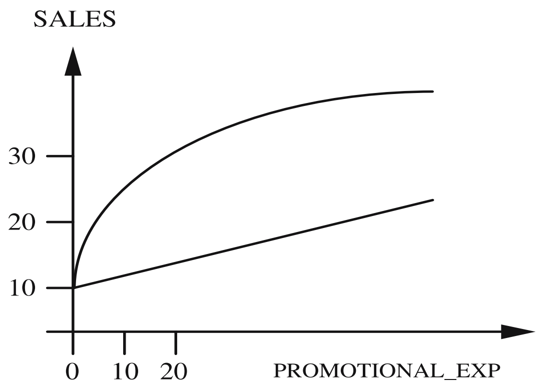


**Figure 5.** Compromise range specification

### 4.1.4 Definitional Knowledge

Definitional knowledge defines specific organizational relationships. They are usually valid in a quantitative sense as well as in a qualitative sense. For example, the fundamental accounting equation "Total assets (TA) equals total liabilities (TL) plus stock owner's equity (SE)" could be specified as:

$$TA = TL + SE$$

which could be used to build (1) a qualitative, QSIM-type constraint—in which case the plus would be interpreted as qualitative addition; (2) a semi-qualitative, interval-based RCR constraint; and (3) a quantitative model in which the definitional relationship would be instantiated as a conventional, algebraic equation.

## 4.2 Representation of Assumptions

In most situations, knowledge has a particular context in which it holds, or it may describe a specific instance of some event (Kwan and Balasubramanian, 2003). For example, there could be a knowledge component that describes a particular engineering design prototype. But most engineering designs are context dependent and have many assumptions that are associated with the design. In this situation, the knowledge component that includes these assumptions will be much more valuable than the one that does not. Likewise, a successful sales proposal put into the knowledge repository is more useful with information explaining why the proposal won. However, conventional knowledge representation schemes do not facilitate an explicit representation of context information, for example, the assumptions under which a piece of knowledge holds. Hence it is the people who use the knowledge base that are responsible for deciding an adequate set of assumptions. In the absence of context, the differing perspectives, beliefs, and assumptions of decision makers are mostly like to collide and thus impede decision-making (Fahey and Prusak, 1998).

An effective EMDSS system, on the other hand, should be able to reason about assumptions and conditions when accessing the knowledge base to build decision models. Therefore, we require that all knowledge components in the knowledge base explicitly state the assumptions under which they apply. As first conceived by Bonczek et al. (1981a, 1981b), we use first-order predicate logic to represent assumptions and specify each knowledge component as a logical implication, where the set of the relationships is the consequence, and the assumptions which are expressed as a conjunction of predicates are taken as the antecedent.

In order to enable the system to reason about assumptions effectively while engaged in a model-building task, we must define a taxonomy of assumptions for characterizing managerial organizational knowledge in the realm of business and management. Normally, organizational problem solving and decision making, which need to access and process knowledge, are made along several dimensions. Hence, we group together those assumptions that represent alternative ways of studying a certain aspect of a problem scenario. Such groupings of assumptions, each capturing one dimension, are called *assumption classes* and are defined for all dimensions. Assumption classes are organized as sets of mutually exclusive assumptions. Each knowledge component has an assumption or a set of assumptions associated with it.

Literature on knowledge representation in the artificial intelligence area suggests several categories of assumptions (Falkenhainer and Forbus, 1991; de Kleer, 1986):

1. *Ontological assumptions* take a certain perspective on the enterprise and select an appropriate method of description. Should the organization be viewed as a collection of employees who are working towards a common, corporate goal? Or is it better described as a collection of interacting subunits where the interaction might be represented as knowledge flows, influence flows, cash flows, or material flows? Kaplan and

Norton (1992), for example, suggest modeling a variety of organizational perspectives, including a customer perspective, innovation and learning perspective, and several internal business perspectives. Ontological commitments shift focus to a particular perspective of the enterprise, and indicate if a cost analysis, a productivity analysis, or if some other kind of analysis is more appropriate.

2. *Topological assumptions* provide structural information on the organization considered. The entire enterprise should be organized as a system of linked subsystems such as branches, departments, or other functional business units. For example, the manufacturing department is part of the company, and plant X is part of manufacturing.
3. *Granularity assumptions* determine the level of analysis detail for which a given knowledge component is appropriate. A production scheduling analysis may require the consideration of each worker and piece of machinery involved in the manufacturing process of the products. A strategic marketing study might need a more aggregated view, and suggest a study in terms of product groups without explicitly considering any details of the manufacturing process.
4. *Approximations* are mainly used to simplify a knowledge component for computational benefits. Linearity assumptions and treatment of variables as constants, for example, abound in all modeling contexts.
5. *Abstractions* are used to reduce the complexity of phenomena. Operative management problems, for example, may require a factual representation while strategic management problems usually suggest a more abstract representation. Choosing an abstraction assumption commits the EMDSS to a specific level of abstraction and thus determines if a knowledge component uses a quantitative, a qualitative, or some hybrid form of representation.
6. *Time scale assumptions* indicate under what time scale the knowledge component is applicable. Enterprise processes work on time scales of different orders of magnitude (Table 1). For example, some manufacturing processes like job scheduling are best represented at a time scale of hours or even minutes. Other processes may be better represented in time units of days, like production planning processes; weeks, like cash flows; months, like sales predictions; or even quarters and years for strategic planning models. A question asking for the key factors that affect the future performance of the company should contain a hint that allows the system to infer if the question refers to short-term performance, or to long-term performance.
7. *Operating assumptions* are finally used in order to help in generating parsimonious answers and to ease knowledge processing. Operating assumptions narrow the scope of the knowledge space search, and delimit different ranges of behavior. Operating assumptions help to focus problem solving and knowledge access, for example, whether a static, quasi-static, or a dynamic analysis is appropriate.

**Table 1.** Examples of business processes operating at different time scales

| Time scale | Business process |
|---|---|
| Hour | Job scheduling |
| Day | Production planning |
| Week | Cash flow |
| Month | Sales prediction |
| Quarter or Year | Strategic planning |

We think that these seven different types of assumptions cover most distinctions that are implicitly made when knowledge is encoded. However, our list of assumption categories is meant to be neither exhaustive nor indisputable. Quite the contrary, we propose it as a rather prototypical assumption schema which serves not only to furnish our knowledge representation schema but also to stimulate further discussion (Kalfoglou et al., 2000). As a matter of fact, we contend that the development of comprehensive and commonly agreed on business ontologies and assumption taxonomies is one of the most important open research topics in organizational knowledge representation.

## 4.3 An Illustrative Example of an Organizational Knowledge Base

In this section, we give an example that illustrates how the principles discussed above apply to the development of an organizational knowledge base (OKB). The OKB is a collection of heterogeneous organizational knowledge, represented as knowledge components, which encompasses both general domain and enterprise-specific knowledge. Constructing such an OKB is naturally an ongoing process and a tremendously time consuming and costly project in itself (Scheer, 1997). For the purpose of this chapter, showing just a small segment of an OKB is sufficient to demonstrate its essential features. Recall that a knowledge component consists of two major parts: one that contains the conditions under which the knowledge component is applicable, the preconditions section, and another that encodes the actual relationships of the knowledge component, the relations section. In Exhibit 1, we show parts of the OKB of the hypothetical CORP-X enterprise. The complete enterprise description would obviously be much more elaborate. For the sake of simplicity, we have left out some of the details in the relationships sections.

Besides the definition of knowledge components, the OKB also contains a rules section that further constrains the use of the knowledge components, and thus help knowledge processing. For example, in the beginning of the project at CORP-X we may restrict our EMDSS to enable solvers like QSIM (rule R-2), RCR (rule R-3) and so on.

**Exhibit 1: OKB** CORP-X

**ALIASES**

/Partnership, Pship/
/Product_Quality, PQual/
/Customer_Satisfaction, CSat/
/Customer_Service, CSrv/
/Marketing_Position, MPos/
/Promotional_Expenditure, PrmExp/
/Productivity, Prd/
/Information_Technology, IT/
/Revenue, Rev/
/Net Income, NInc/
/Production Cost, PCost/
/Performance, Perf/
/Goodwill, Gw/

**END**

**ASSUMPTION CLASSES**

/Ontology Assumption, OntAsm/ (influences, cash flow, material flow);
/Simplifying Assumption, SimpAsm/ (qual, semi-qual, quant);
/Operating Assumption, OpAsm/ (static, quasi-static, dynamic);
/Time Scale Assumption, TScAsm/ (short, medium, long)

**END**

**component** f1 (IT) (Pship)
{qualitative model describing the relationship between IT and Partnership}
**conditions**
OntAsm=influences, SimpAsm=qual, OpAsm=quasi-static, TScale=medium
**relations**
Partnership = $M^{+}$(IT)
**end**

**component** f2 (IT) (Prd)
{qualitative model describing the relationship between IT and Productivity}
**conditions**
OntAsm=influences, SimpAsm=qual, OpAsm=quasi-static, TScale=medium

**component** f23 (Price, Sales) (Rev)
{accounting model describing the quantitative relationship between Price, Sales volume, and Revenue}
**conditions**
OntAsm=cash_flow, SimpAsm=quant, OpAsm=quasi-static, TScale=medium
**relations**
Revenue = Price*Sales
**end**

**component** f24 (Rev) (NInc)
{accounting model describing the qualitative relationship between Revenue and Net Income}
**conditions**
OntAsm=influences,

**relations**
Productivity = $M^+$(IT)
**end**

**component** f3 (Prd) (Pship)
{qualitative model describing the relationship between Productivity and Partnership}
**conditions**
OntAsm=influences, SimpAsm=qual, OpAsm=quasi-static, TScale=long
**relations**
Productivity = $M^+$(Partnership )
**end**

. . .
. . .

**component** f18 (Price) (Sales)
{marketing model describing the qualitative relationship between Price and Sales volume}
**conditions**
OntAsm=influences, SimpAsm=qual, OpAsm=quasi-static, TScale=medium
**relations**
Sales = $M^-$(Price)
**end**

**component** f19 (Price) (Sales)
{marketing model describing the semi-quantitative relationship between Price and Sales volume}
**conditions**
OntAsm=cash_flow, SimpAsm=qual-quant,
OpAsm=dynamic, TScale=short
**relations**
Sales(t)=[68000,92000]+[40000,48000]*Price(t)
**end**

**component** f20 (Price) (Sales)
{marketing model describing the quantitative relationship between Price and Sales volume}
SimpAsm=qual, OpAsm=quasi-static, TScale=medium
**relations**
NetIncome = $M^+$(Revenue)
**end**

**component** f25 (Cost) (Price)
{financial model describing the qualitative relationship between Cost and Price}
**conditions**
OntAsm=influences, SimpAsm=qual, OpAsm=quasi-static, TScale=medium
**relations**
Price = $M^+$(Cost)
**end**

**component** f26 (PCost) (Cost)
{financial model describing the qualitative relationship between Production Cost and Total Cost}
**conditions**
OntAsm=influences, SimpAsm=qual, OpAsm=quasi-static TScale=medium
**relations**
Cost = $M^+$(ProductionCost)
**end**

**component** f27 (Cost) (NInc)
{financial model describing the qualitative relationship between Cost and Net Income}
**conditions**
OntAsm=influences, SimpAsm=qual, OpAsm=quasi-static, TScale=medium
**relations**
NetIncome = $M^-$(Cost)
**end**

**component** f28 (Cost, Rev) (NInc)
{accounting model describing the quantitative relationship between Cost, Revenue, and Net Income}
**conditions**
OntAsm=cash_flow, SimpAsm=quant, OpAsm=quasi-static, TScale=medium

```
conditions
        OntAsm=cash_flow,
SimpAsm=quant,  OpAsm=quasi-static,
TScale=short
relations
        Sales = 80000—44000*Price
end

component f21 (Sales) (Rev)
{accounting model describing the
qualitative relationship between Sales
volume and Revenue}
conditions
        OntAsm=influences,
SimpAsm=qual,   OpAsm=quasi-static,
TScale=medium
relations
        Revenue = M+(Sales)
end

component f22 (Price) (Rev)
{accounting model describing the
qualitative relationship between Price and
Revenue}
conditions
        OntAsm=influences,
SimpAsm=qual,   OpAsm=quasi-static,
TScale=medium
relations
        Revenue = M+(Price)
end
relations
        NetIncome = Revenue—Cost
end

component f29 (Perf) (Gw)
{marketing model describing the qualitative
relationship between Performance and
Goodwill}
conditions
        OntAsm=influences,
SimpAsm=qual,   OpAsm=quasi-static,
TScale=medium
relations
        Goodwill = M+(Performance)
end

        . . .
        . . .
rules
        R-1:    OpAsm(quasi-static)
        R-2:    SimpAsm(qual) =>
solver(QSIM)
        R-3:    SimpAsm(qual-quant)
=> solver(RCR)

        . . .
        . . .
end
```

# 5 Interconnecting Knowledge

Having a flexible knowledge representation scheme is not sufficient. Instead of acting simply as a knowledge repository, the final purpose of the EMDSS system is to retrieve knowledge and build models that support critical organizational decision making. Research indicates that most knowledge management projects view knowledge as a stock that exists on its own and ignore the interconnections between knowledge (Fahey and Prusak, 1998). Our work looks at knowledge as a flow that is continuous and connects multiple knowledge pieces. We recognize that for knowledge seekers to be able to find useful knowledge through the EMDSS, there must be a searching mechanism that can find not only the knowledge components that are relevant, but also the relationships (connections) among the relevant knowledge components.

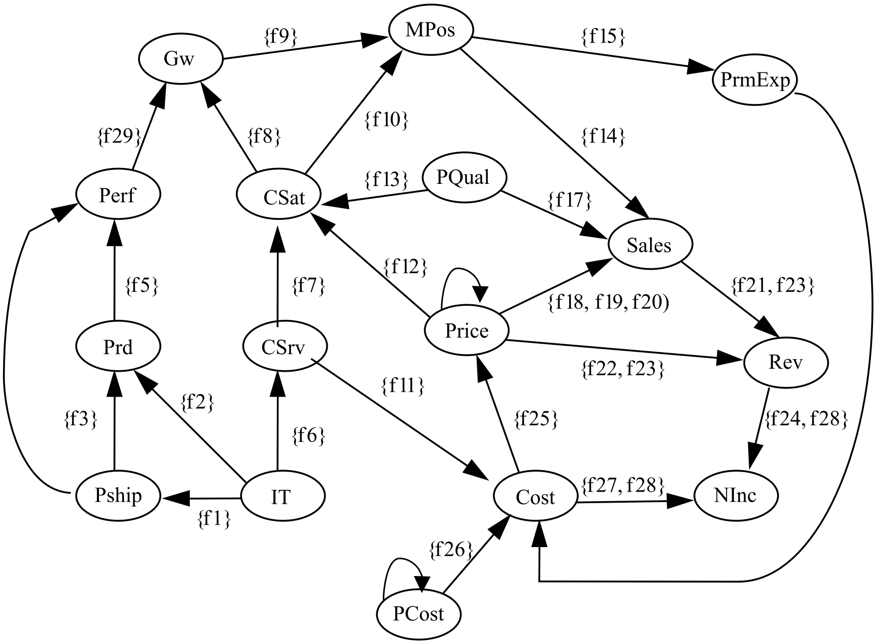


**Figure 6.** The interaction graph of the knowledge network

Unlike other compositional modeling approaches that employ first order logic to connect model components that share variables and parameters (e. g., Bonczek et al., 1981a; Falkenhainer and Forbus, 1991), we are using a graph-theoretic search method as our model composition engine. The *interaction graph*, shown in Figure 6, depicts graphically a comprehensive structure of a segment of the enterprise knowledge represented in the EMDSS. More specifically, the interaction graph relates organizational variables, organizational relationships, knowledge assumptions, and knowledge components to each other. The nodes of the interaction graph represent organizational variables and arcs connecting two nodes indicate the existence of a relationship (expressed references to model components) between the two corresponding variables. Note that unlike most knowledge representation approaches, we do not assume that the variables and relationships are organized in a hierarchical manner.

Arc labels identify knowledge components containing such relationships. The actual specification of a relationship cannot be directly obtained from the interaction graph, but must be retrieved from the relations section of the relevant knowledge components in the distributed knowledge base. Likewise, assumptions are to be found in the conditions section of the identified knowledge component. Finally, self-loops, that is, arcs that leave from and return to the same node, indicate that the corresponding variables are exogenous to the enterprise model. Self-loops are necessary to define the boundary that determines what is modeled inside the OKB and what information needs to be supplied from other sources outside the system. It provides closure to the OKB and separates internal system variables and external environmental variables.

Now we explain how the interaction graph supports knowledge retrieval and model construction for decision-making problems. In the lower left corner of Figure 6, we can see, for example, that knowledge component $f_2$ contains a relationship between the variables usage of information technology (IT) and Productivity (Prd). This means that if we want to build a decision model that predicts or explains the value of productivity, we need to consider component $f_2$ as a potential building block. The actual specification of the relationship and its associated assumptions represented by the arc <IT-Prd> can be looked up in the definition of component $f_2$, which may be stored on the IT department's knowledge server. In this case, we find the monotonic relationship Productivity = $M^+$(IT) (see Exhibit 1), which holds if the four assumptions

OntologyAssumption=influences
SimplifyingAssumption=qualitative
OperatingAssumption=quasi-static
TimeScaleAssumption=medium

are satisfied. Hence, if we are building a qualitative decision model describing the impact of IT usage on productivity, we must consider the inclusion of component $f_2$ in the decision making process.

In general, arcs emanating from a node x indicate the variables directly influenced by variable x. Thus, usage of IT has, in our decision model, a direct impact on Partnership, Productivity, and Customer Service. However, besides the direct influence of IT on Productivity, there is also an indirect influence of IT on Productivity, via Partnership. Indirect influences are represented in the interaction graph as a sequence of arcs called an *interaction path*. Here, the sequence <IT-Pship>–<Pship-Prd>, or more compactly written as <IT-Pship-Prd>, expresses the indirect influence of IT on Productivity. Similarly, IT has many more indirect influences on other variables, for example, the interaction paths <It-Prd-Perf-Gw> and <IT-CSrv-CSat-Gw> represent alternative possibilities of modeling the indirect influence of IT on Goodwill. Incoming arcs of a node x represent the direct influences on variable x. Our example indicates that Productivity is directly influenced by IT usage and Partnership. However, IT has a self-loop as the only incoming arc. The arc going from node IT back to itself means that the only influence on variable IT is IT itself, in other words, IT cannot be explained within the enterprise model. IT has to be determined outside of the model, that is, IT is treated as an exogenous variable whose value needs to be imported from a separate database when IT is included in a scenario model. The level of IT, for example, is determined by the budget proposed and passed by the management.

An arc label actually consists of a list of component identifiers. Such a list may be empty, as in the case of arc <IT-IT>, indicating an exogenous variable; may contain one identifier, as in <IT-Prd> meaning that the OKB knows only about one relationship between IT and Prd; or it may contain several identifiers suggesting alternative relationships. Two examples of multiple relationships are, first, arc <Price-Rev> which lists two components, $f_{22}$ and $f_{23}$, both using a relationship between price and revenue, and, second, arc <Price-Sales> which names three alternatives, components $f_{18}$, $f_{19}$, and $f_{20}$, of modeling price and sales. Relationships involving more than two variables are identified by any of the participating variables. For example, component $f_{28}$, which specifies a relationship between three variables net income (NInc), cost (Cost), and revenue (Rev), must be instantiated when either of the two arcs <Cost-NInc> and <Rev-NInc> is considered.

In short, the interaction graph maintained by the EMDSS reflects the interconnections among knowledge components in the OKB. It helps knowledge users retrieve all relevant knowledge components by following the knowledge linkages. The knowledge components being stored on distributed knowledge servers allow effective collection of knowledge at a point close to its origin. On the other hand, the interaction graph, being centrally maintained and updated, allows complete integration and structuring of dispersed organizational knowledge.

## 6 Model Selection and Model Integration

To illustrate how the EMDSS supports business problem solving, we present a simple example that demonstrates the system's knowledge processing capability in a decision-making situation. Let us consider, for example, a case where the marketing manager is considering raising the price of a particular product and asks the question of "*How does an increase in price affect net income?*" The manager would like to consider all the factors involved with price and/or net income. Being a marketing manager and restricted by the fact that she has ready access only to information residing on the marketing department's knowledge server, she would like to get relevant knowledge from other departments as well. Therefore, the marketing manager would log in to the enterprise knowledge network and access the EMDSS to get an answer to her question.

Conceptually, based on natural language processing, a query elaboration procedure on the knowledge broker's side would analyze the issued query and derive from it a set of elements that can be processed computationally. However, designing a natural language processor is beyond the scope of this chapter and implementing such an interface would certainly constitute a formidable task in itself (Conlon et al., 2004). For our purpose, we simply ask the user to specify a low-level query like *{Increase(Price), Quantity(Net Income)}*, which is essentially a set of ground expressions.

In the first step, the system searches for the input variable Price and the expected output variable Net Income (NInc) in the interaction graph in Figure 6. Then, it needs to be checked whether the initial value of the input variable is provided. Initial values could be derived from the query, supplied by an internal or external database, or computed from other variables. The latter is computationally

**Table 2.** Combinations of different interaction paths

| | Interaction path | # arcs | # nodes | # components | # models |
|---|---|---|---|---|---|
| 1 | Price-CSat-Gw-MPos-Sales-Rev-Ninc | 6 | 7 | 8 | 4 |
| 2 | Price-CSat-MPos-Sales-Rev-Ninc | 5 | 6 | 7 | 4 |
| 3 | Price-Sales-Rev-Ninc | 3 | 4 | 7 | 12 |
| 4 | Price-Rev-Ninc | 2 | 3 | 4 | 4 |
| | Total | | | | 24 |

the most expensive possibility because it entails constructing a more complex decision-making model, and is thus eschewed unless the former two fail. Our example query has no clue on the initial value of price. Fortunately, the second possibility applies, because the node that is representing price has a self-loop. This means that the variable price can be treated as an exogenous variable, that is, its current value can be sought from an external source. Next, the knowledge broker searches the interaction graph to connect the input variable with the output variable. Looking at Figure 6, there are four interaction paths describing different ways of computing net income from price.

Each of the four generated interaction paths suggests making use of a different collection of knowledge components for building a decision model that predicts how an increase of price would affect the net income of the company. Potential model candidates differ in their complexity measured in terms of the number of variables and the number of knowledge components involved in composing them. From Table 2, we can see that the first interaction path relates seven variables by six arcs identifying eight relationships represented in eight components. Because some of the arcs suggest a set of alternative relationships, we can choose from several different combinations of relationships and their associated components. All together, there are 24 candidates to consider when building a decision model to answer the given query "*How does an increase in price affect net income?*"

Recall that each knowledge component has a precondition section that specifies under what type of assumptions the relationships hold. Therefore, when the system searches the knowledge base for appropriate components, it checks the preconditions section for internal consistency of each model candidate and eliminates the models that contain contradictory assumptions. Potentially, there are a large number of relevant model components which can create scalability issues when examining all possible combinations. Ba et al. (1997) present a reasoning algorithm that efficiently prunes infeasible combinations of model components from further consideration. In the present example, this procedure quickly narrows down the 24 original model candidates to leave only four scenario models in response to our query:

$$\{(f_{12}, f_8, f_9, f_{14}, f_{21}, f_{24}), (f_{22}, f_{24})\ (f_{12}, f_{10}, f_{14}, f_{21}, f_{24}), (f_{18}, f_{21}, f_{24})\}.$$

However, as the OKB grows, scalability issues may arise. In our example, each of the four possible scenario models represents an alternative way of describing the effect of a price increase on net income. In a last step, which is omitted here for sake of brevity, the EMDSS system invokes the appropriate solver for the four scenario models and presents the corresponding solution to the decision-maker for evaluation and consideration. The four construed scenario models are added to the OKB as new knowledge components that could be reused in future query analyses. For a more detailed and more complete discussion of the model-building and solution process and its implementation, please see Ba et al. (1997).

# 7 Conclusion

We have presented in this chapter a knowledge-based enterprise modeling decision support system that leverages prior knowledge as building blocks to derive and create new, higher-level knowledge components that can be used for solving organizational decision problems. We contribute to the model management literature a conceptual model for automated model integration based on decentralized organization of knowledge component. It can be used as a decision support tool for operational and strategic corporate decision-making problems.

We outline an implementation of our enterprise modeling system using a three-tier web-based architecture as our organizational computing environment. Some newly emerging Internet technologies are available that could be employed to develop scalable implementations of our approach. Two particularly promising directions are the use of newly emerging web services and peer-to-peer technologies in implementing knowledge-based enterprise modeling systems. A natural extension to this work would be an S.O.A.-based implementation of our enterprise modeling system. The knowledge management functions of the EMDSS, including component selection, model integration, and model solving could be very effectively implemented as web services (Zhuge, 2003; Moitra and Ganesh, 2005; zur Muehlen et al., 2005; Madhusudan and Uttamsingh, 2006). Similarly, one could explore peer-to-peer technologies to support decentralized model management (Kwok, 2002; Kwok and Gao, 2004).

We conclude this chapter by pointing out some practical limitations and challenges that our enterprise modeling approach entails. Technical issues that specific implementations will need to deal with include scalability and limitations in terms of specific representation and modeling languages that any system would be able to handle. Obviously, it will be impossible to automatically integrate any combination of different types of knowledge components. From a managerial perspective, questions of knowledge sharing and system ownership might arise. We also do not address the complexities of managing such an enterprise system in terms of the organizational resources that would be required to maintain the operation of the system in a business organization.

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# CHAPTER 65
# Information Technology Support for Inquiring Organizations

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Inquiring organizations are a type of learning organization modeled on Churchman's inquiring systems. The objective of this chapter is to discuss how current information technology can be used to support decision-making processes in inquiring organizations. Inquiring systems and organizations are described briefly, and issues relating to the support of these organizations are discussed from the perspective of information technology. Because of the variety of processes involved in the various types of organization, a diverse array of technologies is required for their support.

**Keywords:** Inquiring systems; Organizational learning; Information technology (IT) support; Organizational knowledge; Knowledge management; Decision support

## 1 Introduction

If organizations wish to maintain a competitive edge in today's business environment, they have to be capable of continuous learning (Senge 1990). These organizations must have well-developed core competencies, show continuous improvement, and have the ability to fundamentally renew or revitalize themselves. An inquiring organization (Courtney et al. 1998, Courtney 2001) is one whose learning style is based on one or more of C. West Churchman's (1971) inquiring systems. The foundation for this view was provided when Churchman (1971, p. 18) recast the theories of knowledge of the philosophers Leibniz, Locke, Kant, Hegel, and Singer "in the language and design of inquiring systems," to provide "a description of how learning can be designed, and how the design can be justified." Because the emphasis in inquiring systems and organizations is on knowledge creation, consideration of knowledge and its management are of paramount importance in this context.

The main purpose of this chapter is to consider how modern information technology (IT) can be used to support decision making and knowledge creation in inquiring organizations. To set the stage for that discussion, the chapter first briefly reviews decision making, organizational learning, and knowledge management concepts. Then we describe the various inquirers and their associated organization types, and how IT can support the knowledge creation process and decision making in inquiring organizations.

## 2 Decision Making, Organizational Learning, and Knowledge Management

To understand how the inquiring systems of Churchman can be adapted to form the foundation of inquiring organizations, a brief discussion of decision making, organization learning, and knowledge management is warranted. Courtney (2001) described decision making and knowledge management in inquiring organizations and integrated Simon's (1960) well-known intelligence-design-choice model with Mitroff and Linstone's (1993) unbounded systems thinking approach to develop a new decision-making paradigm for wicked problem environments (Rittel and Webber 1973). This model (see Figure 1) suggests that decision problems should be viewed through the various perspectives of Mitroff and Linstone: technical, organizational, personal, ethical, and aesthetic. It emphasizes knowledge creation and organizational learning, as the mental models of organizational participants are updated as decision makers gain experience while iteratively going through the phases of the decision-making process. This is discussed more thoroughly later in the chapter.

Hall and Paradice (2005) discuss the philosophical foundations of the learning-oriented knowledge management system (LOKMS) underlying Courtney's model, and Hall et al. (2003) discuss the architecture of a LOKMS that supports the approach. This body of work emphasizes knowledge creation and organizational learning, as it is based on inquiring systems, which themselves emphasize knowledge generation.

Organizational learning is the development of new knowledge and insights that have the potential to influence behavior (e. g., Fiol and Lyles 1985, Huber 1991, Slater and Narver 1995). When members of an organization share associations,

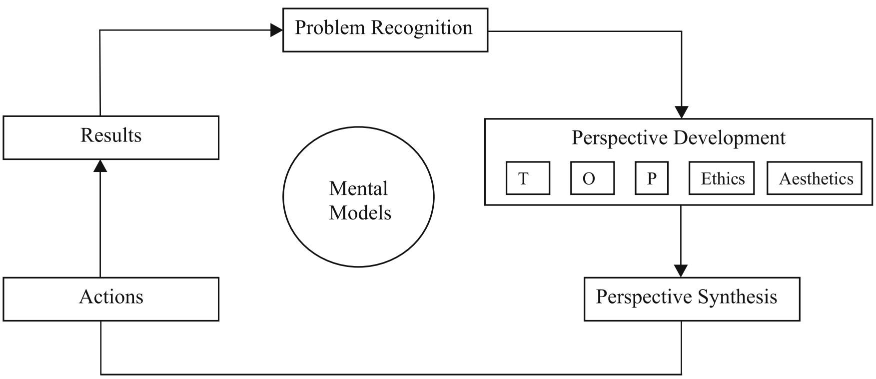


**Figure 1.** Courtney's (2001) decision-making paradigm

cognitive systems, and memories, organizational learning is taking place. Learning by organizations relies on the people and groups as agents for the transferal of knowledge. Over time, what is learnt is built into the structure, culture, and memory of the organization. Lessons (knowledge) remain within the organization even though individuals may change. Shanks et al. (1995) theorize that organizational learning improves performance, enhances value, and creates new beginnings. He argues that well-designed learning programs improve mental models, facilitate effective analysis, forge commitment, and open senses to the real world.

DiBella (1995) makes a case for understanding learning organizations using normative, developmental, and capability perspectives. The normative view, typified by Senge (1992) and Garvin (1993), supports the notion that learning is a collective activity that only takes place under a certain set of circumstances. There is a focus on traits or processes that must be present to ensure learning. This perspective requires some form of managed leadership in order to achieve learning. The developmental perspective considers evolutionary changes and learning through on-going interpretations of experience. Organizations pass through developmental stages in order to learn. This is consistent with models presented by Nevis et al. (1995) and Huber (1991), which sort learning into knowledge acquisition and assimilation, dissemination and sharing, and utilization. Another view considers developmental learning as movement from rote memorization to understanding of concepts, integration of ideas, and finally synthesis of new ideas. A capability perspective posits that there is no one best way for organizations to learn. According to this perspective, learning processes are embedded in organizational structure and culture. Learning occurs through self-discovery and reaffirmation. As new models are presented to the system, it considers where they fit and revises its world view accordingly.

Nonaka (1994) proposes a spiral model of organizational knowledge creation similar to that of organizational learning. The spiral model is based on the dynamic and continuous entanglement of four modes of knowledge conversion: (1) socialization, involving the conversion of tacit knowledge to tacit knowledge among individuals, (2) combination, involving the conversion of explicit knowledge to explicit knowledge, (3) externalization, involving the conversion of tacit knowledge to explicit knowledge, and (4) internalization, involving the conversion of explicit knowledge to tacit knowledge (learning). In Nonaka's model, individuals interact with others to create knowledge through these four modes. Knowledge spirals from individuals to small groups to the organization and perhaps to other organizations and society in general. The hypertext organization is designed to foster these modes of interaction and to promote organizational knowledge creation and sharing. Nonaka suggests that this process, when properly instituted, results in more-humanistic knowledge, as it fosters trust and caring among people. Later in this chapter, a similar knowledge creation process will be discussed in the context of the Singerian organization.

The literature on knowledge management has burgeoned since Nonaka's writing and is too extensive for consideration here. For a relatively recent review of the academic literature, see Alavi and Leidner (2001) and for a more-comprehensive treatment of the topic from many perspectives, see Holsapple's (2003) two-volume set on the subject.

Even though Argyris (1977) examined the relationship between information systems and organizational learning a number of years ago, only recently has there been much interest in integrating the two (Robey et al. 2000). One way of integrating them is founded on Churchman's inquiring systems, which are briefly described in the next section.

# 3 A Review of Inquiring Systems

Churchman (1971) discusses the writings of the philosophers Leibniz, Locke, Kant, Hegel and Singer in the context of inquiring systems. Each of the philosopher's approaches provides for a different way of gathering evidence and building models to represent a view of the world (Mason and Mitroff 1973). The models of inquiry, being systems, have inputs, processes, and outputs. The output of an inquiring system is knowledge that is believed to be true on the basis of some guarantor. One of the most distinctive features of inquiring systems design is the inclusion of elaborate mechanisms for guaranteeing that only valid knowledge is produced. The same is true for inquiring organizations. The basic features of each philosophical inquiring system are summarized in Table 1 and briefly elaborated below, along with a discussion of how they relate to inquiring organizations. Characteristics of inquiring organizations are summarized in Table 2.

**Table 1.** Summary of inquiring systems

| | Leibniz | Locke | Kant | Hegel | Singer |
|---|---|---|---|---|---|
| Input | None | Elementary observations | Some empirical | Some empirical | Units and standards |
| Given | Built-in axioms | Built-in labels (properties) | Space-time framework Theories | Theories | System of measurement |
| Process | Formal logic Sentence generator | Assign labels to Inputs Communication | Construct models from theories Interpret data Choose best model | Construct theses, antithesis Dialectic | Strategy of agreement Sweeping in |
| Output | Fact nets Tautologies Contingent truths | Taxonomy | Fact nets | Synthesis | New standard Exoteric knowledge Simplistic optimism |
| Guarantor | Internal consistency | Consensus | Fit between data and model | Objective observer | Replicability Hegelian over-observer |

**Table 2.** Summary of inquiring organizations and IT support

| | Leibniz | Locke | Kant | Hegel | Singer |
|---|---|---|---|---|---|
| Input | None | Observations | Knowledge sources<br>Organizational memory | Opposing views | Units, standards |
| Given | Standards operating procedures<br>Rule base | Organizational structure and culture | Tacit and explicit knowledge<br>Working theories | Multiple stakeholders<br>Conflict | System of measures |
| Process | Formal analysis<br>Deductive reasoning | Communication<br>Consensus building<br>Reflection | Model building and testing | Arbitration, negotiation, discourse | Sweeping-in variables to overcome inconsistency |
| Output | Suggested course of action | Equivocality reduction | Integrated, timely knowledge | Conflict resolution<br>Enlarged perspective | New measures<br>Exoteric knowledge |
| IT support | DSS models<br>Expert systems | Databases<br>Communications technology<br>Groupware | Knowledge base<br>Model base<br>Problem processor | Group support systems<br>Dialectron<br>Dialectical DSS | Internet and World-Wide Web<br>Intranets and portals<br>Knowledge management systems<br>Modeling and visualization tools<br>Mobile technology |

## 3.1 The Leibnizian Approach

A Leibnizian inquiring system is a closed system with a set of built-in elementary axioms that are used along with formal logic to generate more-general fact nets or tautologies in a deductive manner. These fact nets are created by identifying hypotheses, and then testing them for consistency with the basic axioms. After the hypothesis has been verified it becomes a new fact in the net. The internal consistency of the system acts as the system's guarantor.

The Leibnizian organization takes a very formal and analytical approach to make inferences about cause and effect relationships. Decision-making procedures in Leibnizian organizations exhibit a strict, formal, bureaucratic, by-the-book approach. Missions, policies, goals, and standard operating procedures serve as Leibnizian axioms. Truth is determined in a procedural manner, with focus on structural concerns, and with error detection and correction being a direct consequence of comparing inputs with the accepted axioms of the system.

Decision problems in a Leibnizian organization are attacked in a formal, analytic style. Mathematical models, especially optimization models that attempt to get at the one best answer, would be widely utilized. A management science approach to decision making, and to a lesser extent a decision support systems (DSSs) approach, would be the hallmark of such organizations. Accounting departments within virtually any enterprise would be a prime example, with their emphasis on generally accepted accounting practices, and reliance on very well-defined systems and procedures. These systems attempt to get the financial statements precisely correct (despite the many assumptions and estimates that go into their preparation, such as those related to depreciation). Well-organized manufacturing operations and military units would be other examples.

Information technology most suited to this type of organization includes that related to mathematical models, decision support systems, accounting information systems and expert systems that instantiate the rules and procedures of the organization, and document management technology for describing policies and procedures.

## 3.2 The Lockean Approach

In sharp contrast to the Liebinizian approach, inquiring systems based on Lockean reasoning are formed from inputs from the external world. Each of these inputs is then assigned labels (properties). The Lockean system is capable of observing its own process by means of reflection and backwards tracing of labels to the most elementary attributes. It is also capable of communicating with other inquirers within a community of discourse. Agreement on the labels by the Lockean community is the guarantor of the system's observations.

A community of Lockean organizations, or an organization with Lockean units, learns by observing the world, sharing observations, and creating a consensus about what has been observed. Organizational knowledge is created through observation, interpretation, communication, and the development of shared meaning. The organization's culture or subculture (a Lockean community) must be supportive of this type of environment. That is, organizational members must feel free to observe and express opinions. Moreover, they must have a common language and mindset, which permits effective communication.

Thus the decision style of the Lockean organization is clearly group-oriented and open. Input is sought from a variety of sources, communication is encouraged, and consensus is sought. The deductive, empirical nature of the decision-making process requires tools for data acquisition and management, including the distribution of data to decision makers. The process also requires good communication systems to foster interaction among decision makers. Retail organizations tracking trends of sales in various territories and of different product lines are a good example.

The primary knowledge management tools in Lockean organizations, then, are repositories, such as data warehouses, for storing observations, data mining for analyzing observations, geographic information systems (GIS) such as Google Earth that assign meaningful labels to satellite images or other spatial data, and groupware tools, such as group support systems and e-mail, for facilitating the communication process, and the development of shared meaning. These are all tools that come under the DSS umbrella. Their development was enabled primarily by developments in telecommunications and computer networking.

Several new technologies have been developed to support consensus building among organization and team members. Corporate intranet and portal solutions that provide support to both traditional and virtual teams, Voice and Data over IP communication technologies such as instant messaging applications, Internet accessible databases. Mobile computing and communication technologies such as Internet enabled smart phones that give users the ability to do many things such as send and receive corporate e-mail and work with programs such as Microsoft Office® are also gaining widespread use as support tools for Lockean organizations. These technologies provide mechanisms to bring decision makers together where ever they may be on the planet, giving them access to information online to support the decision-making process. Some of these systems allow anonymous participation to encourage non-biased and unencumbered input.

## 3.3 The Kantian Approach

The Kantian system is a mixture of the Leibnizian and Lockean approaches in the sense that it contains both theoretical and empirical components. A clock and kinematic system are used to record the time and space of inputs received. The system then builds alternative models for the world based on Leibnizian fact nets and tests them according to their fit for the data. The system guarantor is the degree to which the models agree with the data.

The Kantian organization recognizes that there may be many different perspectives on a problem, or at least many different ways of modeling it. Provided with observations about a decision situation, the Kantian inquirer is capable of constructing various models which attempt to interpret and explain those observations. Each model has some goodness-of-fit measure, such as a standard error or variance. An executive routine is capable of invoking a particular type of modeling process, and observing its behavior. It can turn off models that are not performing well. It finally chooses the model which best explains the data.

The decision style of the Kantian organization, then, is to encourage the development of multiple interpretations of a set of data. It is both empirical and theoretical in its approach. The perspectives tend to be very analytically based, however, somewhat akin to combining the Lockean and Leibnizian approaches, but relying heavily on analytical methods for interpreting the data. This approach is appropriate for problems of moderate complexity (Mitroff and Linstone 1993). Bonczek, Holsapple and Whinston (1981) include an intelligent problem processor in their decision support model. The problem processor is an excellent example of model management in a Kantian organization. Data mining applications are an example, in that many different models may be applied to a data warehouse in a search for patterns that may be exploited for organizational goal seeking. Thus data warehouses, online, analytical processing tools, and software for business intelligence and data mining are suited to Kantian organizations.

## 3.4 The Hegelian Approach

Hegelian systems function on the premise that greater enlightenment results from the conflict of ideas. The Hegelian dialectic is comprised of three major players. The first player begins the dialectic with a strong conviction about a fundamental thesis. This player or subject, besides holding a strong belief in the thesis, constructs a view of the world in such a way that information, when interpreted through this world view, maximizes support for the thesis. The second player is an observer of the first subject and generates an opposing conviction to the original thesis. The final player in the Hegelian dialectic is an over-observer of the process with a bigger mind and who is relatively neutral with respect to the debate. The over-observer synthesizes a new (larger) view of the world which absorbs the thesis/antithesis conflict, thereby dissolving the debate; hence acting as the guarantor of the system.

The decision style of the Hegelian organization, then, is based on conflict. Decision makers encourage the development of opposing viewpoints on how to resolve a decision problem. Debate between parties holding the opposing views is encouraged. The decision is forged from the two views in such a way that the problem is not only solved, but also completely dissolved. Mason and Mitroff (1973) found this to be an effective approach to surfacing assumptions in strategic planning problems, leading to more effective plans. This is a more-complex decision style, as it is based on the fact that there is more than one perspective on the problem, and it specifically relies on the two most diametrically opposed perspectives. The two political party system in the U.S. is a good example, with voters serving as over-observers who attempt to form a synthesized view of the debate. Another example is trial by jury in which the defendant and prosecutor serve as the debaters and jurors as over-observers.

The knowledge to be managed in this environment consists of the information that the thesis and antithesis attempt to interpret, the thesis and antithesis themselves, the debate, and of course, the synthesis. Groupware designed to support negotiation and arbitration is well suited for this approach, along with repositories holding the data being debated, document management software, and analysis tools for developing points to support either the thesis or antithesis. An example application is contract negotiation. Hodges' (1991) dialectron and the dialectic DSS of Jarupathirun and Zahedi (in press) exemplify software in this arena.

## 3.5 The Singerian Approach

Two basic premises guide Singerian inquiry, a system of measures and the strategy of agreement (Churchman 1971, pp. 189–191). The first premise establishes a system of measures that specify steps to be followed when resolving disagreements among members of a community. The second principle states that disagreement may occur for various reasons, including the different training and background of observers and inadequate explanatory models. When models fail to explain a phenomenon, new variables and laws are swept in to provide guidance and overcome inconsistencies. Yet, disagreement is encouraged in Singerian inquiry. It is through disagreement that world views come to be improved. Complacency is avoided by continuously challenging system knowledge. Churchman (1971, p. 200) indicates that the Singerian inquirer "…is above teleological, a grand teleology with an ethical base." Singerian inquirers seek the creation of exoteric knowledge, or knowledge for every man, as opposed to scientific, esoteric knowledge that, as it matures, becomes relevant to an increasingly smaller audience. It seeks this knowledge in such a way as to take human and environmental considerations into account. In other words, the Singerian inquirer seeks the ability to choose the right means for ethical purposes for a broad spectrum of society.

The Singerian inquirer views the world as a holistic system, in which everything is connected to everything else. From the Singerian perspective, problems and knowledge domains (disciplines) are highly nonseparable. Complex social and managerial problems must be analyzed as wholes. The artificial division of knowledge into disciplines and the reduction of complex problems into simple components inhibit the solution to social and management problems. Solving complex problems may require knowledge from any source and those knowledgeable in any discipline or profession.

Decision making in the Singerian organization is a complex, open process best illustrated in Figure 1. Once a problem has been recognized it is viewed from the technical, organizational and personal perspectives described by Mitroff and Linstone (1993). The technical perspective derives from the Leibinizian, Lockean, Kantian and Hegelian approaches. The Singerian approach may rely on any of these, or sweep in other approaches as necessary to understand the decision problem and to analyze it. Ethical and even aesthetic issues are also addressed. The widest possible definition of the problem is taken, and the widest possible array of perspectives on the problem are considered. This is systems thinking at its utmost, what Mitroff and Linstone (1993) refer to as unbounded systems thinking. This approach emphasizes human issues individually and collectively, in all their complexity. It may involve formal models, business intelligence, data analysis, but most certainly is very open, seeks a variety of perspectives, and requires a vast amount of communication. As of this writing, it seems that the Bush administration is finally opening up to input from a wide variety of sources on what strategy to pursue regarding the war in Iraq. Participation by other Middle Eastern countries is even being considered. Undoubtedly the military is using data and models to estimate the impacts of increasing or decreasing troop levels or of deploying troops in other fashions. This is a wicked problem of the worst sort, with enormous ethical issues. Only time will tell if the decision-making processes of the administration do change and if so, what the outcome will be.

The Singerian organization has the purpose of creating knowledge for choosing the right means for one's end. Knowledge must be connected to measurable improvements. Measures of performance are judged not only by organizational standards, but also by what is good for all of society. A company has to know the kind of value it intends to provide and to whom. Knowledge is generated to be useful for all. In this regard, Singerian organizations model contemporary management trends where employees are empowered to contribute in the decision-making process. Working environments stress cooperation with fuzzy boundaries where teamwork and common goals are primary driving forces. Anyone may act as designer and decision maker.

Systems and organizations that use metrics practise Singerian inquiry. Accounting systems are perhaps the sine qua non of organizational measurement, as every enterprise must have one. However, accounting systems measure only the financial health of the firm. To understand and explain the organization fully, it is necessary to sweep in variables from a wide variety of sources both inside and outside organizational boundaries. Managers in a Singerian organization should develop measurement standards, continuously compare organizational performance to those standards, and modify models of performance, as is required to achieve the standards.

Numerous examples of metrics exist in information technology. Telecommunications standards reuse libraries, code generators, objects, and software metrics all incorporate standards and systems of measurement. The metrics and standards are constantly evolving due to the rapid pace of emerging and improving technologies.

Because the Singerian organizational processes are so diverse, the information technology to support them must be diverse as well. The Internet and business/competitive intelligence (BI/CI) applications serve as resource and dissemination agents for Singerian inquiry. During the sweeping-in process, inquirers are able to use the web to gather and assimilate information and the BI/CI applications help to refine variables and reduce inconsistencies in the system of measurement. Once defined, new measures and standards can be posted to the web and distributed to all interested parties. One of these interested parties could be technologies such as executive information systems (EIS). EIS assist top-level management by sweeping in variables from the environment such as legislative changes or data obtained from CI systems and combines it with existing organizational knowledge to provide useful information. In this way, the exoteric knowledge goes forward to be useful "for all men in all societies" (Churchman 1971, p. 200).

Modern visualization software and mobile technology can also be highly instrumental in Singerian environments. For example, the new Planners Lab© (PL) developed by GRW Studios integrates a proven modeling language (that of the interactive financial planning system) with Macromedia Flash MX© and mobile technologies to provide a powerful way for managers to use DSS models to visualize decision problems and share the results with others where ever they may be located. Users may operate in occasionally connected mode, a concept promoted by Macromedia that means: (1) the official version of the software resides on and is accessible from a network server, and (2) the fully functional software is also available on a local computer while not connected. If a user has editing privileges, changes in local status can update the network version when next connected. Different users may save different versions of the same model or save various scenarios with that model.

A screen shot of a PL model is shown in Figure 2. It is easy to do what-if analysis with PL models because the trend lines representing what-if variables can be manipulated directly by moving them with the mouse and pointer, and the results are directly observable on the target variables. Graphics software such as this has been shown to help users understand the structure of problem domains and to enhance communication among group members. This is especially important in complex management domains such as those of Singerian organizations.

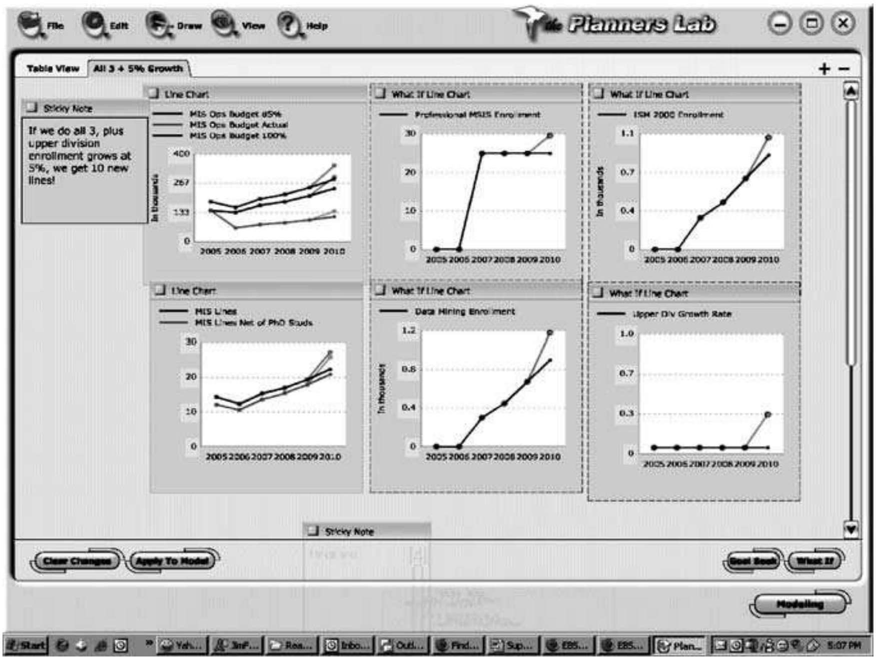


**Figure 2.** Visualizing what-if analysis with a Planners Lab model

## 4 Summary

To be successful, the modern organization must be capable of continuous learning. Churchman's inquiring system models provide the basis for a new perspective on learning organizations. Examining organizations from the point of view of inquiring systems reveals the need for a guarantor of knowledge in learning organizations. A learning system constitutes the core of the learning organization. By exploring models of inquiry, learning organizations can gain insight into how learning systems may be designed. Ways in which information technology may be used to support inquiring organizations have been suggested.

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# CHAPTER 66
# Towards Decision Support for Participatory Democracy

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In many parts of the world there is growing demand for participation in public policy decision making. This demand could be satisfied by the design and deployment of Web-based group decision support systems to aid large groups of, possibly unsophisticated, users in participating in such decisions. After describing several mechanisms for participatory democracy, we provide a framework for decision support in this area and describe decision support functions that could be implemented in such a framework. We illustrate the ideas with a specific system to support participatory budget elaboration through the Web. Several practical issues are discussed along the way.

**Keywords:** Decision support; Electronic democracy; Negotiation analysis; Participatory budgeting; Participatory democracy

## 1 Introduction

Information and communication technologies (ICTs) are influencing politics, much as they have previously revolutionized business, education, and the arts. The changes are affecting both our democratic institutions and democracy at large. They may also shape citizens' behaviors, affect their learning about public policies, and politicians' interaction with the public.

Current models of democracy are mainly representative. At regular intervals, people elect representatives who take charge of making decisions, with little additional input from the citizens, until new elections. This practice has evolved into a political routine in which politicians hardly ever maintain substantial contacts with the citizens, except during election campaigns. The resulting disappointment with politicians and distrust about the political system (Bray and McLaughlin 2005) manifests itself in low voting rates during elections and has led to what is generally termed the democratic deficit (Steffek et al. 2007).

The direct democratic model, typically associated with ancient Athens (Crick 2002), may be viewed as the other extreme of the spectrum of democratic implementations. In such a model, people are involved in almost permanent public decision making. However, at the implementation level, the Athenian model had flaws from today's perspectives of direct democracy; women and slaves had no right to vote and many of the poorer men could not leave their work to attend meetings. It is therefore estimated that only around 15% of the people living in Athens actually took part in the process (op. cit.).

Between the representative and direct democracy models, there is room for many intermediate models, each with a varying degree of citizen contribution and participation. Participatory democracy promises broadened citizen involvement and contribution, leading to greater legitimization and acceptance of public decisions, greater transparency, and efficiency in public expenditures, and greater citizens' satisfaction (Renn et al. 1995, Baierle and Cayford 2002). This is not to say that there are no social and economic costs associated with participatory democracy, including the participants' myopic and short-time perspectives (Irvin and Stansbury 2004). Nevertheless, there seems to be no better way to address the problems associated with the representation-based democracy other than through increasing citizens' involvement in decision making. Participatory democracy emphasizes learning and encourages citizens to consider the preferences of other participants and to justify or modify their own preferences (Radcliff and Wingenbach 2000).

Information and communication technology can improve participation processes by providing tools for the facilitation and support at the following levels of citizens' involvement and responsibility:

1. *Informing* is a one-way relationship between the government, which actively provides access to information, and citizens, who are able to use government services and form opinions (e. g., via government websites and official gazettes);
2. *Consulting* is a two-way relation of consecutive actions, in which the government poses questions and formulates issues for consultation while citizens provide feedback (e. g., via public opinion surveys);
3. *Participating* is a two-way relation of simultaneous actions by both the government and citizens engaging in the design of the process and content of policy making. At this level, the citizens have equal standing in shaping the discussion (e. g., via consensus conferences and citizen juries). However, the responsibility of the final policy (decision) rests with the government; and
4. *Deciding* is the full-partnership relation between government and citizens which, in addition to the activities from the three previous levels, includes involvement in policy decision (e. g., via citizen-initiated referenda).

The first three levels comprise the Organization for Economic Co-operation and Development's (OECD's) public management service analytical framework used in comparative surveys and country case studies (Caddy and Vergez 2001, p. 21). We added the fourth level, which corresponds to direct democracy or institutions in which citizens participate in all activities of the policy-making cycle. At this level, decision analytic techniques, methodologies, and ICTs can provide participants with support throughout the process (Gregory et al. 2005, Grönlund 2005).

Here, we describe how such support can be implemented. We first review several of the standard mechanisms for participation using the language of decision support. We then provide an overview of some of the ICT tools used to support participatory democracy. Next, we introduce a common framework to support decision making in a participatory democracy and describe related practical issues, referring mainly to its viability and stressing that there is more to this approach than just providing large group decision support. We suggest the required support functions for participatory democracy decision support. We then describe how these ideas are implemented in PARBUD, a system to support participatory budget elaboration through the Web. We conclude with discussion of issues related to the implementation of decision support for participatory democracy.

## 2 Theories, Processes, and Mechanisms for Participatory Democracy

Support for participatory democracy should be grounded in the existing theories of democratic policy making. Two classes of theories are introduced, followed by the policy process and selected existing mechanisms (institutions) used in participatory decisions.

### 2.1 Social Choice and Democratic Discourse

There are two competing schools of thought on public involvement in decision making (van Mill 1996) which can be used to provide the theoretical foundations for decision support of participatory democracy.

*Theories of social choice* view politics in terms of the aggregation of individual preferences (Elster 1997). Various models have been proposed, all leading to participation in government through voting and referenda. These theories deal with issues of democratic fairness and problems with rules regarding the majority choice. Arrow's (1952) impossibility theorem and McKelvey's (1976) proof for voters' intransitive preferences are examples of problems that the preference aggregation methods face. Procedures that aim to reduce these and other problems associated with preference aggregation involve preference modification – leading, if possible, toward a consensus – and focus on the participation process and its innate benefits, rather than the fairness of its results (Radcliff and Wingenbach 2000, Dryzek 2001). Some attempts to strengthen the role of the process, with its purpose being to reach as close to a consensus as possible, share much with the theories of democratic discourse introduced below.

*Theories of democratic discourse* focus on the process. They view politics as the transformation of preferences through rational discussion (Elster 1997). Active deliberation and unrestricted discourse allow participants to arrive at consensus and achieve rational outcomes. According to Habermas (1994), Dryzek (1990), and others, the democratic discourse is based on three assumptions: (1) access for all citizens is free and open; (2) transformation of participants' preferences and objectives through debate is possible; and (3) decision legitimacy and approval can be achieved through reasoned deliberation.

Discourse is the process of the communication of reasons and justifications for claims and actions; its purpose is to seek a mutual understanding concerning the course of action. The discourse paradigm posits that open communication coupled with people's willingness to hear and understand leads to the convergence of individual preferences and, thus, to consensus. The obvious difficulties arising from the practical implementation of a democratic discourse model in very large groups led their proponents to suggest elections and voting (Habermas 1994, p. 9). This, however, introduces problems similar to those with which social choice theories must cope.

The key difference between these theories is their consideration of *rationality*. Social choice has a minimalist and instrumental view of rationality (van Mill 1996). What action is chosen depends on the participants' individual preferences, which are fixed and can be, and are, measured using certain democratic institutions (e. g., a referendum). Individual preferences are then aggregated, producing a result that reflects the people's will (the majority). The assumption of fixed preferences is important. Otherwise, they could not have been measured and aggregated. This does not imply that social choice theory does not allow for preference modification, but that its institutions ignore it; they are designed to measure and aggregate. Making more than one measurement would introduce chaos and undermine the concept of rationality based on the preferred outcome.

Democratic institutions are designed to measure preferences at given points in time and they do not deal with the ways in which these preferences occur and are modified. Therefore, numerous other mechanisms (e. g., polls, political rallies, pressure-group interventions) have been established to influence citizens and shape their preferences. These mechanisms precede, but are not part of, democratic institutions because of the assumption that preference aggregation is the sole requirement for process convergence.

Instrumental or substantive rationality is at the core of traditional decision analysis. It is concerned with the process of individual decision-making focusing on the construction of decision attributes and alternatives and the specification of individual preferences. The process leads to the construction of a utility function or another scheme allowing for the selection of an optimal (Pareto-optimal) alternative. However, as Simon (1986, p. 215) notes: "In a substantive theory of rationality there is no place for a variable like focus of attention" nor is there a place for interaction between the process of expressing and reflecting on preferences and preference values. These and other similar variables are in the realm of discourse or procedural rationality which posits that "the rational person … goes about making his or her decisions in a way that is procedurally reasonable in the light of available knowledge and means of computation" (op. cit., p. 211). The person's rationality results from his/her engagement in the discourse process with other participants; they engage in an open and substantive discussion with the purpose of constructing a shared view. The preferences and low-level objectives are tentative and are formulated and reformulated during the course of democratic discourse.

Pure models of deliberative democracy require ongoing participation of citizens as in ancient Athens. Modern propositions aim to address concerns about the democratic deficit and citizens' frustration with politics and politicians. The problem is that "deliberative democracy … remains on the face of it impossible" (Dryzek 2001, p. 651). The cognitive effort and time required for decision making and the inability to engage in any meaningful discussion with millions or even thousands of others render this approach infeasible. Solutions that attempt to alleviate this problem include restricting deliberation to a few extremely important matters (Rawls 1993); restricting the number of participants, but making sure that those involved are representative (Goodin 2000); and two-track deliberation – in the public sphere and in the legislature (Habermas 1996). In all of these situations, effective participation by citizens who may have no training in policy making and insufficient knowledge about the problems at hand is predicated by systems and tools that aid and support them in the individual and group decision-making activities.

## 2.2 The Policy-Making Cycle

Democratic governance is a continuous-cycle process comprised of the following five stages (Dunn 1994):

1. *Agenda setting* establishes priorities among the issues of public concern that require policy action or the change of a previous policy.
2. *Policy analysis* aims at better understanding a public issue on the agenda: the problem is formulated and alternative policies are created to solve it. To do this, the facts are clarified and the interests and objectives of citizens and stakeholders are considered.
3. *Policy decision*: based on the previous analysis, a final decision is made and the chosen policy is fully specified.
4. *Policy implementation:* once a policy of action is selected, it is put into practice. At this stage the necessary public resources and regulations are used and created to make the policy operative.
5. *Monitoring* aims at continually evaluating whether the implemented policy is producing the expected results, identifying whether the policy should be changed or if new issues need to be considered in the agenda.

The level of public participation at each stage of the policy-making cycle defines different democratic models. In the *representative* democratic model, the citizens choose representatives within a fixed period of time, those whose electoral promises better match their interests, who govern the society on behalf of the citizens and in accordance with what they understand is the public interest. Elected representatives take part in stages 1 and 3, whereas civil servants and external expert advisers take part in stages 2 and 4. Public participation is reduced to elections and opinion polls, mainly at the monitoring stage, to sample public satisfaction with the running policies. Occasionally, the public may be consulted via a referendum at stage 3.

The *direct* democratic model proposes that the public should be directly consulted at the policy decision stage in almost every policy decision, and possibly in stages 1 and 2. Finally, the *participatory* democratic model proposes engaging the public at every stage in a variety of ways. It emphasizes public participation in stages 1 and 2 of the policy-making cycle, leading to final policy decisions being made in stage 3 by the public and/or elected representatives.

There are two key aspects that characterize the scope and degree of participatory democracy: (1) participants, that is, those involved in the decision-making process, and (2) problems, that is, what type of decision-making problem the participants decide upon. The number of decision makers and the selection criteria for participants determine the scope of the system: the more participants and the less restrictive the participation criteria, the more participatory the democracy is. Note that in each case the administration is responsible for the implementation of the selected policy, creating the administrative procedures and infrastructures that allow the citizens to access the services and information concerning the implemented policy.

Social choice theories will typically be applied at stage 3 of the policy-making cycle, providing theoretical foundations for designing valid mechanisms for participatory decision making. Theories of democratic discourse can be applied to support public debate at the policy analysis stage. Thus, advocates of the direct model of democracy focus on social choice theories, whereas defenders of the participatory model are usually more interested in democratic discourse theories.

## 2.3 Some Participation Mechanisms

The rules that govern the selection of the decision makers and the decision process determine the primary participatory democracy mechanism. As mentioned in Section 1, there are four levels of the citizens' involvement (informing, consulting, participating, and deciding) and concrete democratic mechanisms may be associated with each level.

We are primarily interested in the mechanisms used at the participating and deciding levels. These include stakeholder workshops, citizen juries, consensus conferences, deliberative opinion polls, negotiated rulemaking, task forces, and town meetings (Noveck 2004, Rowe and Frewer 2005). We briefly describe some of them to gain insights and provide a basis for the general framework presented in Section 4.2. Note that many of these mechanisms essentially refer to a very similar concept. For instance, consensus conferences, citizen councils, deliberative focus groups, citizen panels, and citizen juries are different variants of the same participatory mechanism. There are five key types of mechanisms:

1. *Citizen juries* draw on the symbolism and practices of a jury in a court. The jury is made up of people usually selected at random from the target population. The jurors question experts who provide different perspectives on the topic, and produce a summary of their conclusions. This may be supervised by an advisory panel composed of people with relevant knowledge and interest in the outcome but who take no direct part in the jury deliberations. Members of this group subsequently decide whether to respond to, or act on, elements of the report.
2. *Stakeholder workshops.* A small group of participants who represent various interest groups is convened to examine an issue and discuss it with politicians and administration. Such a group may be used to monitor the progress of the project and inform the community about new information concerning the project's implementation.
3. *Deliberative opinion polls* are a variant of opinion polls incorporating deliberative democracy principles. They aim to establish a base of informed public opinion on a specific issue. They combine small-group discussions involving large numbers of participants with random sampling of public opinions: citizens are invited to take part at random, so that there is a sufficiently large group of participants to provide a relatively accurate representation of the public opinion.
4. *Town meetings* are mechanisms of direct democracy at the local, municipal, and district levels. Open discussion and questioning of authorities may end with voting, which is used to aggregate the citizens' opinions, leading to decisions.
5. *Referenda* are consultative mechanisms of direct democracy in which citizens choose from the available options through voting, each vote having the same weight. Direct universal voting on issues via referenda has many advocates (Westen 1998). However, they raise many political and technical issues (Uleri and Gallagher 1996), including the entitlement to call a referendum, the implications of the outcomes, the required majority[1], and the number of referenda on the same issue[2].

The instruments described above have been proposed, studied, and implemented within the growing field of participatory democracy. Given their importance, it is perhaps surprising that there has not yet been a systematic approach to developing guidance about good practice in this area. Furthermore, given the large number of different participation methods, there has been even less guidance on choosing

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[1] In the last referendum in Catalonia, for example, the turnout was 49.4%, out of which 73.9% voted in favour – resulting in a decision being made by 36.5% of the census.

[2] An example of this is the three referenda held so far in Quebec to try to obtain the independence of the province.

which methods are most appropriate to a particular set of circumstances. A recent report by the Council for Science and Technology in the UK noted (CST 2005) that, despite many experiences with the government engaging in a dialogue with the public, there is a "lack of learning from experiences between and even within organizations."

The typical participation involves discussion during face-to-face meetings and the use of voting, frequently just by raising hands (Rios and Rios Insua 2007). Such meetings can disadvantage people with poor communication skills. It has also proven difficult to involve the young and the poor. In terms of ICT usage, the focus has been on discussion forums or other online discussion tools (Davies 2007), and online pooling and voting tools (Krimmer 2006). However, the problem is the lack of methodologies to identify and manage conflict and support joint problem solving. Decision support technology is usually not employed; no proper problem structuring tools are used, no formal quantification of citizens' preferences is undertaken, and no formal negotiation or group decision support tools are used, except for those based on voting. Here, we discuss possible solutions to change this status quo.

# 3 Support for Participatory Instruments

The above (and many other) participatory mechanisms have been implemented in a variety of ways. Most frequently, ICT allows for their deployment on the Web and for seamless mechanism integration. In this section, we examine some of the ICT-based systems and tools designed for the primary purpose of facilitating and supporting consultation and deliberation. Their purpose is primarily oriented towards discussion facilitation and the gathering and categorizing of citizens' opinions; they aid the activities of democratic discourse. Other systems, in particular electronic voting, are founded on social choice theories.

## 3.1 Online Deliberation

Initial efforts to use ICT in participatory democracy were based on the ability of the Internet to connect large numbers of people and help them to communicate, and aimed at designing explicit or implicit implementations of democratic discourse theories.

Tools and systems for online participation and deliberation are based on group support systems (Jessup and Valacich 1993) and meeting systems that belong to the area of computer-supported cooperative work (Turoff and Hiltz 1993). These systems have their roots in behavioral decision theory, both at the individual and group levels. Early initiatives in online participation and deliberation activities were based on email-based discussion forums using listserv technology; one of the best known participatory democratic initiatives is the Minnesota electronic democracy project, which began in August 1994 (Aikens 1998). Later, such systems incorporated tools for public and private communication, agenda setting and process structuring, brainstorming and idea generating, selecting criteria and idea categorizing, topic aggregating and commenting, conflict identification and even voting. Examples of these systems include Facilitate (http://facilitate.com), GroupSystems (http://groupsystems.com), and Meetingworks (http://entsol.com). These systems were initially developed for local area networks and then redesigned as online applications and Web services. Their purpose is to facilitate decision processes undertaken by small distributed or localized groups, often with the involvement of a human facilitator or moderator.

A research project led to the design of the group report authoring support system (GRASS, http://grass-arena.net); a prototype has been tested with three cases, including the deliberation on the effects of greenhouse gases and the simulation of an earlier discussion in British Columbia regarding issues related to forests and forestry and undertaken by the BCFOR group using a listserv (de Moor and Aakhus 2006). This initiative appears to have stalled and no work has been done since 2004.

## 3.2 Argumentation Support

Argumentation support systems provide enhanced online deliberation tools such as discussion forums with support features for argumentation, helping users to argue in a dialectical manner (Hamalainen et al. 1992, Sillince and Saeedi 1999, de Moor and Aakhus 2006).

The debate is structured so that an inference mechanism, based on logical or probabilistic rules, assists users to arrive at agreed conclusions. It is assumed that participants are open to persuasion in order to reach a consensus regarding the facts, values, and available science via argumentation. The deliberative approach assumes that a decision regarding public conflict issues can be reached through rational argumentation. This requires that participants share a common general objective, which is not always the case, as there may be quite different individual views/perspectives and very strong positions. Thus, in practice, the conclusions obtained from the debate do not lead to a decision itself, although they can be used as an input to making a final decision. Nevertheless, these systems are a good means to gather ideas, for the formation of public opinion, and for problem understanding. Thus, they are useful before a referendum or whenever a public decision will be made by voting, as well as for citizen juries or in participatory decision processes based on decision conferences.

GeoMed (Geographical Mediation) is an example of an integrated system that provides Internet-based support for collaborative spatial decision making, such as for environmental and urban planning (Karacapilidis and Pappis 1997, Gordon et al. 1997). This type of planning involves many parties with diverse backgrounds, interests, and viewpoints. GeoMed has three integrated components: (1) computer support for collaborative work; (2) a geographic information system

(GIS) viewer; and (3) a mediated issue-based discussion forum with argumentation support. Our interest here is in the argumentation model included in the last component. This model is based on an adaptation of the ZENO argumentation framework (Gordon and Karacapilidis 1997) modified for collaborative decision procedures for the urban-planning domain.

GeoMed uses an issue-based information system (Rittel and Webber 1973) that structures the discussion as a tree: the root represents an issue – in our context, the decision to be made or goals to be achieved (e. g., what is the most appropriate location for an airport?). Participants propose and discuss solutions to this issue, arguing their pros and cons. Positions represent statements and are identified as basic discussion elements, belonging to one of the following types:

- Alternative positions propose a solution to the issue.
- Arguments are positions for or against another position. Supporting arguments and counter-arguments allow the participants to voice their views regarding a particular position.
- Constraints are positions that represent the relative importance between two positions. They are used to express preferences and value judgment statements. Redundancy and consistency of constraints are checked.

The activation status of a position (alternative or constraint) depends on its subtree of active arguments for and against, as well as active constraints about the importance of these arguments. A position without active arguments is, by default, active. The status of a position can be computed in various ways: (1) A position will be active if there is at least one active argument supporting it, (2) if there are no arguments against it, or (3) the constraints can be used to weight the pros and cons of a position. In the absence of active constraints, all the arguments of a position have the same weight. Active constraints increase the weight of its more important position and decrease the weight of its less important position. When the difference between the weights of its active supporting arguments and its active counter-arguments is not negative, the position is activated.

The ZENO framework embedded in GeoMed uses this difference among weights to aggregate pro and con arguments associated with an alternative as a score to recommend the alternative having the highest positive score at the end of the discussion. Thus, to support group decisions, the ZENO framework has proposed the above scoring mechanism to compare feasible (active) alternatives.

## 3.3 Electronic Petition Systems

A participatory process may be triggered by citizens through a petition using ICTs (e. g., http://epetitions.scottish.parliament.uk/). Citizens can submit a public petition providing information relating to the issues raised. The e-petitioning system enables the collection of signatures online, rather than just on paper, to support a petition (Macintosh et al. 2002). In this way, petitions become accessible to a potentially much wider audience, allowing a communication channel for participation alternative to the traditional one. Each petition has also its own online discussion forum.

The functionality of the system allows citizens to create a petition, view open petitions, access additional information of a petition issue, join a discussion forum regarding a petition, sign a petition by adding a name and address, and follow the progress of a petition once it has been submitted to the parliament. This initiative for public petitions allows citizens to participate in the agenda-setting and policy-formulation stage of the policy cycle. The e-petitioning system supports potential participation via the Internet. Thus, this system provide a more effective and efficient version of the petition process. As mentioned above, the system gathers signatures for a petition of those citizens who are in favor of it. However, there is no possibility of signing against a petition.

## 3.4 Electronic Voting Systems

Internet voting systems have gained popularity and have been used for government elections and referendums in Estonia and Switzerland, with trials in many other countries. In Switzerland, where it is already an established part of local referendums, voters receive their passwords to access the ballot through the postal service. Most voters in Estonia can cast their vote in local and parliamentary elections, if they want to, via the Internet. This has been made possible because most Estonians carry a national identity (ID) card equipped with a computer-readable microchip, which they use to access the online ballot. All a voter needs is a computer, an electronic card reader, his/her ID card and PIN, and he/she can vote from anywhere in the world. Corporations and organizations routinely use Internet voting to elect officers and board members.

Systems used for e-voting include Opinions-online (http://www.opinions.hut.fi/introduction.html), a Web tool to organize voting; Vote-pro (http://www.vote-pro.com) and 2ask (http://www.2ask.net), which are proprietary software; the VoteSecure Project (http://www.votesecure.org), which is open source; and the freeware KOA System (http://sort.ucd.ie/projects/ucdkoa).

A key concern with e-voting systems is security. There are, however, cryptographic solutions that allow voters to verify that their vote is recorded and tabulated; to provide evidence proving how they voted with a form of electronic receipt, signed by the voting authority using digital signatures; and to allow voters to present proof of how they voted to a third party through a receipt with a randomly generated identification.

## 3.5 GIS and Participatory Spatial Decisions

Many decisions that involve citizens are spatial. That is, they deal with location problems regarding, for example, the storage or disposal of radioactive waste, the location of new facilities or the expansion of existing ones, or transportation. One of the key forms of decision support is via a geographic information system (GIS), which, in its core, is a computerized interactive map with a database to store and manage spatially referenced data.

In their traditional mode of operation, GISs are seen as an impediment to participation and empowerment because they have traditionally been operated by trained decision makers using restricted databases, behind closed doors (Pickles 1995). Making GIS tools, and their associated databases, available to the public is the prerequisite for placing all stakeholders on equal footing. The proliferation of the Internet is helping to make GIS tools accessible through the web, so that they can be used by citizens to develop understanding of the spatial consequences of the proposed projects and actions affecting their communities. As the public will need to interpret and use these tools on the Internet effectively, their interface design should be adapted for public use and technical jargon should be avoided.

Online GISs also enable users to link any amount or kind of data to a location on a map. Thus, in order to provide the spatial information necessary for a decision analysis, spatial knowledge and preferences can be collected and easily shared and distributed via participatory GIS tools. In multicriteria decision making (Carver 1991), both spatial and nonspatial attributes may be considered. GISs allow the spatial consequences of alternatives to be displayed on a map. For example, costs, pollution, servicing areas, affected areas, and revenue have all been successfully included in GISs.

Concerning the type of public decision problems in which a participatory GIS may be used, we note that, as the spatial scale of a decision increases from the local to the regional and ultimately the national scale, the proportion of people willing to participate actively gets smaller (Kingston et al. 2000). We also note that the ownership and copyright covering some spatial data may be a disincentive to develop and deploy participatory online GIS solutions for local decision problems (Carver et al. 2001).

## 3.6 Systems Based on Decision Analytic Support

Increasingly, the ubiquitous Internet and its various associated technologies allow a strategy of deploying generic decision support tools to aid groups in undertaking political decisions to be devised. So far, the most ambitious effort in this direction is the Decisionarium site at the Helsinki University of Technology (Hämäläinen 2003), which aims at somewhat sophisticated users of decision analysis tools. It provides tools and systems to support preference modeling through the construction of value functions, to support negotiation, voting and opinion polling, together with related e-learning materials. The tools are somewhat isolated and little attention is paid to such desirable support functions as decision making under uncertainty or process management facilities. Decisionarium has been used to support participatory environmental decision making, albeit on a small scale (Hämäläinen et al. 2001, Mustajoki et al. 2004).

Although one possibility would be to deploy generic decision analytic tools complemented by simple communication tools, most of the applications of decision support systems (DSSs) to e-democracy are translations of those DSSs that have been used to support civil servants in analyzing technical issues that should be decided by the representatives or technical staff of the administration. In order to deal with different inputs from the participants, sensitivity analysis tools are added to facilitate the group elicitation of a common preference representation. An example of this trend is the Älgö experience (Danielson et al. 2005), in which a structured process involving all the interest groups was used by local authorities to engage the stakeholders in analyzing a problem that had been unresolved for several years.

A decision support tool for individual decision making, *DecideIT*, was used to incorporate the input from all the participants into the analysis and to support decision analysis using techniques from sensitivity analysis. This tool uses multi-criteria analysis and can handle numerically imprecise inputs using triangular distributions over intervals and comparative judgments. It allows the incorporation of different views and values into a decision model through intervals.

Finally, one could also think of developing specific tools aimed at supporting participation in particular public settings. An example here is PARBUD (Rios and Rios Insua 2006), a system to support participatory budget elaboration through the Web.

## 3.7 Software Agents

A typical criticism of direct democracy, participatory democracy, and even e-democracy in general is that people who are not professional politicians will not typically have the time, skills, and will to take part in the ensuing participation processes. We have already mentioned the low participation rate in ancient Athens. Indeed, because of the potentially heavy demands of participatory democracy on the participants, in terms of time and cognitive load, a potential participant could delegate his intervention in the process to a software agent, which would act on his behalf in some of the tasks or in the whole process, possibly with consultations from the agent to the owner when in doubt. These agents could also be used to detect a relevant public issue in which its owner would be willing to participate.

In our context, the agent would have a built-in utility function, elicited from the owner. The agent would invoke this whenever it was facing a decision, choosing among alternatives, or voting among options. The agent would refer to its owner whenever the decision was not clear enough (e. g., when two alternatives are too close in value, as determined via a sensitivity analysis). It would also periodically revise such functions depending on queries from the owner. The agent utility function would be based on an ample set of objectives and adapted to each problem by retaining only those attributes that are relevant to the problem at hand.

# 4 Decision Support Framework for Participatory Democracy

Participatory democracy requires that individuals understand the implication of their values and mechanisms to incorporate them into the decision analysis. The most advanced mechanisms of participatory democracy (e. g., negotiated rule making and town hall meetings) require that individuals make decisions. Because the participants may have different interests and objectives, their views need to be identified, analyzed, and compared – requiring support for both individual and group decision making. Another important aspect of participatory democracy refers to the provision of support to a very large number of users who might be very diverse in cognitive and decision-making skills and styles. Gregory et al. (2005), without referring to ICTs, claim that decision analytic methodologies provide an effective and valuable means for public policy deliberations. We explore here how such methodologies can be enhanced and implemented through ICTs.

## 4.1 Decision Analytic Methodologies for Group Decisions

From an operational point of view, French et al. (2007) suggest categorizing decision analytic methodologies for group decision support into five modes with somewhat fuzzy boundaries. Here, we adapt this taxonomy for the purpose of participatory democracy support, noting that our focus is on modeling and supporting citizens as decision makers in both individual and group settings, rather than analyzing, structuring, and representing the decision problem(s).

GDM1. *Informed voting* implies working with each participant and developing his/her personal decision analysis to guide his/her choice. In light of this, each participant votes and the group choice is made according to these votes (Nurmi 1987).

GDM2. *Explicit preference aggregation* involves eliciting each participant's subjective probabilities and utilities, combining the individual probabilities and utilities into group probabilities and utilities, respectively, to form the corresponding group-level expected utilities, and choosing accordingly (Luce and Raiffa 1957, French 1985).

GDM3. *Joint evaluation* involves gathering the group together and facilitating discussion of issues. Through discussion, group values are elicited directly with no intermediate step for individual members. Areas of disagreement are noted and explored through sensitivity analysis, leading to a decision reached by consensus without formal voting (French 2003).

GDM4. *Negotiations* involve the group participants interacting and discussing how to solve an issue of public concern, while trying to reach an acceptable agreement (Raiffa 2002).

GDM1 and GDM2 use procedures for aggregating an individual's preferences; in the first, ordinal preferences are used and in the second, cardinal preferences. A voting procedure is defined as a rule to combine individuals' ordinal rankings in a complete and transitive order for the group. Although there are many possible voting rules, not all are considered acceptable. GDM1 studies criteria satisfied by specific voting rules, as well as conditions under which a voting rule that satisfies a set of reasonable requirements exists. It is known tha,t while voting is quite well understood by participants and easy to use in very large groups, it can be subject to manipulation and, more importantly, it suffers with respect to Arrow's (1951) impossibility theorem.

One way to alleviate the problems arising from the Arrow's result is to obtain more information about individuals' preferences. Thus, instead of asking each participant to order alternatives, a GDM2 procedure (also called arbitration) asks participants for cardinal information about strengths of preferences. There are two possibilities from which the explicit aggregation of an individual's preferences can be considered:

- *Authority aggregation* is made from the perspective of a single supra decision maker (SDM) who has the authority to make the decision on behalf of the group and wants to consider the preferences of the group members in his decision analysis (Keeney and Raiffa 1976). When a government agency has the legal responsibility and accountability for making a decision, but does want to take into account the views of citizens and stakeholders, then the assumption of an SDM becomes plausible.
- *Axiomatic aggregation* is used when the group shares the responsibility for decision making. An equity-based axiomatic aggregating procedure may be used here to compute a group choice (e. g., the Nash solution). It requires that the group accepts the axiomatic procedure before its use.

Additive and multiplicative multiattribute preference models have been implemented in GDM2, using the preference values of the group members as attributes to evaluate consequences. These models for aggregation of cardinal preferences require interpersonal comparison of the individuals' strengths of preferences, which are the cause of inconsistencies when axiomatic aggregation procedures are used. When the aggregation procedure is determined by an authority, the trade-offs on the impact of a decision among the group members' values are made subjectively within the mind of the authority, defining valid interpersonal comparisons. Note that the Nash (1950) solution is invariant with respect to positive affine scale transformation of the individuals' preferences, and, therefore, it does not require interpersonal comparisons. However, it requires determination of the individuals' disagreement values.

Models under GDM3 involve the evaluation of consequences directly by the group without considering individual evaluations, and, therefore, no aggregation is necessary. Thus, it is the group that should reach a consensus in an interactive way to determinate the group values.

The direct model of democracy and the social choice theories favor modes GDM1 and axiomatic GDM2. However, although one can define algorithms in these two modes to move the numbers and votes around so that ultimately a group ranking is mathematically defined, if one examines the underlying assumptions, one can almost always find inconsistencies, typical of Arrow's theorem (1951). Authority GDM2 favors representative models of democracy where the entity responsible of the decisions is concerned in its analysis with the preferences of the members of society. It favors the design of mechanisms to extract a valid input from the public. Most decision analysts have proposed group decision support based on GDM3 to guide public deliberations within the participatory model of democracy. GDM3 uses facilitated workshops or decision conferences in which the group discusses facts and values that should lead to a decision for the group. Disagreements are investigated using sensitivity analysis to focus the discussion on the differences of opinions that matter, aid participants to communicate and mutually understand their positions, and build consensual understanding. This process can be supported with elements of the democratic discourse theories described in Section 2.1. GDM3 assumes that, while there may be quite different perspectives represented among group individuals, they share a general common interest and are willing to reach a consensus. Finally, GDM4 allows a softer facilitated social process to which individuals bring very different interests and perspectives. This mode uses negotiation analysis principles and democratic discourse theories to design valid participatory processes to support the public within the participatory model of democracy.

All in all, we should briefly recognize a number of issues that participatory democracy brings to standard group decision support. Some of these are answered below. First, we have the issue of scalability. GDM1 and GDM2 are suitable provided that the analysis and elicitation are undertaken with the aid of a system. However, their contribution to the citizens' participation is limited. GDM3 and GDM4 were initially conceived for five, 15, perhaps 50 participants, but not for the thousands or even millions that one may expect in a participatory process. Then, there is the issue of capability; these modes were designed for participants who have analytical inclinations. Note, however, that analytical sophistication should be expected only from the facilitators supporting the processes. The idea therefore would be to create a user-friendly facilitator. A third issue refers to time and will, as there is a clear underlying assumption that users should have the time and will to participate in the process. This is not so frequent in modern times. We return to this issue later when discussing participation incentives and delegation of participation to software agents. Finally, the issues of communication and coordination should be considered. It is not clear how decision analyses should be communicated to the general public. Coordination is even more difficult because no approaches that would be appropriate for such potentially large groups are available.

## 4.2 Framework

Various approaches have been proposed by researchers and been used in decision making. Many rely on the decomposition principle and use analysis as the method of inquiry. For instance, see French and Rios Insua (2000) or Raiffa (2002). Others rely on intuition, reductionism, holistic approaches, or partially or ill-defined methods including muddling through or garbage-can approaches (Lindblom 1959, March 1978). It is clear that, when dealing with a very large number of people coming from different backgrounds and having different education and professions, one cannot expect a uniform approach to decision making. We must recognize this and, in general, allow participants to have access to decision aids that meet their needs and abilities. Regardless, here we use frameworks relying on the standard decision analysis cycle (French 1986). We thus follow standard frameworks for policy as the five-phase model of the policy-making cycle presented in Section 2.2, or Holtzman's (1989) three-stage process (*formulate, analyze, decide*). To account for the involvement of multiple participants, we complement the standard decision analysis cycle with ideas and methods from negotiation analysis and group decision support (Raiffa 2002).

As a consequence, we suggest a hybrid process that arranges a number of participation mechanisms throughout the deliberation process. In proposing this framework, we need to introduce the key roles that are involved in the activities comprising it, drawing on standard participation roles in applications. Specifically, three roles are distinguished in this framework:

1. The problem owner, who decides to run the participatory process. This could be a group of citizens, the mayor of a city, or the president of a country;
2. The participants, who take part in the process by providing their inputs; and
3. The facilitator, who aids the participants in running the process.

Our framework is devised as a general approach, and consequently some phases might be eliminated in specific applications. Also, if necessary, we could cycle through one or several of the stages until a decision is obtained for the group (Phillips 1984). This framework shares the same decision analysis paradigm as one discussed in Section 4.1, so it is conceived for analytically inclined participants. We shall, however, also discuss alternatives in which different participants may use different mechanisms.

1. *Preparation*. In this stage, the decision-making problem is structured, identifying uncertainties, alternatives, their interrelations, constraints, criteria with which to evaluate consequences, and consequence assessment. The degree of sophistication of the structuring might go from a simple list of alternatives, perhaps with some constraints, to an influence diagram. Because of the assumed participants' tendency to think in myopic terms, we suggest that the problem owner, supported by technical

staff, provides a seed document with an initial structure, which is then discussed and consolidated by the participants.

2. *Discussion and consolidation*. The participants discuss and consolidate the basic structure, aided by facilitators, to promote and enhance creativity. The agreed common structure will be used later on in the process. If uncertain aspects are involved, we suggest that these should be modeled with the best available science.
3. *Individual problem exploration*. At this stage we extract the participants' preferences (e. g., in terms of their value or utility functions, depending on whether the problem is certain or uncertain). The participants may use this information to uncover their preferred optimal alternatives and reasons for such a choice. We can also use this information for later discussions and negotiations. If all participants obtain the same optimal alternative, we stop. If not, then the conflict needs to be addressed.
4. *Conflict resolution.* When several participants prefer different alternatives we need specific methodologies to integrate their values, and problem-solving techniques to reach a feasible group action. We could do this by arbitration, or negotiation and voting, or negotiation and arbitration, just voting, or possibly the consecutive use of several of these approaches. For example, if we assume that we know the participants' preferences, an *arbitration* approach just needs the corresponding algorithm to compute the chosen arbitrated solution based on some equitable criterion (Thomson 1994). A shortcoming of this approach is that these solutions could be seen as imposed; an advantage is the possibility of mitigating the stress produced by the presence of a potentially very large pool of participants discussing the advantages and disadvantages of various alternatives. Instead of arbitration, we could use *negotiation.* Although there are various generic schemes, negotiations essentially consist of a process in which alternatives are iteratively offered, until one of them is accepted by a reasonable percentage of participants. Otherwise, no offered alternative is globally accepted. If negotiations end up in a deadlock, we may solve it through arbitration or through voting. Again, we could appeal to numerous voting schemes (Brams and Fishburn 2002). As mentioned, alternatively, we could directly move on to *voting,* but this might have the shortcoming that it does not sufficiently motivate deliberation among the participants.
5. *Post-settlement*. If the outcome of the previous scheme is obtained through negotiation or voting, it could be the case that it is socially unacceptable (i. e., the outcome is dominated in a Pareto sense). In this case, participants should try to improve the solution in a negotiated manner, through a scheme designed to converge to a nondominated alternative that is better than the outcome obtained previously.

Note that the information obtained at stage 3 would be useful not only to compute the participants' optimal alternatives, but could also be used to evaluate alternatives offered through the negotiation phase, to help the participants be better informed during voting and finally to check whether our outcome is dominated and consequently start at stage 5. One possible comment is that participants may be reluctant to make public information concerning their preferences. We assume in this design that the participants will provide this information to a secure and trusted intermediary, in a framework that may be called full, open, and truthful intermediary disclosure (FOTID).

There are many different decision-making styles and differing levels of analytical sophistication among participants. Therefore, we could conceive an alternative framework. Phases 1 and 2 would be essentially the same, allowing the construction and manipulation of problem representation, solution generation, and consequence assessment, with facilitated discussions among participants. Phase 3 would allow the manipulation of the representation by individual participants to better understand the problem and the implications of their judgments; these could involve sophisticated modeling with value functions and also less-sophisticated methods such as goal setting or debating with other participants. Phase 4 would entail the construction and manipulation of the representation by the group, allowing sophisticated negotiation methods using value functions as well as simple methods like those based on debating the pros and cons of options in a forum and voting on options. Phase 5 would entail, in this case, exploring whether the outcome may be improved.

Some of the stages could be implemented in a virtual environment, whereas others could be based on a physical environment. It is interesting at this point to analyze in such a context a specific case study in which one of us was involved. This concerned the development of the current Madrid regional research plan (2004–2007)[3]. Through it, we may show how some of the above stages are repeated, some are skipped, and how various participatory mechanisms are implemented through electronic or physical means.

In 2002, the government of Madrid started designing its new research plan through a participatory process. *Preparation*: In the first stage, several focus groups were created around vertical topics (mathematics, ICT, energy, nanotechnology, etc.) and horizontal topics (internationalization of research in Madrid, large infrastructures, etc.). Each focus group included about 12 people (researchers, businessmen, etc.) led by a chairman. The discussion was facilitated by two people, one leading the group, the other recording the session, and ideas were generated ideas during a one-day session. The chairman was in charge of producing a seed document published on the web and discussed through an Internet discussion forum by all focus groups, and consolidated again by the chairman (*discussion and consolidation 1)*. Then, each focus group convened physically to produce a final consensual document that included strategies and actions concerning the corresponding topic (*discussion and consolidation 2)*. The whole list of documents was then published on the Web to be discussed over the Internet by anybody in Madrid who was interested, and finally consolidated by the chairmen

[3] See http://www.madrimasd.org/queesmadrimasd/pricit/default.asp

(*discussion and consolidation 3)*. The final document was then assessed from the technical and economic perspectives by the Research Directorate (*problem exploration)*, voted on and approved by the government of Madrid (*conflict resolution 1),* submitted to the parliament who voted and approved it with some amendments (*conflict resolution 2),* and published it as a regional law. No *post-settlement* was undertaken.

# 5 Support Functions in Participatory Democracy

Decision support and DSSs have been devised to aid individuals and groups both in conflict and nonconflict situations. Participatory democracy or decisions made by very large groups of highly diverse persons introduces additional challenges that DSSs and their various incarnations in the past have not considered in sufficient depth. In this section, we briefly discuss selected issues that need to be addressed when one considers designing and implementing systems to support participatory democracy.

## 5.1 Information, Access, and Presentation

Efficient use of the available technology should address the issue of how to provide citizens with relevant information in an understandable and accessible way. Technologies that can contribute to alleviating this issue are search engines, adoption of extensible markup language (XML) standard to facilitate searches (Rubio and Rios Insua 2007), tools to merge documents in a collaborative way (Lourenco and Costa 2005), and statistical tools to generate information, among others.

If we want to design valid participatory processes, we need to guarantee that participants are informed in an unbiased way before making a decision or contributing their inputs. If we provided them with enormous quantities of raw data from which information can be extracted, we will also need to provide them with suitable statistical tools. Otherwise, this raw data would not be very informative, and might even be misunderstood and misused within decision-making processes. *Better access to information does not necessarily imply better knowledge* (Sartori 2002). We should also pay special care to the way the information is provided and displayed to the citizens, to avoid extra manipulations. We should note that when people decide on their own how they want to be exposed to information, then they may choose to attend only to those sources that support their previous opinions. However, to be able to judge properly, it is necessary the challenge others' arguments and give contrasts. *If I only listen to those of my tribe, if I can decide not to listen to the discrepancy, my decision is made beforehand* (Sunstein 2001). Therefore, some control over the information to which participants are exposed may ensure that they receive all of the adequate information from which they will compose their judgments.

We have assumed here that, once we provide citizens with the tools engaging them in a participatory process, they will access and use those instruments in a universal and equitable way. However, participants do not always have access or the necessary skills to use these ICT-based instruments. The term *digital divide* has been used to describe the fact that the world can be divided into people who do and those who do not have access and the capability to use these technologies Therefore, there is a real danger of incorporating in participatory processes nearly the same people all the time, and isolating others including the most vulnerable population. In such a case, the process will lack sufficient legitimacy due to the unrepresentative participation of the population and the input obtained from this process will not be valid, even if the participatory process is appropriate from a theoretical point of view. Once the accessibility issue is resolved, the question would be how ICT can be used to enable wider participation, and support those citizens who lack the skills to use them.

Indeed, it is far from clear that untrained users interacting with Web-based participatory support tools will understand the cognitive tasks that face them. Hence, neither may the system inform their judgement and understanding nor may their inputs inform the policy-making process. With training, as can be provided within organizations, these cognitive issues may be overcome. However, in our context, there is less opportunity to provide prior training in the use of the tools and the citizens' interactions may be neither effective nor well founded. The design of the human-computer interface should be done within a wider socio-technical context, with particular reference to youth and the elderly, and their use of ICT at home. Grima and Rios Insua (2007) propose to address these problems with the design of simple and easy-to-use graphical user interfaces.

We should also consider how to alleviate the resistance of people who think that their power or comfort decreases with the implementation of a participatory process. In the worst-case scenario, people who perceive these initiatives as disturbing might try to sabotage them.

## 5.2 Communication

Citizens participate in decision-making activities either indirectly, through their representatives, or directly. ICT extends the ability of participation from same-place, same-time to any-place, anytime. At the same time, the communication bandwidth that can be provided with ICT-based computer-mediated communication (CMC) is much narrower than in face-to-face (F2F) communication.

Various media are available for CMC including video, voice, sound, email, instant messaging, short message service (SMS), bulletin boards, shared workspaces, virtual reality spaces, and so on. An important issue in communication support is to select the appropriate communication channels to fit the participants.

Research on media richness theory may help us answer this question. This theory suggests that richness in these communication media can be determined by the degrees of availability for instant feedback, capacity to transmit multiple cues

(e. g., body language, voice tone, and inflection), natural language support, and personal focus. Thus, face-to-face (F2F) communication has the highest degree of media richness, whereas synchronous CMC has higher media richness than the asynchronous mode.

However, experimental research suggests that it is not always beneficial to provide the highest degree of media richness. Certain media work better for certain tasks than others, and effective management should consider matching a particular communication medium to a specific task and to the richness degree required by that task (Daft et al. 1987, Suh 1999). For example, Ocker et al. (1998) study four modes of communication support: F2F, synchronous distributed CMC, asynchronous distributed CMC, and combined F2F-asynchronous CMC. They find that the combined F2F-asynchronous mode yields better performance in idea generation tasks than any other mode. This may indicate that F2F meetings combined with asynchronous communication support (e. g., a discussion board) may be appropriate for idea generation tasks such as agenda setting, while the asynchronous communication support may be appropriate for decision-making tasks such as voting on policy alternatives.

There is a large number of experimental studies on the effects of CMC, but not all of them find significant differences and some of them result in conflicting outcomes (Fjermestad and Hiltz 1998, 1999). This indicates that the existing knowledge should be interpreted carefully considering the context. In addition, in participatory public decision-making processes, it may be that not all participants use the same communication mode – for those who attend the meeting, it may be F2F-asynchronous, but for those who did not attend the meeting, it becomes just asynchronous. Such heterogeneous situations open a new avenue of CMC research.

## 5.3 Support for Individuals

When an individual prepares for public participation in democracy, they should first think about what they like, want, and aspire to, as well as what they consider fair. Secondly, they should gather information about public issues, feasible courses of action, and their expected consequences. Individuals can explore and analyze the expected consequences of different strategies in complex problems through scenario construction and simulation tools. Thirdly, if possible, they should find about the needs, preferences, and aspirations of others stakeholders and, finally, identify potential conflicts and their extent.

We may advise individual participants about how they should behave to shape public decisions that concern them to be as close as possible to their interests, given their beliefs about how others might behave. When advising an analytically oriented party, we may use subjective expected utility models to analyze the problems. In such a case, a utility function representing the participant's preferences should be elicited. Preference elicitation procedures require time and effort from the advised participant, but they allow the participant's preferred action in a decision problem to be identified. Should we want to provide support for holistically oriented individuals, we can use case-based reasoning as an alternative to the logic of consequence, in order to recommend an action to be used in a recognized situation.

In a democracy, there might be many decisions that affect an individual, but in which they do not have the time to participate actively. As described in Section 3.7, in such cases software agents could help individuals with the automation of certain facets of decision tasks and information searches, reducing the cognitive load associated with active participation.

## 5.4 Support for Interest Groups, Coalitions

When individuals face public settings, they may be interested in searching for others with similar interests. This would open the possibility of defining a common strategy or trying to lobby the government or other interest groups. When a very large number of people are in the public arena, coalition formation might become difficult. Individuals interested in creating a coalition could use software agents to help them identify people with similar interests in order to invite them to join the coalition. In this process, the coalitions formed should be also identified so that interested individuals can join them. Another possibility, if individuals disclose their preferences to a neutral intermediary, would be to use statistical clustering techniques to identify groups with similar preferences and put them in contact through a forum or distribution list.

Note that, in such a case, coalition formation is problem dependent, because it is based on individuals' preferences regarding the creation or modification of a policy associated with a specific public issue. Thus, individuals will join coalitions based on a specific public issue rather than join a political party that will not be able to support the interests of all its supporters in all public issues. Coalitions act strategically to pursue a common interest in a specific issue. This makes a coalition act jointly for the problem solution it prefers. Coalitions empower their members as they can reach more by belonging to the coalition than as themselves. If coalitions enter in the negotiation arena to try to settle a public issue, coordination between internal and external negotiations also requires support.

## 5.5 Facilitation, Coordination, and Mediation

Process support is critical to improving the productivity of individual and group work. Wide differences among participants' interests, knowledge, cognitive abilities and skills, cultural, education, and other characteristics may make purely computer-based support insufficient and ineffective.

Facilitation may impact relationship development, participation, issue-based conflict, interpersonal conflict, negative socio-emotional participation, as well as satisfaction and quality of the group decision (Miranda and Bostrom 1999). There are various models for the facilitator. Facilitation may be performed by the internal leader of the group, one of the members of the group, an external leader, or even by a system. The facilitator may focus on interactions or content facilitation. Facilitation may be restrictive or flexible. A facilitator may also provide training on the system and process. In any case, solving socio-emotional issues is an important role of the facilitator (Kelly and Bostrom 1998). In terms of timing of intervention, a facilitator may engage in activities before, during, and/or after the meeting.

In the environment of F2F group meetings supported by a system (a so-called decision room), the facilitator typically provides technical support such as training and answering questions, as well as process support. In this case, the role of the facilitator is critical because the facilitator promotes effective use of the system. In the synchronous distributed environment, the role is simpler because the technical support function is usually not provided by the facilitator.

In the asynchronous distributed setting, which is of most interest in this application, the role of a facilitator can be more complex. First, a meeting in the asynchronous mode may last days, weeks, or even months. In addition, interactions of participants may happen whenever it is convenient for them and messages sent by a participant may be received by other participants in a different order. Furthermore, because participants have more freedom to work individually and interactions are less frequent and immediate, coordinating participants may be much harder (Tung and Turban 1998).

Turoff et al. (1993) suggest four types of coordination methods:

1. Parallel coordination allows the problem to be approached independently;
2. Pooled coordination extends the parallel method, by having the participants produce an outcome according to a standard procedure such as a vote;
3. Sequential coordination requires the participants to undertake problem solving in a sequential manner; and
4. Reciprocal coordination requires that changes be made by one participant (or subgroup) to necessitate other participants to reconsider their positions.

It has been argued that a group supported by the synchronous communication mode typically uses a self-imposed sequential method of coordination, because the group uses agendas that force participants to go through the process step by step.

When the asynchronous mode is used, coordination mechanisms should be more explicitly considered. For sequential coordination, the agenda should be defined and enforced. For reciprocal coordination, frequent communication is required to let individuals reconsider earlier activities and make the necessary adjustments. For pooled coordination, there should be a signaling mechanism to indicate that individual approaches should be finished and the standard procedure should be started (Tung and Turban 1998). Considering the nature of the communication mode and difficulty in group coordination, we expect that system facilitation or system-aided facilitation will play a crucial role in the asynchronous distributed environment.

## 5.6 Knowledge and eExpertise

The role of experts is to provide relevant information for risk assessment, assess the likelihood of uncertain events, model dependence relations among uncertain variables, evaluate economic consequences, and so on.

When uncertain aspects of the problem are considered, the Bayesian approach is often the most appropriate. In the Bayesian approach, probabilities are interpreted as measures of subjective beliefs rather than long-run frequencies to be estimated from data. They are particularly important when probabilities cannot be determined from historical data. Thus, this approach requires reliable probability assessment methods to extract knowledge from experts to be expressed in probabilistic terms, taking into account the psychological heuristics that experts use in forming these judgments and the potential for biases. Formal procedures have been developed to address these difficulties (Keeney and von Winterfeldt 1991). One problem is that for many uncertainties there might not be sufficient evidence for scientists to agree on a common judgmental probability distribution modeling such a variable. In such a case, the opinions of experts may diverge. This raises the question of how to combine or aggregate these expert opinions to form a consensus probability distribution to be used as input in the model. The Bayesian approach to this problem (Morris 1977) is based on Bayes' rule, but requires difficult assessments. In practice, there are still many complex modeling challenges and questions about the effectiveness of various combination procedures (Clemen and Winkler 1990, French and Rios Insua 2000).

Formal models for dialectical argumentation can be used to aggregate expert knowledge in a consistent manner when it is distributed and not individually sufficient to prove particular hypotheses (Hitchcock et al. 2001). These frameworks help gain an understanding of the logical implications of scientific knowledge and the arguments concerning the consequences of a policy of action. As an example, Risk Agora is a deliberation system that allows for modeling and support of scientific debates in the risk domain (McBurney and Parsons 2000, 2001). Its initial focus was on providing support for discussion about the potential health and environmental risks of new chemicals and substances, and their appropriate regulation. The authors have drawn on Habermas's theory of communicative action to define types of speech acts appropriate for such discussions.

## 5.7 Trust and Confidentiality

Suppose that the above functionalities are built into an implementation of our framework in a Web-based system supporting e-participatory processes to the satisfaction of the problem owner and the facilitator. We still need to gain trust from the participants using the system and the professional politicians whose role would undoubtedly have changed. Issues related to easy access, fair representation, the digital divide (Norris 2001), and the potential for hijacking an e-participation process by a pressure group are also relevant.

The first issue to be addressed is to secure trust in the system and the correct implementations of algorithms and methods. One clear possibility would be to develop the system in the open-source manner, so that it can be openly verified by third parties to ascertain that all opinions are taken into account in the manner announced by the implemented framework.

The second important issue refers to confidentiality so that our opinions, preferences, and votes remain only known to ourselves, so as to avoid pressures potentially derived from preference profiling. The FOTID framework described above may be used effectively for that purpose with the aid of a recent plethora of powerful cryptographic methods.

## 6 PARBUD: A System to Support E-participatory Budget Elaboration

As an illustrative example, we now describe how our framework is specified for the case of participatory budget decisions and how the framework may be implemented in a system.

Two or more mechanisms may be applied to problems that are both complex and of particular interest to the citizens. One such problem is participatory budgeting; traditionally this issue has been managed through a mix of direct and representative participation (Souza 2001). A well-known and successful example is participatory budgeting in Porto Alegre (Santos, 1998).

Participatory budgets are set up along well-defined rules that regulate the number of delegates in each body, the role of public authorities, the prerogatives and powers of a participatory budget council, the discussion forums, the voting rules, and the amount assigned in the participatory budget process to be allocated. The budget process is usually organized by territorial sectors and themes (e. g., culture, education, social services, safety) and implemented according to three levels, based on the degree of participation and the tasks to be carried out:

1. The first level is local. It involves small groups made up of streets or neighborhoods. Participants discuss specific problems and the necessary interventions. Finally, priorities are established and representatives are designated to defend them at the next level.
2. At the sector or theme level, assemblies discuss the strengths and weaknesses of the first-level results, define global priorities for sectors, and designate delegates to become members of the participatory budget council.

3. The third level is the participatory budget municipal council. Its members are designated for a period of time and represent sectors and themes, as well as the municipal executive, public services, and associated movements. The council supervises participation and ensures communication between the municipal administration and the participatory pyramid.

We view participatory budgets as a resource allocation procedure in which citizens have to decide how to spend the available resources by selecting several projects from a list. Each project has an estimated cost and is evaluated by each citizen according to multiple criteria. The total cost of the selected projects must be smaller or equal to the maximum budget limit. There could be other constraints that restrict a feasible selection of projects. For example, there could be several projects concerning a new hospital and only one should be chosen, or there could be a project that can be selected only if another project is selected. The citizens represent a wide variety of interests and may prefer different projects. Therefore, sheer selection will be inadequate, requiring debate, leading to an agreement. We describe here how we have adapted the framework presented in Section 4.2 to support the participatory elaboration of a budget.

1. *Preparation*. The problem is structured before a final list of proposals is identified. We structure the criteria with which to evaluate projects, prepare an initial list of projects together with their associated costs and technical features, and identify constraints. This phase is fully conducted by technical staff who will post the resulting document.
2. *Discussion and consolidation.* Participants are allowed to propose new projects and criteria, or eliminate some of them, supervised by a facilitator, to consolidate the final list of proposals and criteria. This phase also provides an opportunity for participants to understand the general features of the problem better. This may be undertaken through moderated discussion forums or through physical meetings.
3. *Individual problem exploration*. We elicit the participants' preferences to guide and provide analytical support during the process.
4. *Conflict resolution: negotiation*. Participants are allowed to make offers and debate them through a supported discussion forum. Participants are allowed to accept or reject each proposed offer by voting in favor or against it. The offer with highest percentage of acceptance among participants will be implemented if this percentage is sufficiently high. Otherwise, no offered budget will be globally accepted.
5. *Conflict resolution: voting*. If the negotiations fail, a voting session allows the budget to be determined. We use approval voting over the projects to compute the winning budget, although other voting schemes could be used.

6. *Post-settlement.* In the case that a potential budget obtained through voting or as agreement in the negotiation would be jointly improvable, participants should try to improve it in a negotiated manner. We use a modification of the balanced increment method (Rios et al. 2005) to support such negotiations, as it is designed to converge to a non-dominated budget.

This approach supersedes the standard participatory budgeting methodology, which roughly speaking, consists of phase 2, in which participants prepare a list of initial proposals, and phase 5, in which participants vote over such a list. By including phase 1 before phase 2 we mitigate the issue of an overly myopic vision of participants. By including phase 5 after phases 3 and 4 we allow participants to vote with a better knowledge of the voted options. By including phase 6 we provide a mechanism to verify whether a potential list of projects is socially suboptimal.

We have adapted our proposed methodology to support groups in the elaboration of participatory budgets and implemented it through the web in PARBUD. This system assumes the role of the facilitator. It is a neutral external helper that gathers confidential information from participants, allowing a FOTID framework: the system will know the participants' true preferences, which will not be disclosed to counterparts. The FOTID framework enables (e. g., detects whether an outcome is dominated and, in such case, improves it in a negotiated manner), suggesting efficient and equitable budgets for possible acceptance based on knowledge of the participants' preferences and some concept of fairness, until one is jointly accepted. Rather than using physical meetings, allowing for alternative generation and voting, PARBUD promotes virtual meetings in which participants discuss the problem and explore the consequences through an integrative methodology, confidential revelation of preferences to the system, and negotiation for conflict resolution.

# 7 Discussion

We conclude by discussing several practical issues concerning decision support in participatory democracy. First of all, as may be seen from a number of governmental initiatives and pilot projects and the interest in the field from a number of consulting companies and software vendors, e-participation processes will soon be standard practice in our political life, and the decision support community could contribute a lot in this. Our purpose here is to suggest a robust framework that can accommodate many current participatory processes and that relies on decision support tools. Our experience with small groups of quantitatively sophisticated users involved in specific problems such as participatory budgets has been very rewarding. However, we still need to test our proposal with large groups of unsophisticated users on general problems. To do so, we would first need to develop the corresponding generic architecture, possibly based on Web services, which would include, among others, problem structuring, voting, negotiating, arbitrating, problem exploration, preference modeling, debating.

An important issue is that these tools are aimed at promoting and increasing participation, but will they achieve it? If people are not currently participating in democratic processes, will the introduction of these tools increase the interest for participation? Barrat (2006) discusses these questions in depth. After all, modern times are characterized by a hectic life in which citizens might find little time to participate. Note, however, that we are not suggesting that we should be involved in all decisions that affect us, but rather that there would be occasions in which we could be interested in taking part, such as when determining budget priorities. In this connection, it might be of interest to study what type of incentives one could use to promote citizen participation. As we mentioned, trust in systems is also an important issue in the field. For this, it might be a great opportunity to develop open-source systems.

All in all, we have called attention to and illustrated an emerging and exciting application area to which the DSS community can make substantial contributions.

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# PART X

# Decision Support Horizons

# CHAPTER 67
# The Internet and DSS – Massive, Real-Time Data Availability Is Changing the DSS Landscape

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The Internet can serve as a source of massive, micro-level data. We discuss the opportunities and challenges in capturing and utilizing real-time data off the Internet, intranets, or extranets. Emphasis is placed on developing dynamic decision support systems (DSSs) in our new data-enabled environment. Illustrations of real-time data capture and potential DSS use are provided from work on online auctions, e-retailing, piracy, and intellectual property.

**Keywords**: Decision support systems; Real-time data; Online auctions; e-retailing; Piracy; Intellectual property

## 1 Introduction

Though there are many definitions of the term decision support system (DSS), virtually all include Sprague's (1980) two key ingredients: a model base and a database. Over the ensuing quarter century, researchers have continually expanded the breadth and sophistication of the model-base component of DSSs (see D. J. Power's interesting discussion of the history of DSSs at DSSResources.com). DSSs have been developed with model bases incorporating advanced statistical models, complex financial models, and elaborate data-driven model formation processes. Bonczek, Holsapple, and Whinston (1981) suggested the importance of artificial intelligence and expert systems modeling in developing DSS.

The database side of DSSs advanced as well, especially as relational database technologies and then data warehouses evolved. However, the focus on and sophistication of our model bases have far exceeded that of data. But that is about to change. As technology progressed, DSSs moved into the realm of web-based DSSs and web-enabled DSSs. While these terms are now commonplace, both terms miss what we argue is the fundamental aspect of the Internet that can transform the impact of DSSs: the opportunity provided to us by the continued expansion of the Internet and company intranets and extranets. Quite simply, the continuing emergence of Internet, intranets, and extranets activity opens access to massive amounts of micro-level data and correspondingly opens major new opportunities for DSS advances. We have moved rapidly from a data-constrained to a data-enabled landscape (Bapna et al. 2006). The Internet and company intranets and extranets increasingly provide the opportunity for a firm to obtain repeated observation of individual choices and actions. Firms now often have access to the information necessary to track the "progression to transaction". This abundance or rush of real-time information poses significant opportunities and challenges for DSS development and implementation.

In a recent article, Bapna et al. (2006) contrasted Internet data with the four most common data sources: field data, controlled experiment data, survey data, and simulation data. While the authors provide a very detailed analysis, we wish to focus our spotlight on the following factors:

1. Internet data may be available to the data-capturing entity for only a fleeting moment; if not captured and recorded, the data is lost;
2. Internet data is often on the individual or micro-level with observations available on intermediate steps in a dynamic process;
3. Internet data availability has the potential for compiling massive data sets on a level rarely achieved.

Bapna et al. (2006) focused on the role of Internet data in developing and testing new theories and patterns of individual behavior and market performance. We focus here on how such abundance of real-time data offers new horizons for DSS development and continual recalibration.

In what follows, we consider possible DSS enhancements enabled by the availability of Internet data. As one would expect, there are potential pitfalls that must be avoided. We also present three illustrations to demonstrate the evolving options and new roles for DSSs in the Internet's data-rich environment. The first considers the rapidly expanding arena of online auctions, with particular emphasis on business-to-business (B2B) auctions within the supply chain. The second centers on the use of Internet, intranet, and extranet data when dealing with issues facing e-retailers. The third considers the arena of the regulation of Internet activity, especially the critically important areas of piracy and intellectual property rights. In each illustration, we identify the types of data available in real time, processes that are being developed to automatically capture and verify such data, and the DSS opportunities provided by the data availability. We also consider an important underlying question that is critical to development of appropriate DSSs – *are electronic markets so different that we need to development completely new approaches to analyze and understand these markets*?

The illustrations and discussions that follow were supported by the Treibick Electronic Commerce Initiative (TECI) and the new Center for Internet Data and Research Intelligence Services (CIDRIS). TECI focuses on supporting e-business research, including research specific to each illustration provided below. CIDRIS supports the development of an array of automated data-gathering tools that can operate across multiple platforms including hypertext markup language (HTML) pages (both static and dynamic), non-HTML software interfaces, portable document format (PDF) files, and images. In addition, our thoughts on issues related to computational intensity and navigating massive amounts of data have benefited from our interaction and exposure to colleagues from statistics. Recently, a small group of statisticians, computer scientists, and management information systems (MIS) researchers have begun an annual symposium on statistical challenges in e-commerce. In our concluding remarks, we note a variety of sources where interested readers can continue to track evolving related research.

## 2 DSS and Online Auctions

Electronic auctions continue to gain in popularity and importance. eBay alone was reported to have over 147 million registered users in 2005 (Forbes.com, 4/21/05). Along with their familiar presence in end-point markets, electronic auctions have an ever-increasing presence across the supply chain. In a recent Purchasing.com article, Carbone (December 8, 2005) reported that Sun Microsystems spent over one billion dollars a year in reverse auctions purchasing "displays, application specific integrated circuits, memory integrated circuits (ICs), disk drives, power supplies, and other production materials."

Typically, electronic auction sites provide the following information for each auction: product description, minimum required bid, lot size, and the current highest bid. But, by repeatedly accessing the auction site, it is possible for one to track auction progression and obtain detailed data on all valid (increasing) bids submitted, the total number of bids, and the final auction outcome. Bapna et al. (2004) investigated whether bidding strategy differed from behavior detailed in the pre-e-business auction literature. The authors developed automated data-gathering tools that repeatedly harvested information from uBid.com, Onsale.com, and Pricegrabber.com, including product attributes (type, life cycle, condition), bidder information (time of entry, exit, number and amount of bids), auction parameters (lot size, bid increment, duration), bids (number of bids and amount bid), and sales price (transaction bid amount and posted prices). Bapna et al. (2006) summarized the necessary steps in the data-harvesting process as follows:

> "… to track the progress of the auction and the bidding strategies the same hypertext page has to be captured at frequent intervals until the auction ends. The raw HTML data is then sent to a "parsing" application that searches for specific strings that correspond to the variables of interest, say the price or the lot size. The parsing application condenses the entire information for an auction (including all submitted bids) into a single spreadsheet. Data is cleansed to screen out auctions in which: (a) sampling loss occurs (due to occasional sever breakdown), and (b) insufficient interest exists (some auctions do not attract any bidders)."

The pioneering work of Bapna et al. (2004) found distinct differences between bidding strategies in electronic auctions and bidding strategies in earlier traditional auction settings. Subsequent research by Steinberg and Slavoya (2005) found similar results in a different electronic auction setting.

Consider how a decision support system could be developed to assist businesses participating in supply chain auctions. A business seeks to obtain inputs that meet a set of specific requirements including quantity and quality specifications and delivery within specified conditions including location and time frame. Specifying the full set of conditions may be quite complex. Fenstermacher and Zeng (2000) offer the following:

> "Supply chains are often complex graphs that require coordination among multiple suppliers to produce complex products. For example, automobiles require parts from hundreds of suppliers, and the parts must arrive together to avoid delays in manufacturing. Agents that buy the needed parts must either … centralize the purchase of such parts themselves, or cooperate with agents purchasing the other parts."

While we recognize the complexity of supply chains, our purpose here deals with the potential usefulness of a DSS driven by real-time data for a business seeking to optimize its business purchasing in a fully specified (and no doubt complex) supply chain. Fenstermacher and Zeng (2000) emphasize one supply-chain input acquisition problem that seems custom made for a DSS using efficient automated search and data collection:

> "For most goods, online marketplaces are widely scattered and finding a suitable exchange or auction site is a difficult task."

An automated process can be structured to monitor existing online marketplaces, including auctions, to identify, track, and compare alternatives providing products meeting the business' specific requirements. Further, intelligent search capabilities (now under analysis at CIDRIS) offer the ability to update the set of online marketplaces dynamically.

Building upon research such as that of Bapna et al. (2003a, 2003b, 2004, 2005), a DSS could be structured to monitor and update possible bidding strategies for the business based upon observed bidding pattern and strategies.

To summarize, we have argued the following:

1. The availability of electronic marketplaces, especially e-auctions, provide significant supply-chain input acquisition opportunities;
2. To be successful, a firm must be able to continuously monitor and understand the electronic marketplaces and e-auctions. As in business practice, the firm seeks to identify and pursue winning strategies;
3. The Internet (or applicable intranets and extranets) contains vast amounts of potentially useful data and information, though some might be available for only a fleeting moment. Recent research has demonstrated the ability to automate data harvesting, parsing. cleansing, storage, and analysis – all critical steps in developing a dynamic DSS that is continually refreshed as real-time data and analysis updates occur; and,
4. Current research in intelligent search processes utilizing data and text mining offer the potential to continually update the array of live e-marketplaces for a specified supply-chain input acquisition task.

We include both general e-marketplaces and e-auctions since tracking the former enables the business to identify an upper bound for any auction bid they might make.

As Fenstermacher and Zeng suggest, supply chains can be complicated structures that require significant coordination. Once developed, however, the required constraints, conditions, and coordination can be built into one or more real-time data-sourced DSS.

# 3 DSS and e-Retailers

Consider an e-retailer who is seeking support for appropriately pricing his products as he seeks to maximize profit. The variety of Internet information that can be helpful inputs into this decision making process would typically include the following: (1) customer perceptions of the e-retailer's service quality, (2) the range of prices charged by different retailers for the same product, and (3) the reach of the e-retailer's website. While each of these data types are available, they must be acquired from many different sources including websites of competitors, comparison pricing websites, websites of web-based information intermediaries (service quality information), and the e-retailer's own website.

Venkatasan et al. (2006) developed and demonstrated processes for collecting the following data for each specified product sold by the e-retailer (Internet source sites provided in parentheses):

1. service quality – survey ratings from online customers on each of the following: on time delivery, customer support, actual product versus expectations, willingness to shop with e-retailer again (BizRate.com)
2. transactional channels – online only, national chain with online presence, local store with online presence (manual Internet search and validation)
3. size – number of unique visitors to the online store (Alexa.com)
4. competitive intensity in market – number of e-retailers offering identical product; corresponding service quality ratings of each such e-retailer (BizRate.com)
5. price – posted by each e-retailer for the specified product

With the exception of the manual search indicated for the transactional channels, the authors used a web crawling agent to collect the data. The authors summarized the challenges they faced in collecting the necessary information on some 300 retailers and more than 2,800 products:

> "An extremely challenging aspect of this study was learning how to successfully integrate and utilize data from multiple sources with different levels of structure and aggregation. This led to development of standardized procedures for: 1) automated identification and collection of relevant and related information from different sources; 2) automated cleansing and transformation of data; 3) collating of information at different levels of aggregation; and

4) identification and marking of potentially problematic data for follow up verification requiring human intervention. These procedures allow for larger scale and scope of data collection, without compromising on quality of data."

The authors focused on analyzing price dispersions among e-retailers and the relationship between price, customer rating of service quality, and the level of e-retailer competition. However, their efforts demonstrate the ability to automate the gathering of the type and range of Internet data necessary for the implementation of a DSS to support an e-retailer's decisions on product price.

In addition to the Internet data gathering detailed in Venkatasan et al. (2006), e-retailers may have access to significant data from intranets constructed for activities such as customer service and/or extranets developed to give limited system access to particular selected customers, business partners, and suppliers. By carefully structuring their web presence and intranet and extranet sites, the e-retailer can collect and track individual data such as customer site access patterns, click and navigation movements, and satisfaction.

But perhaps the most straightforward and directly useful application for any e-retailer or traditional brick-and-mortar retailer lies in the area of real-time competitive price checks and dynamic pricing decisions. Even a retailer handling thousands of individual products can utilize web crawler technologies to track competitors' prices for each product. This information can be monitored using a digital dashboard or heat map DSS interface format where numerical or color signals alert the retailer to situations where his prices fall outside specific competitive pricing ranges. The retailer can then decide whether or not to alter his pricing. Such decisions may require additional investigation including:

1. Are the shifts in competitors' prices short-term "specials" or do they represent on-going market shifts?
2. Based upon the type of market and customer analysis detailed earlier, the retailer can determine the likely impacts of adjusting or not adjusting his prices in response to competitors' pricing changes.
3. The retailer may utilize the tracking of competitors' prices and comparison sale related information (e. g., shipping options and costs, return policy, customer satisfaction ratings) as a marketing tool; given real-time price tracking, the retailer can go far beyond typical weekly market basket comparisons offered by various supermarkets or limited comparisons offered by at least one auto insurance company.

## 4 Piracy and Intellectual Property Rights

Along with all the benefits of enhanced information flow, the digital age has brought enhanced possibilities of piracy and threats to intellectual property rights. While much has been written about music piracy, there was little actual knowledge of the level of sharing activity until recent investigations developed and utilized automated Internet data gathering and storage processes. In a series of papers, Bhattacharjee et al. (2005, 2006a, 2006b, 2006c) demonstrated these techniques in the investigation of the levels and impacts of file sharing on peer-to-peer (P2P) networks. The authors developed automated software applications to search and capture data from two popular P2P sites, WinMx and KaZaA, and commercial sites such as Billboard.com. The authors took care to ensure that each application captured the information without downloading any copyrighted content from any computer on a P2P network. In one data-gathering process (see Bhattacharjee et al. 2006c), the authors used key words from Billboard's top 100 album list (e. g., artist, album name) to enter and search file sharing availability on WinMx. They chose WinMx because there was no limitation on the number of hits returned in a search. Thus, the authors were able to obtain the total amount of sharing activity (files offered for sharing) for each of the billboard chart albums on any given day over the period studied. Their results included the following:

1. on average at any point in time there were 338 + files available for sharing – numerical observations indicating significant piracy opportunity and activity for each top 100 album;
2. evidence suggesting both pre-purchase quality sampling piracy as well as lost-sales piracy – in fact, they found that the level of sharing activity or opportunity was a better prediction of upcoming direction of sales than current chart position.

The latter finding offers an important strategic implication for the music industry. The empirical finding supports an implication of the theory presented by the authors (Bhattacharjee et al. 2006b) that there are conditions under which firms can benefit from piracy. This occurs, suggest the authors, since part of music file-sharing piracy is actually pre-purchase sampling where positive results enhance the businesses' bottom line. In an ironic twist, the authors juxtapose the music firms' payola activities (bribing radio stations to increase air time or sampling opportunities for their music products) with the firms' strict anti-file-sharing stance.

The work of Bhattacharjee et al. illustrates real-time information gathering that could be useful in a DSS providing a firm with continuous guidance on predicting sales and market trends (billboard chart ranks are sales based) of their products. The authors summarize the potential in the following way:

> "Our findings, however, do suggest that the initiatives aimed at shutting down the operations of these P2P online sharing networks would have a "throwing the baby out with the bathwater" effect. Strategies that help foster the pre-purchase sampling and advertising aspects of online sharing networks, while minimizing the lost-sales effects, will enable the music industry to better leverage the information technologies in the new era of increasing digitization of the music product."

We suggest that proper development of a DSS is an important step in enabling firms to accomplish such leverage.

While firms may seek to foster certain types of sampling piracy while avoiding lost sales piracy, regulators are charged with protection of intellectual property rights. But how can the impact of a new regulation or a legal action (e. g., threat of suit, actual filing of a suit, or a trial outcome) be evaluated? A recent paper by Bhattacharjee et al. (2006a) demonstrates how automated Internet data gathering can provide a direct view of individual reactions. The authors identified over 2000 individuals that were frequent sharers, that is, individuals who were frequently logged onto a P2P network and willing to share music files. Bhattacharjee tracked these 2000+ individuals for more than year, repeatedly searching for both the presence of each individual on the P2P network and the set of music files each was willing to share at any point in time. The data-collection time period happened to coincide with a series of legal threats and suit filings by the music industry and its association, the Recording Industry Association of America (RIAA). In addition, there was one major court holding that impacted on the RIAA strategy. The authors observed and analyzed the P2P presence and the sharing behavior of each individual before and after each of four key occurrences: (1) the RIAA threats of legal action, (2) the initiation of legal actions, (3) a legal setback to the RIAA (Internet service providers could not be required to identify individual customers), and (4) a reiteration by the RIAA of continuing legal actions through John Doe lawsuits. The authors found that the large sharers (various reports indicated that the RIAA was targeting those sharing more than 800 or more than 1000 music files) consistently reduced the files shared to below the red flag threshold levels. The authors summarize the results as follows:

> "… before-and-after event comparisons suggest that, over the course of the four events, the majority of substantial sharers decreased the number of files shared, typically by more than 90%. During this period, a majority of nonsubstantial sharers dropped sharing activity, typically to a third of their original levels."

In addition, the authors noted that many of the nonsubstantial sharers simply stopped logging on. Those that continued to log onto the P2P network did so less frequently. While the authors find individual response patterns consistent with the RIAA indicated intention of reducing file sharing, they also found that significant opportunity for piracy remained. After the final event where the RIAA persisted in filing a large number of individual suits, the authors found an average of 351 music files available for sharing for any album on the billboard chart. The fewest for any such album was 33 files and the largest was 1,245 files. Thus, despite individual actions in line with RIAA intent, piracy opportunity remained abundant.

The work of Bhattacharjee et al. presents a rare insight into how individuals react to legal threats and actions. Their work provides direct observations on individual actions. Previously, investigations into responses to legal actions were limited to conjecture or to surveys. But how much reliability can we expect from a survey focusing on illegal activity? What incentives are there to provide accurate information? As the Internet continues to expand its role in commerce, more and more opportunities arise to track individual responses to legal actions (such as new consumer legislation or important court holdings), to evolving threats (increasing threat of identity theft or credit fraud), and to enhanced regulation or regulatory enforcement. The approach set out by Bhattacharjee et al. offers a means of feedback on individual behavior – feedback on the impact of a court holding, a new piece of legislation, a major fraud alert, or a new regulation.

Such feedback holds significant opportunity for incorporation into DSSs for industry decision makers, policy makers, and regulatory authorities. A well-structured DSS could provide the ability to dynamically monitor and evaluate responses to industry actions, policy shifts, or regulatory changes. With such real-time monitoring and analysis, decision makers can gain the advantage of informed mid-course corrections or adjustments as necessary.

# 5 Concluding Remarks

The Internet continues to grow in importance for efficient operation of supply chains, for expanding e-retailing, and for the exchange of digital goods. This growth results in the Internet being a trove – sometimes for only a fleeting few seconds – of detailed micro-level information. It is possible to track the individual behaviors and market adjustments that occur along the way to completion, or failure, of a transaction. By developing signaling or dashboard format DSSs that automatically harvest and analyze this information in real time, companies can identify conditions under which various supply chain auctions are optimal and move rapidly to operationalize the preferred methods. E-retailers can use DSSs to make dynamic price adjustment decisions as the market landscape shifts or competitors alter their pricing structure. Developing and implementing DSSs to track and analyze behavioral data "on the fly" offers industry decision makers, policy makers, and regulatory authorities the ability to monitor the impacts of their decisions and make mid-course corrections as necessary.

In the discussions presented here, we have drawn upon the work of various researchers to illustrate how, in real time, massive amounts of micro-level data can be automatically harvested from the Internet. As a natural next step, we have suggested the use of dynamic DSSs to incorporate, analyze, and present results to decision makers. Our contention is quite simple. The Internet is rapidly becoming both a major hub of commerce and the most accessible source of real-time observations of micro-level choices, actions, and decisions. Structuring dynamic DSSs that integrate with this data source can provide significant advantage for the savvy decision maker.

While suggesting such DSSs is quite easy, developing the necessary data harvesting, data analysis, and information representation components of such DSSs are certainly complex tasks. Research entities like CIDRIS are structured to help lay the foundations. There have been significant advances in harvesting and analyzing real-time data from clearly identified Internet source sites such as eBay, uBid.com, Onsale.com, Pricegrabber.com, winMx, and KaZaA. The next generation of automated data harvesting, now being developed at CIDRIS, is directed at utilizing intelligent searches across networks to identify appropriate relevant data sources and utilizing intelligent design adaptation to capture, validate, and analyze the data across myriad sources. In fact, the intelligent search continues over the decision horizon since appropriate data sources may change significantly over time. New auction sites may arise or disappear frequently. Sites that are currently relevant may have no relevant auctions or commerce by later today. There are also possible legal issues that must be carefully monitored. A recent law article by Winn (2005) provides a list of conflicting holdings on whether automated data gathering can give rise to successful trespass to chattels claims. But the author goes on to note that, "… the trend in recent cases has been for courts to be more skeptical of such claims and to ask computer owners to tolerate more unwanted interference with the use of computers connected to the Internet" (see Winn 2005 and additional detailed discussion in Bapna et al. 2006). As part of its mission, CIDRIS will be maintaining a citation and access list of relevant published papers, working papers, and research in progress activities (see www.CIDRIS.org). The intention is to foster a research community that freely shares advances and insights. There will be many challenges along the way, but consider the potential value of dynamic DSSs that incorporate multisource real-time data and that can yield real-time outputs and recommendations.

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# CHAPTER 68
# Information Visualization for Decision Support

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While the amount of business information increases at a phenomenal rate, decision makers could easily feel overloaded. Simultaneously, they could also feel the lack of related information for decisions at hand. Various visualization techniques have been developed to help people gain more value from large-scale information collections, but applying visualization in the context of decision-making is not well understood. Through a review of related literature in information visualization and decision support, we identify different roles that visualization technologies could play in decision support. We also elaborate how evaluation studies could help decision makers take better advantage of existing visualization technologies.

**Keywords:** Information visualization; Decision support; Visualization technology

## 1 Introduction

Since the first model-driven decision support system was developed in 1965, information technologies have been applied to support decision making. The history of decision support systems (DSS) has evidenced the development and application of different types of information technologies, including model-driven DSS, expert systems, multidimensional analysis, query and reporting tools, Group DSS, OLAP (Online Analytical Processing), and Business Intelligence (Power, 2003). Regardless of the underlying technology, information visualization has played a crucial role for the success of a decision support system. The importance of information visualization could be corroborated by the graphical components included in commercial decision-support products such as AVS (http://www.avs.com), Datadesk (http://www.datadesk.com), Inxight products (http://www.inxight.com), and Spotfire (http://www.spotfire.com).

The advent of the Internet and the popularity of e-commerce have generated an increasing amount of business information, which in turn makes visualization even more crucial for decision-making. While the amount of business information increases at a phenomenal rate, decision makers could easily feel overloaded. Simultaneously, they could also feel the lack of related information for decision tasks. Various visualization techniques have been developed to help people gain more value from large-scale information collections, but applying visualization in the context of decision-making has not been well understood. To most managers seeking to use business graphics effectively, visualization is still new (Plaisant, 2004). This chapter thus reviews related literature in the fields of information visualization and decision support to understand how decision-making could be supported by information visualization techniques and to speculate how to help decision makers better capitalize on visualization technologies.

Following the Introduction in Section 1, this chapter reviews the concept, history, and theoretical foundation of information visualization in Section 2. Section 3 begins with the literature on decision-making to identify roles that visualization technologies could play in decision support and is followed by a review of visualization technologies and applications in Section 4. Section 5 presents related evaluation studies in visualization research and elaborates how a visualization system should be studied to enhance its usability in decision making. The chapter ends with the Summary and Conclusions in Section 6.

# 2 Information Visualization: Concept, History, and Theoretical Foundation

## 2.1 Concept and History

Visualization used to be a concept adopted to represent the human mental process of developing mental images (Miller, 1984; MacEachren, 1991). It now is used to encompass amplifying such a mental process by using an interactive visual interface (Card et al., 1999). Human eyes can rapidly process a series of different visual cues, whereas advanced information analysis technologies make computers a powerful system for managing digitized information. Visualization offers a link between these two potent systems, human eyes and computers (Gershon et al., 1998) and thereby helps to identify patterns and extract insights from large amounts of information. The identification of patterns is important because it may lead to a new scientific finding, a discovery of criminal cues, a prediction of catastrophic weather, a successful financial investment, or a better understanding of human behavior in a computer-mediated environment. Thus, visualization technology has been shown to be a promising candidate for use in increasing the value of a large-scale collection of information.

Although (computer-based) visualization is a relatively new research area, visualization itself has existed for a long time. For instance, the first known map was created in the 12th century (Tegarden, 1999) and multi-dimensional representations appeared in the 19th century (Tufte, 1983). Bertin identified basic elements of diagrams in 1967, whereas Tufte published his theory regarding maximizing the density of useful information in 1983. Both Bertin's and Tufte's theories have substantially influenced the subsequent community of information visualization. Most early visualization research focused on statistical graphics (Card et al., 1999). Recent visualization research has focused on data and information visualization as the result of the data explosion in the 1980s when complex simulation models were made possible by the use of supercomputers and advanced scientific sensors sent back from space huge quantities of data (Nielson, 1991). Scientists from the fields of earth science, physics, chemistry, biology, and computer science turned to visualization for help in analyzing copious amounts of data and identifying patterns. The National Science Foundation (NSF) launched its "scientific visualization" initiative in 1985 (McCormick et al., 1987), and IEEE held its first visualization conference in 1990.

Simultaneously, visualization technologies were applied in many non-scientific domains, including business, digital libraries, human behavior, and the Internet. As the application domain expanded, visualization techniques continued to improve as computer hardware and software became more powerful and affordable. Since 1990, a vast amount of non-scientific data has been generated as a consequence of the ease of information creation and the emergence of the Internet. The term "information visualization" was first used by Robertson and colleagues (Robertson et al., 1989) to denote the presentation of abstract information through a visual interface. Initial information visualization systems emphasized the development of generic technologies, including interactivity and animation (Robertson et al., 1993), dynamic query through interface (Shneiderman, 1994), and various layout algorithms on a computer screen (Lamping et al., 1995). Later, visualization systems presenting the subject hierarchy of the Internet (Chen et al., 1998), summarizing the contents of a document (Hearst, 1995), describing online behaviors (Zhu and Chen, 2001; Donath, 2002), displaying website usage patterns (Eick, 2001), and visualizing the structures of a knowledge domain (Chen and Paul, 2001) became more domain specific and focused on both the development and application of visualization technologies.

A decade of research has led to the maturity of the field of information visualization, as evidenced by the development of several commercial visualization products using existing visualization technologies. From FilmFinder (Ahlberg and Shneiderman, 1994) to Spotfire (http://www.spotfire.com), from TreeMap (Johnson and Shneiderman, 1991) to Smartmoney.com, and from the Hyperbolic tree (Lamping et al., 1995) to Inxight (http://www.Inxight.com), visualization technologies are moving out of research labs to end users. However, the adoption of visualization in decision support is still at an early stage and very few successful stories have been published thus far.

## 2.2 Theoretical Foundation for Visualization

A person's ability to accomplish a complex task is mainly determined by cognitive capacity. Cognitive capacity consists primarily of two components: working memory and long-term memory (Kieras and Meyer, 1997). Incoming visual information enters working memory in a temporary visual storage area called iconic memory (Ware, 2000) for less than a second before part of it is "read out" into *working memory*. Working memory integrates information extracted from iconic memory with that loaded from long-term memory for the purpose of solving a particular problem. It holds information for pending tasks. People allocate working memory space to their tasks based on what they are attending to at the time. The capacity (or span) of working memory significantly affects task outcomes (Daneman and Carpenter, 1980). *Long-term memory* stores information associated with a lifetime of experiences and thoughts. It is not simply a repository of information, but a network of linked concepts (Collines and Loftus, 1975; Yufic and Sheridan, 1996) and the locus of domain knowledge. Appropriate long-term memory is the domain knowledge that helps people accomplish complex tasks more efficiently and effectively. In other words, appropriate domain knowledge could help people utilize their working memory more efficiently.

Because human eyes can process visual cues in a parallel manner, visualization could be applied to enhance both working memory and long-term memory. Visualization can augment working memory in two ways: *memory extension* and visual *cognition extension* (Ware, 2000). The high bandwidth of visual input enables working memory to load external information at the same speed as loading internal memory (Card et al., 1983; Kieras and Meyer, 1997). Thus, visualization can serve as an external memory, saving space in working memory. In addition to memory extension, visualization can facilitate internal computation. Because it makes solutions perceivable (Zhang, 1997), visualization reduces the cognitive load of mental reasoning and mental image construction necessary for certain tasks. Interaction with a visual interface can enhance such a cognition extension. Therefore, visualization could convert a required conceptual process by mental inference into a perceptual process requiring less cognitive effort. The best example is a computer aided design (CAD) system that helps an engineer make design decisions without having to build a real product.

On the other hand, the way that the concept network is built in long-term memory determines whether certain ideas will be easier to recall than others. This, in turn, affects how an individual utilizes their working memory for tasks. A sketch of links among concepts is believed to be an effective learning aid for students to learn the relationships among concepts (Jonassen et al., 1993). Interestingly, using proximity to represent relationships among concepts in constructing a concept map has a long history in psychology (Shepard, 1962). Visualization systems such as SPIRE (Wise et al., 1995) and ET Map (Chen at al., 1998) also use proximity to indicate semantic relationships among concepts. Those systems generate from a large collection of text documents a concept map that may help users better understand the concept relationships embedded in a large-collection of documents. Therefore, visualization could facilitate the grasp of domain knowledge that might be useful in making future decisions.

In summary, visualization augments human memory in different ways. While there are many related studies conducted by psychologists and neuroscientists, a complete survey is beyond the scope of this chapter. Interested readers are referred to Ware (2000).

# 3 Information Visualization vs. Decision Support

Many previous studies have explored how visualization affects decision making from the perspective of cognitive psychology and sought to identify the interaction between visualization and the process of decision making. Very few studies establish the relationship between the type of decision-making tasks and type of visualization technologies. Focusing on decision making at the individual level, this section summarizes the impact of visualization on decision making, followed by elaboration of various roles information visualization could play in supporting different types of decision-tasks.

## 3.1 The Impact of Information Visualization

The availability of information could lead to better decision-making outcomes by reducing the uncertainty involved (Varian, 1999). This statement holds true only when a decision maker has the capability to process the available information (Bazerman, 1998; Lachman et al., 1979). Therefore, a decision maker could be overloaded easily when too much information becomes available because of the limited cognitive resource he/she has. However, visual representation of information may enhance a decision maker's capability of processing information (Coury and Boulette, 1992).

A decision-making process usually includes the acquisition of related information, the construction of a mental representation of the problem and solutions, and the identification of an optimal solution (Carroll and Olson, 1987). Each of these processes could be augmented by visualization in different ways. Decision makers could better identify trends and comprehend the summary of information from its visual representation (Jarvenpaa and Dickson, 1988; Tan and Benbasat, 1993; Vessey, 1991). Because of its ability to extend the working memory and cognition, visual representation of information has been found to enhance the capability of the decision maker to process information (Coury and Boulette, 1992). With the support of visualization, decision makers could solve complex problems that would be impossible without visual support (Speier et al., 2003).

However, visualization's support for decision-making tasks is task-specific. Only when the information structure delivered by a visualization system is consistent with a decision maker's mental representation of a decision problem, can such visualization be helpful to the decision task (Meyer et al., 1999). As indicated by the cognitive-fit theory (Vessey, 1991), the outcome of a decision-making process is the result of the interaction between the decision maker's skill, the characteristics of the decision task, and the representation of the problem space. Therefore, a well-designed visualization may facilitate the process of decision making when it takes the features of decision tasks and the characteristics of decision makers into consideration. While many visualization technologies have been developed in the field of information visualization, there does not exist a universal visualization that works for all decision-making tasks. The issue of how the variety of visualization techniques could be applied to support different types of decision-making tasks merits further attention and will be discussed in the following subsection.

## 3.2 Supporting Different Types of Decision-Making Tasks

Nutt (1998) identified four alternative approaches a decision maker could apply to assess alternatives. The approaches include the analytical approach, bargaining approach, subjective approach, and judgmental approach. Given that our focus is on supporting decision making at the level of the individual, this subsection will concentrate on the application of visualization in supporting analytical, subjective, and judgmental approaches. The bargaining approach is not discussed because it is applied only when a decision maker seeks consensus among stakeholders. The other three approaches discussed here involve extracting related information from various sources. Because information visualization helps users grasp patterns embedded in large amounts of information, it could be applied to support the information acquisition required by a decision-making process. The rest of this subsection will discuss in detail how visualization techniques could help different decision approaches after related information becomes available.

### 3.2.1 Supporting the Analytical Approach

The analytical approach is a computational approach applied to well-structured decision tasks and usually involves a mathematical model. A decision maker interacts with the model for the answers to his/her “what-if” questions in seeking an optimal solution. Two types of information visualization technology could be applied to support an analytical approach. The first type converts the interaction between a decision maker and the mathematical model from a difficult conceptual process into a simple perceptual process. One handy example is electronic spreadsheet software, which can be used to translate a decision-making task into a mathematical formula and to find the optimal solution. The visualization of outcomes of the mathematical model help decision makers determine the optimal solution more efficiently. This type of help usually requires a decision maker to possess a sufficient knowledge about the mathematical model so that he/she knows how to interact with it.

When a mathematical model is too complex for a decision maker to understand and such an understanding is crucial to the decision task at hand, the second type of help provided by a visualization system could be utilized. In addition to visualizing the model outcomes, this type of system visualizes the model itself to support the understanding of it. For instance, Sengupta and Styblinski (1997) discuss several representations to help decision makers familiarize themselves with the trade-offs between different design goals. Colgan and colleagues (Colgan et al., 1995) apply visualization to present interrelationships among model variables. Visualization systems described in Anderson and colleagues (Anderson et al., 2000) and Scott and colleagues (Scott et al., 2002) enable decision makers to visually modify the model variable to leverage human expertise with an automatic method. A decision maker could use these visualization systems to understand and modify the mathematical models involved.

### 3.2.2 Supporting the Subjective Approach

The subjective approach is applied when decision makers draw subjective conclusions about the information collected. They use archived data, consult experts, or evaluate users' opinions for subjective inferences (Nutt, 1998). As the main objective of a visualization system is to help users explore information and identify patterns, many existing visualization technologies could be candidates to support this type of decision-making approach. It is possible for the subjective approach to benefit from the variety of visualization technologies in different ways. In fact, many existing visualization technologies have been commercialized for the purpose of supporting decision making. For instance, smartmoney.com (http://www.smartmoney.com) utilizes TreeMap (Johnson and Shneiderman, 1991) technology to support the exploration of stock market information, whereas the visualization software provided by Inxight (http://www.inxight.com) employs such technologies as Hyperbolic tree (Lamping et. al., 1995) and perspective wall (Robertson et al., 1993) to assist in the examination of large-scale information. Many other visualization technologies are also candidates; these will be discussed in Section 4.

### 3.2.3 Supporting the Judgmental Approach

The judgmental approach is utilized when decision makers make decisions intuitively. They identify optimal solutions based only on their previous experience, domain knowledge, and awareness of the situation. Thus, visualization technology does not provide a direct help to this type of decision approach. However, the success of decisions using the judgmental approach may largely depend on decision makers' domain knowledge and situation awareness. Technologies can indirectly support this decision-making approach through facilitating the grasp of domain knowledge and enhancing the awareness of situations. The link between visualization technology and the comprehension of a knowledge domain has been established in previous studies (e. g., Ware, 2000). Help in understanding the information at hand may also help a decision maker become better aware of the situation. Visualization technologies that can be employed to support this approach overlap with those applied to support the subjective approach and will be reviewed in Section 4.

# 4 Related Information Visualization Technologies and Applications

Information visualization helps users identify patterns, correlations, or clusters. The information visualized can be structured or unstructured. Structured information, usually in numerical format, has well-defined variables. Examples include business transaction data, Internet traffic data, and web usage data. Visualization of this type of information focuses on graphical representation to reveal patterns. Widely used commercial tools including Spotfire (http://www.spotfire.com), SAS/GRAPH (http://www.sas.com/technologies/bi/query_reporting/graph/), SPSS (http://spss.com), ILOG (http://www.ilog.com), and Cognos (http://www.cognos.com) offer interactive visualizations to help users gain value from structured information.

The visualization of both structured information and unstructured information involves the integration of techniques of the two aspects of visualization technologies (Shneiderman, 1996). One focuses on mapping abstract information to visual representation and the other provides user-interface interactions for effective navigation over displays on a screen. However, structures that can be visualized need to be extracted from unstructured information before they can be visualized. For instance, a collection of text documents is one type of unstructured information and cannot be visualized directly. But different topic areas and the semantic relationship among those topic areas could be identified through analyzing the content of documents. A visualization system then presents the topic areas and their relationship to each other to help users browse the collection. Thus, the visualization of unstructured information usually engages a third aspect of information visualization: information analysis. This aspect of visualization technology serves as a pre-processor, deciding what is to be displayed on a computer screen. Such an automatic pre-processing becomes especially critical when manual pre-processing is not possible. The remainder of this section reviews the three research dimensions that support the development of an information visualization system: information analysis, information representation, and user-interface interaction, followed by emerging applications of visualization technologies.

## 4.1 Visualization Technologies

### 4.1.1 Information Analysis

Confronted with large-scale unstructured information, an information visualization system applies information analysis technology to reduce complexity and to extract salient structure. Such an application often consists of two stages: *indexing* and *analysis*.

The *indexing* stage aims to extract the semantics of information to represent its content. Different pre-processing algorithms are needed for different media types, including text (natural language processing), image (color, shape, and texture based segmentation), audio (indexing by sound and pitch), and video (scene segmentation). The main goal of applying those techniques is to infer semantic structure that could be impossible for users to infer manually (Krippendorff, 2003). This subsection briefly reviews selected technologies related to textual document processing.

*Automatic indexing* (Salton, 1989) is a method commonly used to represent the content of a document by means of a vector of key terms. When implemented using multi-word (or multi-phrase) matching (Girardi and Ibrahim, 1993), a natural language processing noun-phrasing technique can capture a richer linguistic representation of document content (Anick and Vaithyanathan, 1997). Most noun-phrasing techniques rely on a combination of part-of-speech-tagging (POST) and grammatical phrase-forming rules. This approach has the potential to improve precision over other document indexing techniques. Examples of noun-phrasing tools include MIT's Chopper, Nptool (Voutilainen, 1997), and Arizona Noun Phraser (Tolle and Chen, 2000).

*Information extraction* is another way to identify useful information from text documents automatically. It extracts names of entities of interest, such as persons (e. g., "John Doe"), locations (e. g., "Washington, D.C."), and organizations (e. g., "National Science Foundation"), from textual documents. It also identifies other entities, such as dates, times, number expressions, dollar amounts, e-mail addresses, and Internet addresses (URLs). Such information can be extracted based on either human-created rules or statistical patterns occurring in text. Most existing *information extraction* approaches combine machine learning algorithms such as neural networks, decision trees (Baluja et al., 1999), the Hidden Markov Model (Miller et al., 1998), or entropy maximization (Borthwick et al., 1998) with a rule-based or a statistical approach. The best systems have been shown to achieve more than 90% accuracy in both precision and recall rates when extracting persons, locations, organizations, dates, times, currencies, and percentages from a collection of New York Times articles (Chinchor, 1998).

At the *analysis stage*, *classification* and *clustering* are commonly used to identify embedded patterns. *Classification* assigns objects into predefined categories (using supervised learning), whereas *clustering* groups objects into categories dynamically based on their similarities (unsupervised learning). Both classes of methods generate categories by analyzing characteristics of objects extracted at the *indexing stage*. Widely used classification methods include the Naïve Bayesian method (Koller and Sahami, 1997; Lewis and Ringuette, 1994; McCallum et al., 1999), k-nearest neighbor (Iwayama and Tokunaga, 1995; Masand et al., 1992), and network models (Wiener et al., 1995; Ng et al., 1997; Lam & Lee, 1999).

Unlike *classification*, categories are dynamically decided during *clustering*. A commonly used clustering algorithm is Kohonen's self-organizing map (SOM), which produces a 2-dimensional grid representation for *N*-dimensional features and has been widely applied in information retrieval (Lin et al., 1991; Kohonen, 1995; Orwig et al., 1997). Other popular clustering algorithms include multi-dimensional scaling (MDS), *k*-nearest neighbor method, Ward's algorithm (Ward, 1963), and K-means algorithm.

Information analysis technologies help represent a textual document with semantically rich phrases or entities (indexes) and identify interesting patterns by using classification and clustering algorithms. Supporting a visualization system with these analysis technologies enables the system to deal with more complex and large-scale information.

### 4.1.2 Information Representation

Information representation technologies map abstract semantic structures into visual objects that can be displayed on a computer screen. Seven visual structures have been identified to map abstract information, including the 1D, 2D, 3D, multi-dimension, tree, network, and temporal (Shneiderman, 1996). A visualization developer needs to select an appropriate visual structure to visualize the semantic structure of interest. According to the cognitive fit theory (Vessey, 1991), only when the selected visual structure is appropriate for the semantic structure, can the users comprehend the information that the developer intends to deliver. For instance, a tree structure is applied to display a hierarchical relationship, while a network structure is employed for more complex relationships. One semantic structure could be mapped into the same visual structure through different algorithms. Tree visualization systems such as Tree-Map (Johnson and Shneiderman, 1991), the Cone Tree system (Robertson et al., 1991), and Hyperbolic Tree (Lamping et al., 1995) utilize different layout algorithms to map a hierarchical relationship into a tree structure. Readers interested in various layout algorithms for different visual structures are referred to Zhu and Chen (2005) for a detailed review.

Various visual cues such as color, size, shape, or texture could be integrated with these visual structures to deliver patterns. For example, the Tree-Map (Johnson & Shneiderman, 1991) uses size to present the attributes of nodes in a tree structure. The integration of visual cues usually needs to follow human perception rules described in Ware (2000) to make salient patterns visually apparent to users.

The seven types of representation methods turn abstract semantic structures into objects that can be displayed. A visualization system usually applies several methods simultaneously. There are 2D Hyperbolic Trees and 3D Hyperbolic Trees. The multi-level ET map created by Chen and colleagues (Chen et al., 1998) combines both 2D and the tree structure, where a large set of websites are partitioned into hierarchical categories based on their content. While the entire hierarchy is organized in a tree structure, each node in the tree is a two-dimensional SOM on which the sub-categories are graphically displayed.

The "small screen problem" (Robertson et al., 1993), denotes to the fact that a computer screen is always too small to present the information that needs to be presented. This problem is common to representation methods of any type. To achieve effectiveness, a representation method needs to be integrated with techniques of user-interface interaction. Recent advances in hardware and software allow quick user-interface interaction, and various combinations of representation methods and user interface interactions have been employed. For instance, Cone Tree (Robertson et al., 1991) applies 3D animation to provide direct manipulation of visual objects, while Lamping and colleagues (Lamping et al., 1995) integrate hyperbolic projection with the fish-eye view technique to visualize a large hierarchy.

### 4.1.3 User-Interface Interaction

Immediate interaction between an interface and its users not only allows direct manipulation of the visual objects displayed, but also allows users to select what is and is not displayed (Card et al., 1999). Shneiderman (1996) summarizes six types of interface functionality: overview, zoom, filtering, detail on demand, relate, and history. Techniques have been developed to facilitate various types of interactions. This subsection briefly reviews the two most commonly used interaction approaches: overview + detail and focus + context (Card et al., 1999).

Overview + detail provides multiple views, with the first being an overview, providing overall patterns to users. Only details about the part the user is interested in will be displayed. These views can be displayed at the same time or separately. When a detailed view is needed, two types of zooming are usually involved (Card et al., 1999): spatial zooming and semantic zooming. Spatial zooming refers to the process of enlarging selected visual objects spatially to obtain a closer look. In contrast, semantic zooming provides additional content about a selected visual object by changing its appearance.

The focus + context technique provides detail (focus) and overview (context) dynamically on the same view. One example is the 3D perception approach adopted by systems like Information Landscape (Andrews, 1995) and Cone Tree (Robertson et al., 1991), where visual objects at the front appear larger than those at the back. Another commonly used focus + context technique is the fisheye view (Furnas, 1986), a distortion technique that acts like a wide-angle lens to amplify part of the focus. The objective is to simultaneously provide neighboring information in reduced detail and supply greater detail on the region of interest. In any focus + context approach, users can change the region of focus dynamically. A system that applies the fisheye technique is Hyperbolic Tree (Lamping et al., 1995). Using this technique, users can scrutinize the focus area and scan the surrounding nodes for a big picture. Other focus + context techniques include filtering, highlighting, and selective aggregation (Card et al., 1999).

Overview + detail and focus + context are the two types of interaction usually provided by a visualization system to help users deal with large-scale information.

## 4.2 Related Applications of Visualization Technologies

The review in Section 3 indicates that analytical decision making involves structured information only and is supported by visualization technologies in limited ways. In contrast, involving both structured and unstructured information, subjective/judgmental decision tasks could be supported by visualization in various ways. In addition, many strategic decisions are made by decision makers using subjective/judgmental approaches (Nutt, 1998). Thus, we focus on the visualization applications that could be candidates for supporting subjective/judgmental decisions. Subjective decision makers draw subjective conclusions through exploring information, consulting experts, and understanding customers, whereas judgmental decision makers' performance could be affected by their domain knowledge and situation awareness. This subsection describes some sample visualization applications that facilitate the comprehension of situations. It explores related approaches to building a visualization system in the domains of criminal and financial analysis, where decision makers usually make subjective/judgmental decisions and the decision outcomes may largely depend on decision makers' situation awareness.

### 4.2.1 Criminal Analysis

Criminal analysis plays a crucial role in crime investigation decisions. Accurate decisions lead to the identification of suspects, the arrest of criminals, and the prevention of future crimes. Such analysis usually involves the examination of relationships that exist among various entities (i. e., crime location, suspect, vehicle, organizations, car registration, etc.) related to the crime case at hand to support investigation decisions. For instance, a vehicle could have been used in previous crimes. Thus, vehicle registration information could reveal details about the suspect in the case. Therefore, exploring relationships among related entities could be an important step before any investigation decisions are made. A crime usually involves a large number of entities and complex relationships among them. Providing visual support for the exploration of such network information becomes necessary as the number of entities increases. Focusing on the aesthetic aspect of the visual representation of network information, many network layout algorithms have been developed and could be applied to support the visual exploration of network information. The most popular algorithms include the spring-embedder model of Eades (1984) and its variants (Fruchterman and Reingold, 1991; Davidson and Harel, 1996).

However, those algorithms can be applied only to an existing network relationship. But the manual construction of such a network from the variety of criminal databases that store case reports of previous crimes could be an intellectually challenging task, even with the help of search engines. A criminal analyst could be easily overloaded if he/she needs to read related cases to identify entities and determine how they are related. Therefore, in the domain of criminal analysis,

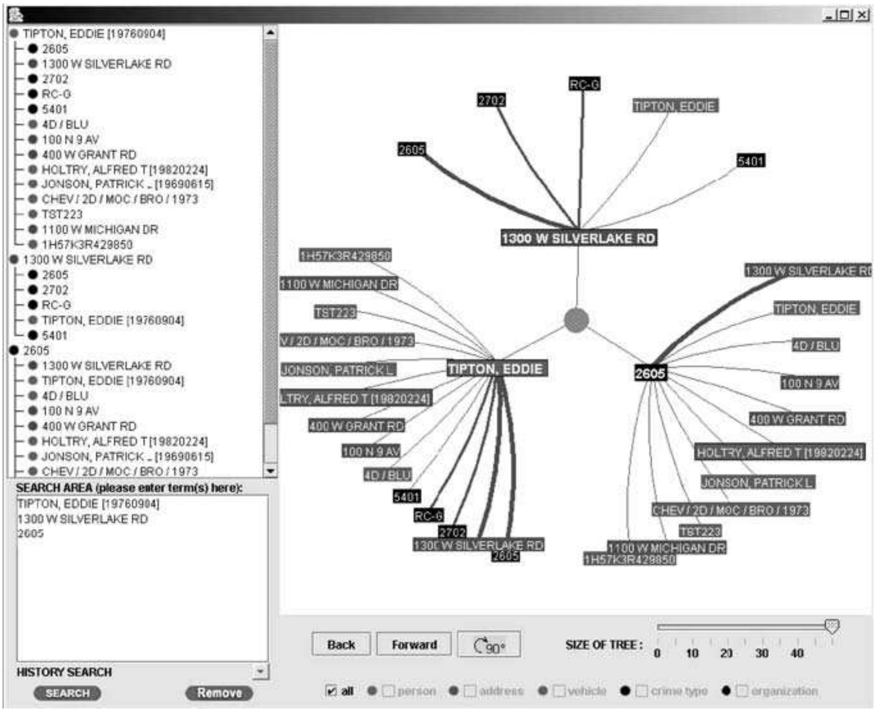


**Figure 1.** COPLINK Visualizer Interface

a visualization system needs more than just a network layout algorithm. It also requires an information analysis algorithm for automatic network construction.

Figure 1 displays one such system, the COPLINK Visualizer system. The system utilizes co-occurrence analysis to automatically detect entities related to a criminal case at hand and construct network relationships among identified entities. In Figure 1, the combination of a hyperbolic tree and a text-based hierarchy is applied to display entities related to the three query terms entered by a criminal analyst. The types of entities, such as organizations, people, plate numbers, and addresses, are color-coded on the interface. The thickness of the link denotes the strength of that relationship. The tree could be expanded to display more entities related to an entity selected by a user. The interface reveals overall patterns such as what type of entities are related to the case at hand, how the entity type is related to the strength of relationships among them, and where the strongest relationship is. The grasp of these patterns may help analysts better comprehend criminal cases and make better investigation decisions. The investigation decision could include such subjective/judgmental decisions as allocating resources, identifying suspects, and determining the appropriate investigative approach.

Although the COPLINK Visualizer uses data in the domain of criminal analysis, the technologies involved can be applied to support decision makers in other domains such as human resources, marketing, and knowledge management when network information is involved.

### 4.2.2 Financial Information

Smartmoney.com demonstrates a successful example of applying information visualization technologies to support financial decision making. The voyage takes more than ten years from the Treemap algorithm (Johnson and Shneiderman, 1991) to smartmoney.com. The popularity of the website shows that a visualization system can be successful in supporting subjective/judgmental decision making. Confronted with complex market changes and increased transaction speed, the ability to react to events is of great value to decision makers in the financial market. They need to quickly explore information about existing market and infer market trends to make profitable decisions.

Manual exploration of financial market information could take the decision maker hours due to the large number of stocks in the market. Additionally, pattern recognition would likely be almost impossible without visual support given that financial information can sometimes be very complex. Figure 2 displays the application of the TreeMap technique to financial information. The visualization

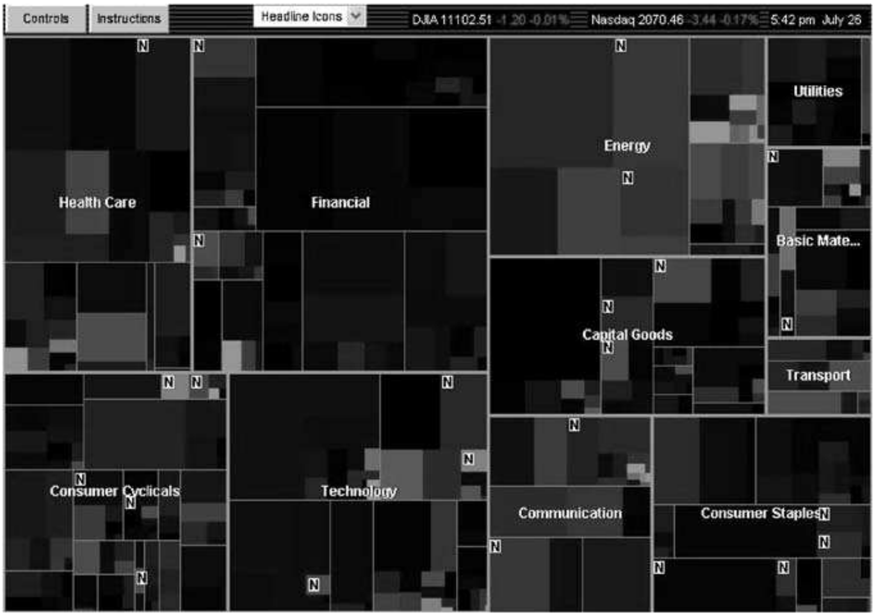


**Figure 2.** Using the TreeMap to support financial decision making (adopted from http://www.smartmoney.com)

presents complex information about more than 500 stocks. In Figure 2, stocks are grouped based on their market sector. The size of a stock indicates its market capitalization (total market value of a company's outstanding shares) and the change direction of the stock price is color-coded. In Figure 2 the colors red and green denote decreases and increases in stock price, respectively. The color hue of a stock suggests the range of the change. The letter "N" reveals that there is news about this stock today.

The Smartmoney interface provides a summary of the financial market, enabling decision makers to obtain an overview of the market and to grasp changes in each market sector in a single glance. A decision maker could also infer the reason for the change in stock price by clicking on and reading related news. The visualization could be applied to support such subjective/judgmental decisions as a buy/sell decision and future investment decisions. Therefore, the visual interface converts the expensive mental processing of information into an easy perceptual processing, saving decision-makers' time and cognitive resources.

The smartmoney.com involves almost no information analysis technology because the tree metaphor appears to be a natural representation of the hierarchical structure of the stock market, where the market consists of sectors and stocks belonging to sectors. However, when applied to other domains where a tree structure needs to be extracted and constructed, the development of visualization systems usually must involve information analysis technologies.

## 5 Evaluating Visualization Systems for Decision Support

Although the maturity of information visualization research has led to the commercialization of a variety of visualization technologies as described in the above sections, visualization remains a novelty for most users and decision makers (Plaisant, 2004). Having demonstrated that visualization technologies could lead to better task outcomes and faster completion of tasks, evaluation studies in visualization still need to provide more evidence to convince decision makers to capitalize on existing visualization technologies. This section summarizes existing evaluation studies and speculates how evaluation studies can contribute to the adoption of visualization technologies in decision making.

Our literature survey identified two types of empirical studies in information visualization: (1) Fundamental perception studies that seek to investigate basic perceptual effects of certain visualization factors or stimuli and (2) empirical usability studies that aim to understand the pros and cons of specific visualization designs or systems. In the following, we will summarize the studies in these two categories. We will also discuss the role each type of study plays in promoting visualization technologies for the support of decision making.

## 5.1 Fundamental Perception Studies and Theory Building

Fundamental perception studies are primarily grounded in psychology and neuroscience. Theories from those disciplines are applied to understand the perceptual impact of such visualization parameters as animation (Bederson and Boltman, 1999), information density (Pirolli et al., 2000), 3D effect (Tavanti and Lind, 2001), and combinations of visual cues (Nowell et al., 2002). What distinguishes this type of study from conventional psychology perception studies is that they usually involve computer-based visualization systems. For instance, Bederson and Boltman (1999) used Pad++ to investigate the impact of animation on users' learning of hierarchical relationships, while Hyperbolic Tree with a fisheye view was applied by Pirolli and colleagues (Pirolli et al., 2000) to explore the effect of information density. The hypotheses, tasks, and measures are developed under the guidance of theories from psychology studies. This type of study plays a crucial role in helping visualization designers understand various design factors. However, they may have a limited contribution to a decision-maker's adoption of visualization technologies.

## 5.2 Empirical Usability Studies

Most empirical usability studies employ laboratory experiments to validate the performance of visualization systems or developed designs. Examples include comparing a glyph-based interface versus a text-based interface (Zhu and Chen, 2001), comparing several visualization techniques (Stasko et al., 2000), or studying a visualization system in a working environment (Pohl and Purgathofer, 2000; Graham et al., 2000).

Studies such as those by Stasko and colleagues (Stasko et al., 2000), Graham and colleagues (Graham et al., 2000), Morse and Lewis (2000), and Zhu and Chen (2001) utilized simple, basic visual operations for evaluation. Sometimes referred to as the "de-featuring approach," they examine generic operations such as searching for objects with a given attribute value, specifying attributes of an object, clustering objects based on similarity, counting objects, and visual object comparison. Accuracy of operation results and time to completion are two commonly used measures. Taking such an approach would make it easier to design an evaluation study and to attribute task performance to differences in visualization designs. Results from this type of evaluation study could benefit the design of visualization systems. But they provide limited evidence for adoption by decision makers. For example, several investigations have been conducted to evaluate popular tree representations such as Hyperbolic Tree (Pirolli et al., 2000), Treemap (Stasko et al., 2000), multi-level SOM (Ong et al., 2005), and Microsoft Windows Explorer. These studies all involve simple visual operations of node searching and node comparison. Representations such as Treemap and multi-level SOM appear to be effective for node-comparison operations because they offer more visual cues for each node. In contrast, Hyperbolic Tree and Microsoft Windows Explorer provide a global picture and are more effective in supporting node-searching operations. However, a particular visualization's performance in simple tasks might not translate easily into improved decision-making outcomes. Thus, results from this type of study may not be convincing enough for a decision maker to adopt the technology for the decision task at hand.

Complex, realistic task-driven evaluation studies have also been conducted in visualization research (e. g., Pohl and Purgathofer, 2000; Risden et al., 2000; North and Shneiderman, 2000). Their experimental tasks are designed based on the functionalities that a visualization system intends to provide. Subjects conduct tasks assigned in a practical scenario, such as maintaining a hierarchy of subject categories (Risden et al., 2000), writing a paper (Pohl and Purgathofer, 2000), or selecting different visualization methods to display different information (North and Shneiderman, 2000). The usefulness of a given visualization system can be directly measured by this approach. Therefore, results from this type of study may help decision makers understand the feasibility and usefulness of the visualization technology tested.

In summary, most evaluation studies are controlled lab experiments seeking to improve the design of visualization systems. Results from these studies have limited effects on translating visualization technologies into performance improvement of decision-making tasks. Therefore, more evaluation studies should be conducted to provide actionable evidence to promote the adoption of information visualization technologies (Plaisant, 2004). These studies should examine visualization tools with real world tasks, enabling decision makers to envision the application of visualization in their own task domains. As such, the design of such evaluation studies requires a deep understanding of real world problems. Although the results may apply only to a specific type of task, decision makers maybe more inclined to adopt the technology if they feel related to the type of task tested.

In addition, how to design more realistic measures for an evaluation study remains a challenge. Most existing studies use task completion, time to task, error rate, and satisfaction of users as measures to demonstrate better performance and faster task completion of visualization systems. However, for the promotion of visualization technologies, evaluation studies should find links between applications of visualization and measures indicating the success of a decision-making process. These measures may include the perceived difficulty of making a decision, the adoption of the decision within an organization, and the implementation time of a decision (Nutt, 1998). Only when such links are identified can decision makers be convinced that visualization technologies could be a legitimate investment.

In summary, the promotion of visualization technologies requires evaluation studies to provide evidence of usefulness in decision support. While controlled lab experimentation has been a useful evaluation methodology, we believe other well-grounded behavioral methodologies such as protocol analysis (to identify qualitative observations and comments), individual and focus group interviews (to solicit general feedback and group responses), ethnography studies (to record behaviors and organizational cultures), and technology and system acceptance survey studies (to understand group or organizational adoption processes) also need to be considered. Instead of a one-time, quantitative laboratory experiment, other qualitative, long-term assessment methodologies may help visualization researchers find more evidence to support the adoption of visualization technologies.

## 6 Summary and Discussion

This chapter reviews information visualization research in the context of decision support. Through the review of related visualization and decision support literature, the chapter describes the concept, history, and theoretical foundation of visualization research and identifies different roles visualization technologies could play in supporting individual decision making. Focusing on supporting the individual level of subjective/judgmental decision making, we have reviewed related visualization technologies, including information analysis, information representation, and user-interface interaction. We also illustrate some visualization applications that could be candidates to facilitate subjective/judgmental decision making.

Overall, we feel that visualization systems enhance domain and situation comprehension and could be applied to support decision making. Therefore, most existing visualization systems have the potential to support decision making. However, although visualization technologies are applied in the real world through commercialization, only a handful of success stories supporting decision making have been published. We, therefore, believe that when it comes to decision support, the focus should not only be on the development of more advanced technology but also on the creation of a framework to guide the applications of existing visualization systems to the task domains of decision making. Such a framework may come from a series of evaluation studies that demonstrate the effectiveness of different visualization systems in supporting different real world decision-making tasks. While most existing evaluation studies in information visualization focus on helping to improve visualization designs, more effort should be invested into promoting the application of visualization systems. Designing evaluation studies in more realistic settings and using more practical measures could produce results to serve this purpose. Such a stream of research remains a challenge but could lead to a sustained proliferation in the field of information visualization research.

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# CHAPTER 69
# The Decision Hedgehog for Creative Decision Making

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This chapter introduces a fundamental evolution of the group decision support model from the single "decision-spine" which focuses on a single proceduralized context, to provide comprehensive Group Communication and Decision Support (GDACS). We show how GDACS can support creative decision-making through *collaborative authoring of outcomes*, within a plethora of decision spines, and also within the rhizome that constitutes the body-without-organs of the *decision hedgehog* in which these spines are rooted. We position decision making through the construction of narratives with the fundamental aim of enriching contextual knowledge for decision-making. Localized processes developing proceduralized contexts for constructing and exploring specific prescriptions for action ("pricking the real" at the tip of a decision spine) are rooted in this rhizome. We identify the variety of contexts that are involved in group decision making and include a case study that provides a comprehensive account of process design for GDACS.

**Keywords:** Collaborative authoring; Decision hedgehog; Decision process design; Enrichment of context; Group decision and communication support; Group decision support system; Rhizome

## 1 Introduction: Proceduralizing Context in a Decision-Spine

The limitations of rational perspectives on "decision-making as choice" have frequently been raised in the context of providing effective GDSSs—group decision support systems (e. g., Cyert and March, 1992; Carlsson, 2002). These perspectives have been called into question, not only in the interests of advancing the academic GDSS field, but also out of the perceived need to plug gaps that sophisticated GDSS systems throw up in practice (Huber, 1981; Stabell, 1987; Humphreys and Brezillon, 2002).

As a result of such challenges, alternative perspectives on decision-making processes within organizations have come to the fore, particularly those centered on the attention-based view of the firm (Occasio, 1997), which has its origins in the work of Herbert Simon. Simon (1960) conceptualized organizational decision making processes as linear, moving through three stages: intelligence, design, and choice. *Intelligence* involves a search for "the conditions that call for decisions." *Design* focuses on "inventing, developing, and analyzing possible courses of action" through the construction of "a model of an existing or proposed real world system." Finally, the *Choice* phase focuses on "selecting a particular course of action from those available" according to what has been represented in the model. For example, Hammond, Keeney, and Raiffa (1998), in their book *Smart Choices*, suggest PrOACT as a reminder that "the best approach to decision situations is a proactive one" where PrOACT stands for Problem, Objectives, Alternatives, Consequences, Tradeoffs.

Decision-making is thus cast as problem solving, where the process model aims to develop a representation of "the problem" which can then be "solved by" implementing a prescribed course of action identified as "preferred" or "optimal" within this representation. Yet the "small world" (Savage, 1955) in which the problem is represented is imaginary, and the "solution" is chosen on the basis of a collective fantasy, located in the planes of the *imaginary* and the *symbolic* developed by the participants in the "problem" representation process (Humphreys and Berkeley, 1986) who often lack the resources for adequate "reality testing" before committing to a prescription for action (Humphreys, 1989).

## 1.1 The Circular Logic of Choice

In practice, the process of problem definition has its roots in the formulation of the issues of concern and spirals within what Nappelbaum (1997) calls "the circular

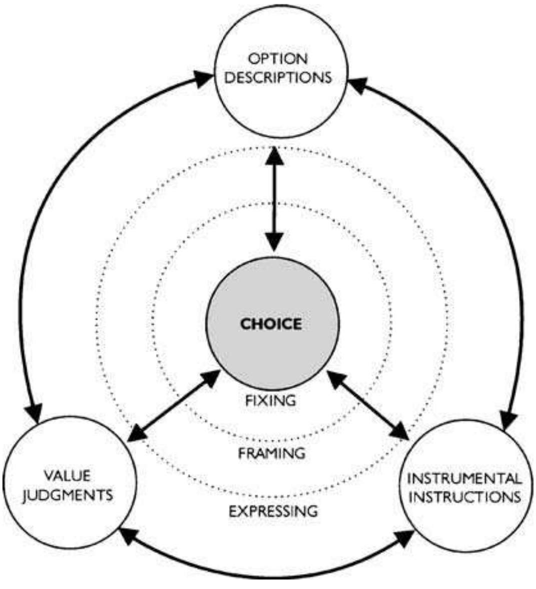


**Figure 1.** The circular logic of choice

logic of choice" (see Figure 1) as a decision-making group sharpens the description of the problem by cycling through option descriptions, value judgments, and instrumental instructions, reducing discretion in how these may be defined in developing structure and spiraling toward prescribed choice.

## 1.2 Proceduralizing Context

Brezillon and Zarate (2007), following Brezillon and Pomerol (1999), describe how, in initiating the spiral vortex of the circular logic of choice,

> "One must distinguish the part of the context that is relevant at this step of the decision making process and the part that is not relevant. The latter part is called the external knowledge. The former part is called contextual knowledge and obviously depends on the agent and the decision at hand. Always at a given step of a decision process, a part of the contextual knowledge is proceduralized. We call it the proceduralized context, i. e., the part of the contextual knowledge that is invoked, structured and situated according to a given focus."

Thus, decision making and problem solving is, according to the circular logic of choice, a process of a decision making group coming to an understanding and determination of the contextual boundaries (what is in and what is out), and of what knowledge is relevant to the situation, and shifting toward a proceduralized understanding of what is required to frame and fix a choice of action (Chatjoulis and Humphreys, 2007).

# 2 The Decision Spine

In practice, decision-making processes founded on the circular logic of choice spiral within five levels of increasing constraint, though a *decision-spine,* which, as we describe below, is located in the symbolic-imaginary, capable of pricking the real at its point. The name decision-*spine* is chosen to reflect an analogy with the structure and characteristics, in the real world, of an uprooted spine from a hedgehog, as illustrated in Figure 2.

The desire to take a decision-prescribed action is generated from a feeling that there is a lack (or a gap) between the actual state of affairs (as perceived by the decision maker) and some imaginable preferred state. In theory, the participants in a decision-making process can start out, at the level of feeling, with complete freedom about how to think about translating this desire into action. At the outset all imaginable courses of action are candidates for implementation. The group process, aimed at developing a single, collectively agreed, representation of "the problem" then aims at progressively strengthening the constraints on how the

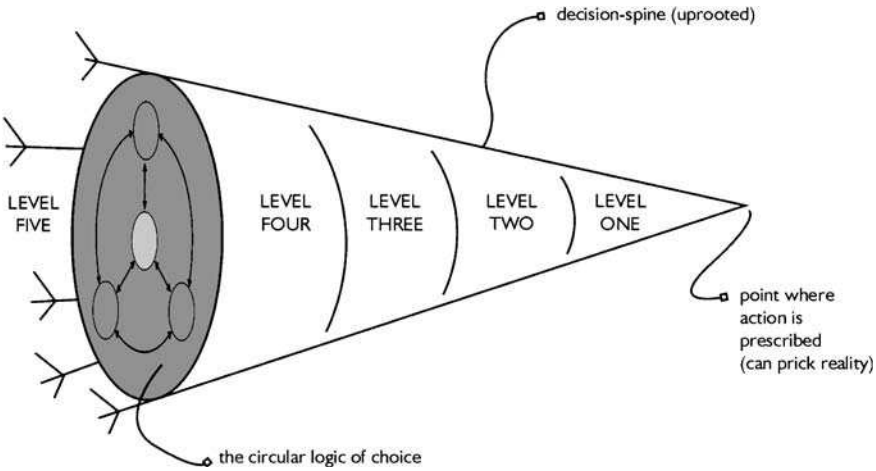


**Figure 2.** Decision spine

problem is represented within a proceduralized context until only one course of action is prescribed: the one that "should be" actually embarked upon in the *real*.

## 2.1 From Feeling to Action Through the Decision Spine

Five qualitatively different levels of constraint setting may be identified, each associated with a different kind of discourse concerning how to structure the constraints at that level (Humphreys, 1998). The nature of the knowledge represented at each level, and the cognitive operations involved in generating these knowledge representations, has been discussed in detail elsewhere (Humphreys, 1984, 1989; Humphreys and Berkeley, 1986). These levels are depicted in a point-down triangle as shown in Figure 3, indicating the progressive decrease in discretion to exploring contextual knowledge as one moves downward from level 5 (exploring fantasy scenarios and dreams with conjecturality beyond formalization or structure) towards fixed structure, within a fully proceduralized context (with all other knowledge now external to the "representation of the problem") and zero discretion at level 1 (making "best assessments"). At this point in the process, the problem-representation model is developed to the extent that the "best" course of action is inevitably prescribed.

In the actual decision-making process, the sequence of movement through the levels is not linear, but corresponds to a spiral through the circular logic of choice (Figure 1) to the point where a particular course of action is prescribed as the "true solution" to the decision problem. Decision conferencing methodologies essentially provide process designs to enable the decision making group to move efficiently and effectively through these levels within a general process that Phillips (1988, 1989) calls "conferencing to consensus."

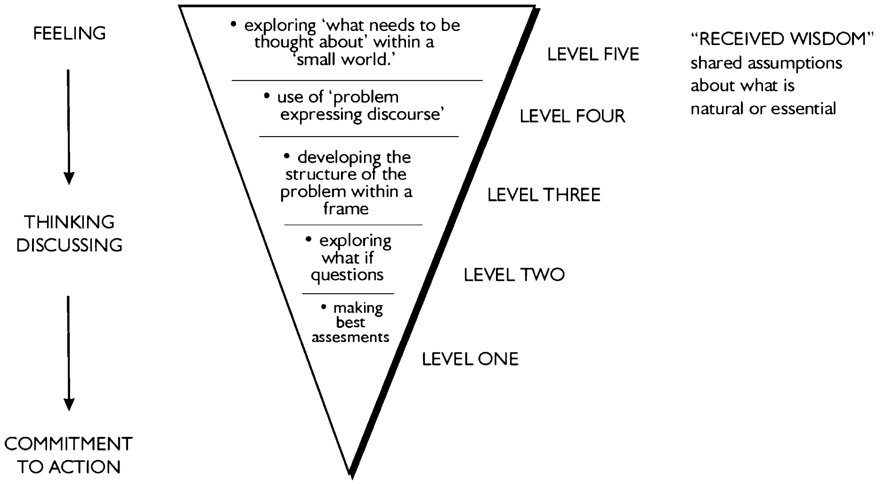


**Figure 3.** Five levels of constraint setting along the decision spine

At the top level (level 5 in Figure 3), the roots of the decision problem are imagined through explorations carried out within a "small world" (Savage, 1955; Toda, 1976) whose bounds are defined by what the participants in decision making within the spine are prepared to think about. Explorations within these bounds are made within what Sandler and Sandler (1978) call "the background of safety." The results of what is encountered in this exploration constitute the contextual knowledge which is available in forming the content elements of problem representations that are manipulated in problem structuring at lower levels.

At the next level down, (level 4 in Figure 3), problem-expressing discourse may be employed to make claims that particular elements of what was explored should (or should not) be included in the representation of the decision problem (Vari, et al., 1986). This discourse determines the parts of the contextualized knowledge, expressed as "representatives in illocutionary acts" (Searle, 1979, following Austin, 1962) that will be proceduralized. This discourse is usually argumentative; involving *claims* about what aspects of context should be explicitly proceduralized. These are expressed by their advocates, who support them with warrants and *backings* (c.f. Toulmin, 1958; van Eemeren et al., 1997) in order to gain their acceptance by all participants in the decision-making process. Thus, this discourse serves both to develop the proceduralized context and to define the constraints on what claims can be linked into frames, so that their collective implications for potential prescriptions for action can be explored (Beach, 1990).

At level 3, framing discourse is employed to develop the structure of the problem within a frame. Within "soft systems methodology" (Checkland, 1981; Checkland and Scholes, 1990; Humphreys, 1989), this process is described as "conceptual model building" and is located within proceduralized context. The frames generally employed here are (i) those that structure future scenarios, for example, through modeling act-event sequences with decision trees, (ii) those that structure preferences between alternatives, for example, through decomposition and re-composition within multi-attribute utility hierarchies, and (iii) rule-based structures aimed at reducing the problem-solution search space. Framing discourse is also employed to police the coherence of the material drawn from the proceduralized context into the frame until sufficient coherence is reached where it is possible to explore the structure so developed using "what-if?" discourse at level 2. "What-if" explorations may be used to investigate the impacts of changing the assessment of an element located at one node within the structure on the values of other nodes of interest to the decision making group within that structure.

At the stage in the decision-making process where level 1 is reached, sufficient constraints will have been set for the remaining task to be only to make best assessments of "the most likely value" at those points in the represented problem that have been represented as "uncertain" within the constructed decision-making frames, such that a particular course of action is prescribed.

Figure 3 is not intended to indicate a prescriptive process model for decision-making (e. g., "start at level 5, establish constraints, then go down, one-by-one through the levels until action is prescribed at level 1"). All that can be established, *in general*, is that the employment, within the group decision-making process, of the discourses identified at each level in Figure 3 serves to constrain what can be explicitly considered, at the levels below it, in establishing the "truth about the decision situation" (Chatjoulis and Humphreys, 2007).

## 2.2 Discourses of Truth Within a Decision Spine

According to Foucault, "truth is a thing of this world: it is produced only by virtue of multiple forms of constraint" (Foucault, 1980, p.131) and, in this sense, all the discourses identified at the various levels of constraint shown in Figure 3 are involved in the process of identifying "relevant" contextual knowledge, developing the proceduralized context, structuring the "problem" and prescribing choice of the one and only best course of action (the "true solution"). Collectively, they can be considered as particularized and, sometimes, artificial discourses of truth. Conversely, the representation of the proceduralized context, constructed through the use of this discourse, does not reveal the "real" situation. Rather it is an artifact, providing and structuring information about objects and relationships within a frame, to be communicated in restricted language (Eco, 1985, De Zeeuw, 1992). Such *telling* about what "is" or what "will be if these prescriptions are implemented" may be useful for establishing control or coordination in local decision-making processes, but locks out consideration and exploration of potential resources and pathways that are not described explicitly and exhaustively in the structure of the problem representation (Humphreys and Brezillon, 2002).

## 2.3 Drawbacks of the Decision-Spine as the Hegemonic Container for Decision-Making Processes

The decision spine is rooted in contextual knowledge at level 5—"exploring what needs to be thought about"—(see Figure 2), which, as we see in the following sections, is *not* necessarily always bounded within the spine, and ready for proceduralization, but extends throughout the unbounded body of an imaginary and symbolic *decision-hedgehog*—"a body without organs" in the language of Deleuze and Guattari (1988, pp 149–166). Conversely, the process of proceduralizing amenable aspects of this knowledge through the use of "problem expressing discourse" within the interaction context at level 4 in a decision spine serves to exclude most of this contextual knowledge which thus becomes "external knowledge." But this knowledge is external only to the particular decision-spine, not to the body-without-organs of the decision hedgehog.

In a survey of attempts to implement, in a wide range of organizational contexts, courses of action prescribed as "true solutions" through decision conferencing and related group decision support techniques, Humphreys and Nappelbaum (1997) find that the process of proceduralizing context is frequently too limited and narrowly driven by what could be structured within the decision-analytic model employed, resulting in failure to identify important side effects of the modeled effects and innovative pathways to goals.

Moreover, the process of trawling external knowledge in establishing the proceduralized context is often too narrowly focused, resulting in underestimation of the value of (or even the existence of) a variety of sources of potentially relevant knowledge. In general, within the group process the *interaction context* (Brezillon and Zarate, 2007) is too narrow: resulting in missing opportunities and creating problems for decision implementation management.

In conventional decision-theoretic logic, the act of choice within a single decision spine "solves the problem" and therefore terminates the decision-making and the processes that support it (Kleindorfer, Kunreuther and Schoemaker, 1993; Nappelbaum, 1997).

Narrative accounts of the decision-making process that led to the chosen action tend to be justificatory (Humphreys, 1998). These accounts are formed and located within the immediately proceduralized context through tracing back along the paths modeled within the frame from the point of choice.

They ignore (as "irrelevant" or "confusing") any narratives that traverse pathways that were not connected to the "mainline" trajectory of the ever-increasingly constrained path to the choice point at the tip of the spine. This is a major contributor to failures of practical efforts at decision support, predicated on this decision-theoretic logic.

Not surprisingly, the view that the core of successful organizational decision-making lies in the process of constructing and prescribing the solution to "the decision problem" within the proceduralized context of a single decision-spine has come to be contested. Qualitatively different views of the core process of decision making, not founded on the hegemony of proceduralized context, have emerged. These include decision-making as learning (Schein, 1992; Argyris and Schon, 1996; Senge, 2003) and decision-making as an integral function of the authoring of collective narratives in a literary view of organization (Imas, 2004).

## 2.4 Saving Grace of the Decision Spine: It's Ability to "prick the *real*"?

We do not challenge the useful, and indeed essential, function of constructing decision spines and developing prescriptions to solve decision problems by spiraling within a spine: moving from feeling that "something has to be done," experienced in the plane of the imaginary, through symbolic structures that reduce the variety of the group imagination about "what is to be done" to the prescription of a single course of action to be implemented in the real.

The ability of this decision technology to enable the group's imagination to "prick the *real*" is invaluable as this is crucial for effective reality testing of the collective fantasy about the context of the decision making that, in the first place, identified the action to be taken in the real as "preferred" or "optimal" (Humphreys, 1989; Checkland and Scholes, 1990).

However, in the following sections, we contest the hegemony of proceduralizing context within a single decision-spine as the sole fundament of support for effective, innovative, and creative decision-making—understood as a rich and continuing process at the core of organizational and social life.

# 3 The Decision Hedgehog

Conceptualizing decision making as "learning" requires gaining feedback from the effects of embarking on "chosen" courses of action (pricking the *real* to gain

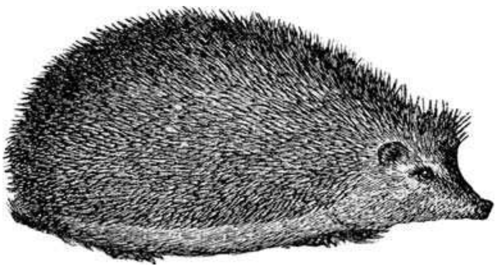

**Figure 4.** Decision hedgehog: Body-without-organs, covered in decision-spines, open for exploration and nurturance in the symbolic/imaginary plane

information) that is not treated in isolation, like a diagnosis within a proceduralized context, but which extends the *rhizome* that constitutes the *body-without-organs* (c.f., Deleuze and Guattari, 1998) of the decision-hedgehog in which the roots of the decision spines are located, enriching the contextual knowledge for subsequent decision making along a plethora of other spines rooted in this rhizome (Figure 4).

## 3.1 Body-Without-Organs

A body-without-organs is richly populated semantically (rather than physiologically). It is identifiable as a "body" because of its dense local semantic structure within the symbolic-imaginary (Bateson, 1981; Delouse and Guattari, 1988). Its "presence" is defined not by the existence of an internal physical structure ("organs"), as would be the case for a body located in the real, but by its positioning and function as a locally intense structure of semantic plateaus within an infinitely wider, amorphous, and less-explored general context (in the symbolic-imaginary).

As established through group communication and decision processes, the body-without-organs of the decision hedgehog establishes that part of the external context to any decisions in which the group may be involved. This is accessible through imagination and communication—usually through story authoring, communication, and exploration within the group. Its internal structure is that of a *rhizome* (Deleuze and Guattari, 1988, Humphreys and Brezillon, 2002).

## 3.2 Rhizome

The rhizome that constitutes the decision-hedgehog's body-without-organs is not simply a reference structure or high-level frame informing the selection of decision spines. Deleuze and Guattari (1988, p. 12) point out:

> "The rhizome is altogether different. Make a map, not a tracing. … What distinguishes the map from the tracing is that it is entirely oriented toward an experimentation in contact with the real … It is itself part of the rhizome. The map is open and connectable in all of its dimensions; it is detachable, reversible, and susceptible to constant modifications. It can be torn, reversed, adapted to any kind of mounting, reworked by an individual, group or social formation."

Figure 5 shows a cross-section of the decision-hedgehog's body-without organs. Plateaus linking strata comprising restricted and rich language root the decision-spines in the rhizome of contextual knowledge that constitutes the decision hedgehog's body-without-organs. Following Bateson (1979) and Deleuze and Guattari (1988), these plateaus are areas of intense knowledge linkages that provide the interaction contexts in GDACS.

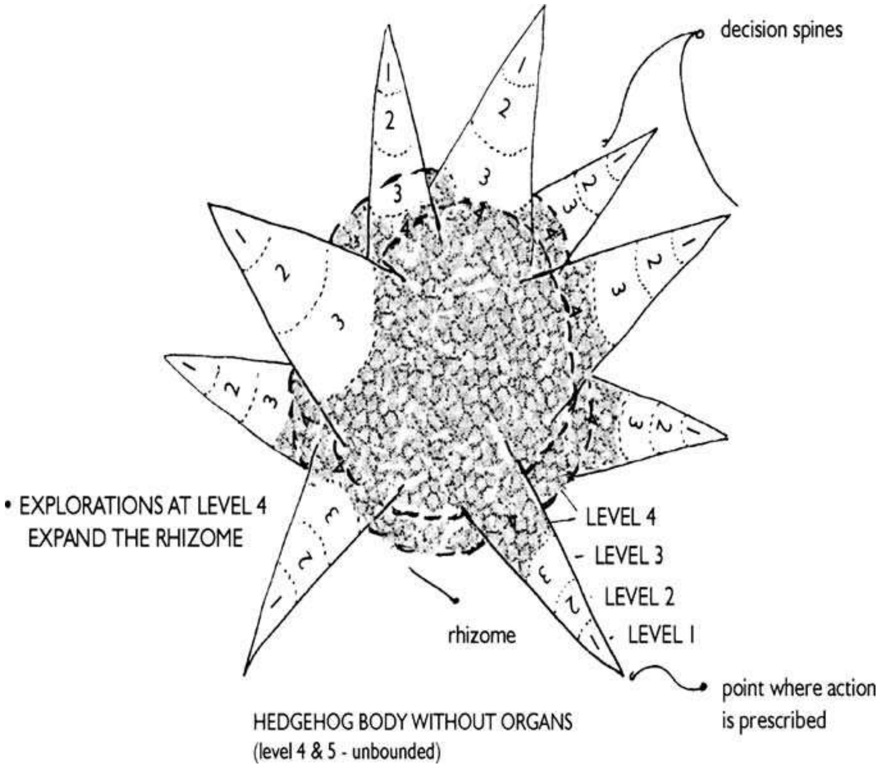


**Figure 5.** Cross-section of decision-hedgehog body-without-organs: Decision-spines rooted in the rhizome

## 3.3 Role of the Rhizome in Creative Decision Making

At the personal level in creative decision-making, the rhizome is experienced as a map formed through exploring potential pathways to develop contextual knowledge, rather than as a tracing of "reality." Resources for conceptualization of collaborative outcomes may be innovatively accessed and their transformation imagined through voyages along these pathways, doubled in imagination and in reality.

At the social level in creative decision making, the rhizome is activated, extended, and revised by the participants in the group, through making and exchanging stories about discovery and innovation in the conceptualization, utilization, and transformation of resources for living. When they are authored in multimedia, these stories involve *showing* as well as *telling* what is, and what *could* be, thus enriching context—rather than *being told* what *should* be, thus proceduralizing particular aspects of context (Humphreys, et al., 2001; Humphreys and Brezillon, 2002).

## 3.4 Nurturing the Decision-Hedgehog's Body-Without-Organs

In creative decision making, the fundamental dilemma about how to proceed, at least at the outset, is: whether to aim for immediate decision taking (action) by spiraling down a decision spine, with the aim to "prick the real" or whether to nurture the decision hedgehog's body-without-organs by telling and exchanging stories that fertilize story-relevant plateaus in the rhizome by increasing their semantic richness and intensity of connections. Enriching the context for subsequent decision taking within a spine, Humphreys and Brezillon (2002) note that this is achieved through:

> "[The] generation, exchange and interpretation of communications that enriches the context for distributed decision making within an open and extensible arena. Such communications would need to be in multimedia: comprising audio-visual strata founded in rich, open, language which can support innovative conceptualization and generate new possibilities for exploration of the rhizome." However, in order to prevent the interpretation of these communications by their receivers into what Eco (1985) called "infinite semiosis," it is desirable that such communications also comprise strata employing restricted language to provide directions on the pathways appropriate in assessment and monitoring these possibilities and in making tradeoffs in deciding between alternatives—a necessary precondition for turning fantasy into real action."

Thus, two kinds of story telling are intertwined in creative decision-making:

- Telling and exchanging stories that support the process of spiraling down a spine to "prick the real," where the "outcome" is the interpretation of the subsequent impact of the decision on local reality, and;
- Telling and exchanging stories that nurture the decision-hedgehog, enriching and improving the granularity of context in the rhizome, accessible through the local plateau.

Creative decision-making does not presume the hegemony of either type of outcome in directing the design of decision-making processes and support for these processes. Rather, it aims for a dynamic balance between them through the manner in which the processes supporting their generation are designed.

# 4 Story Telling that Nurtures the Decision Hedgehog

Throughout the process of storytelling that nurtures the decision hedgehog, the fundamental aim is to enrich contextual knowledge for decision making through authoring of narratives within the rhizome. This story-telling activity can be linked with localized processes involved in proceduralizing parts of this contextual knowledge, on a conditional basis, in constructing and exploring decision-spines.

Groups engage in story and artifact construction activities, producing mediated authored narratives (Imas, 2004) moving through levels 4 and 5 of the decision process, no longer constrained within a spine[1], with the general aim of enhancing contextual knowledge: working with imaginary ideas and developing a variety of open symbolic representations within a rhizome rather than a frame (Deleuze and Guattari, 1988).

When we communicate these, we engage in real authoring activities using our imagination to create symbolic content and our production skills to communicate this content as mediated narrative. Brezillon and Zarate (2007) describe the arena for this as the *interaction context*.

It may be decided, on occasion, by the participants communicating within the interaction context that it is appropriate to proceduralize aspects of this knowledge with the aim of moving down a particular decision spine, in order to take action (make an intervention in a local context) in the real, and thus gain feedback, but this in now seen as a situated, rather than hegemonic, process within the interaction context. According to Brezillon and Zarate (2007):

> "Here the co-building of the procedural context [by actors communicating within the interaction context] implies that, first, their interpretations are made compatible and, second, the proceduralized context will go to enrich their shared contextual knowledge thereafter."

The construction of mediated authored narratives is not only a means of more powerfully enabling attention within an organization, but also a means of exploring pathways though the rhizome, as collaborating groups construct maps of possibilities and opportunities, thus enriching contextual knowledge—and improving the resources for developing proceduralized contexts—within a variety of decision spines—within the doubling structure of a rhizome taking form on a variety of levels (Kaufman, 1998).

We call the convergence of processes supporting collaborative authoring of outcomes GDACS: Group Decision and Communication Support. GDACS supports creative authoring—enriching contextual knowledge that can inform and improve the process of developing proceduralized context at levels 5 and 4 within a decision spine. This creative activity nurtures the rhizome wherein decision spines are rooted in the Decision Hedgehog's body-without-organs. It also incorporates artifacts crafted within proceduralized contexts at levels 3 and below in spiraling through individual decision spines.

GDACS works through continuous cycles of conjecturality, contingency, and encounter with artifacts (Eco, 1986) to yield collaboratively authored outcomes, informed qualitatively by the convergence of processes that lead us from feeling to

[1] The lack of contrasts at these levels ensures, that, in Deleuze's terminology, the creativity discourse generated through these stories is not *territorialized* and the ability to take lines *of flight* through the rhizome is not hindered (Jeans, 2006).


**Figure 6.** Converging processes in collaborative authoring of outcomes

action. Humphreys and Jones (2006) identify the converging processes involved as shown in Figure 6.

*Facilitating Environments* range from specially built decision conferencing rooms and "Pods" (Phillips, 1989) to Accelerated Solutions Environments (Jones and Lyden-Cowan, 2002) and Flexible Learning Environments (Jones, 2005). They incorporate knowledge-rich arenas, interactive technology, feedback systems (visual and data), production support, and spatial facilitation of group, private, and interpersonal work. In most cases, the idea of the *proscenium* exists: a back stage and a front stage, where participants are enabled, and the work mediated, by facilitators and support teams. Multi-media, however, enables us to create a stage on which the players, actors, authors, stagehands, and audience are all present and where the proscenium shifts to the interface with the screen.

The fundamental principle for support within facilitating environments for GDACS is that "help is focused at the point within the problem structuring and decision-making process where the participants are currently experiencing difficulty in proceeding" (Humphreys and McFadden, 1980). Such environments provide a means of enabling rapid and creative progress both in enhancing contextual knowledge in the body-without-organs of the decision hedgehog and in developing proceduralized contexts as required to "prick the real," unencumbered by structural, logistical, and knowledge restrictions (Humphreys and Jones (2006).

# 5 Case Study: Application of GDACS Within a Flexible Learning Environment

This case study on "project dreams and reality" illustrates how the processes illustrated in Figure 6 were employed in an integrated way to provide comprehensive GDACS for a one-day event, mounted in a *flexible learning environment* (Jones, 2005) where:

- Zones could be configured for large group work, break-out areas, places to relax, areas to socialize, and areas to work on one's own. There were zones for both formal and informal learning, presentation surfaces, and on-line access to resources—enabling participants to access information rapidly.
- Multi-media authoring capabilities existed for audio-visual support, knowledge objects, and the publication of artifacts created during the process of collaborative authoring of outcomes.
- An ambience was created within the environment that was soothing and relaxing, or upbeat and theatrical, or beautiful and inspiring, as required. Modes of learning and authoring are supported with music and audio-visual material.

As the process modalities shifted rapidly within the interaction context during the event, equipment in the flexible learning environment could be moved around, packed away, and reconfigured as required. The "Crew" (event designers, facilitators, creative and technical personnel) assisted in the shifting of these modalities: supporting the creative learning process and providing the participants with ready access to tools and information as and when required.

The participants were 36 students of the Organizational and Social Psychology MSc course at the London School of Economics and Political Science. They were facing collective and individual problems of all kinds on how to develop and manage their MSc research work and logistics over the next nine months, leading to production of their MSc dissertations, as well as how to collectively gain mutual support for this work and for their career paths beyond this time. The activities of the day were digitally recorded (sound and vision) by the Crew and integrated into a web-journal, providing an interactive and extendable resource on the activities, outcomes, comments, and links relating to the activities integrated into the event. This web journal can be accessed at http://www.psych.lse.ac.uk/dreams, and provides a useful companion when reading section 5.

## 5.1 Event Design, Production, and Facilitation Processes

The Crew for this event met for a half-day pre-event design session, at which the specific event aims were clarified and the event design was developed as a sequence of modules. The processes implemented in these modules collectively

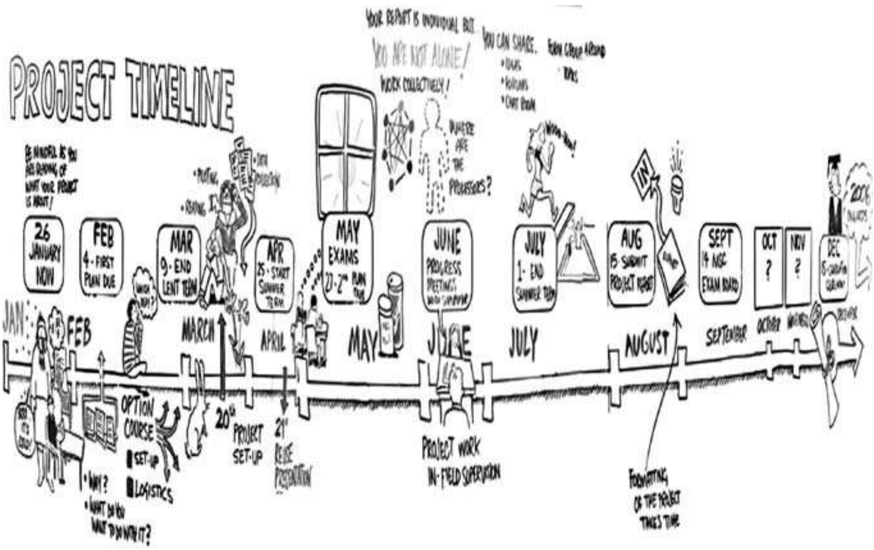


**Figure 7.** Timeline for project dreams and reality

aim to enrich context—extending the rhizome where possibilities for group and individual support could be created and explored (thus nurturing the decision hedgehog). This was intertwined with modules supporting participants at proceduralizing the context in which they would investigate and refine strategies and actions for their personal research and dissertation production[2]. In the following, we present brief descriptions of the modules, in the sequence they were implemented, indicating how the decision-hedgehog model informed their design and implementation in this event.

***Module: Introduction.*** This module explores the aims for the event and introduces the context in which the event is located—presented as a ‘spark’ session between two expert presenters performing in front of the plenary group.

***Module: Timeline.*** This provides for plenary group exploration, of the time line (on display, elaborated as shown in Figure 7), examining, as we move along the timeline, the range of contexts that need to be explored and the aspects that may need to be proceduralized in different ways by individual participants in optimally achieving their own milestones.

***Module: Swarm synthesis.*** Everyone gathered in the center of the space and exchanged thoughts and impressions of what they had seen and heard, and pointed their colleagues in the directions of other colleagues looking at similar topics. This provided an *interaction context* (Brezillon and Zarate, 2007) wherein elements of

[2] The actual implementation of these modules during the event is described in detail in multimedia (including streaming video) in the case study website: www.psych.lse.ac.uk/dreams

previously individually proceduralized chunks of knowledge could now, through the diverse story-telling going on in the Swarm Synthesis, enrich the patterning of knowledge contained in the body of the decision-hedgehog. Brezillon and Zarate point out that this is similar to the externalization process given by Nonaka and Takeuchi (1995). However, within the decision-hedgehog model, this is externalization from individual spines, effecting *deterritorialization,* into *lines of flight* through *the* rhizome that constitutes the body-without-organs of the decision-hedgehog (Jeanes, 2006). It is an example of what we call nurturing the decision hedgehog.

***Module: Take-a-flip (and Shift-and-share).*** Working in parallel on individual flip-chart sheets, the students developed individual short-term solutions—proceduralizing context within decision spines—on how to manage and develop their own MSc Dissertations over the next 6 months. The module's design ("shift-and-share") enabled the participating students to develop communications in multimedia (graphics, text, verbal discussion) on issues they faced and possible solutions, thus exchanging elements from a variety of individual proceduralized contexts rather than attempting to develop a shared group solution within a single proceduralized context (c.f. Brezillon and Zarate, 2007).

***Module: Communities of interest (and Report-out).*** Participants formed five loosely knit groups based on similar interests (as discovered through the swarm synthesis); the groups scattered around the space with the following assignment:

> "Working as a group, take the time to discuss and plan "what needs to be done in order to create the best possible support environment?"

*Useful questions, which you might want to think about, are:*

- What support from each other do we need to get started?
- How will we do it in the time?
- How can we structure this so that we enjoy the process of conducting our projects and making our project happen?
- What support can we give to each other (group that meets together, communication networks), and what do we need to do to set it up?
- How can we provide or get support for how we conduct our research?
- Can we provide, or get support for how we conduct our research?"

Each group worked collectively to develop a project context, collectively transforming the granularity of the contextual knowledge available within the body of the decision-hedgehog. Each group then reported back to the rest of the participants, sharing multiple contexts and thus enriching context as a long-term resource for future projects, realizing and sharing group decision support tools and techniques.

***Module: Scenarios (and Presentations).*** Participants divided again into five groups, each with the assignment:

> "Create, design and rehearse a five-minute presentation that tells a story about the journey from doing a successful project and gaining a successful career (you can tell it as an allegory if you wish with obstacles as well as achievements along the route)."

Each group then performed its presentation for the rest of the participants (these presentations are available in streamed video at www.psych.lse.ac.uk/dreams). Here, the focus was on enriching and sharing multiple contexts, collectively exploring and extending the rhizome that constitutes the body of the decision hedgehog, providing resources for individual career decision-making in future contexts that, at this time, may be enriched but, cannot yet be proceduralized.

***Module: Process Discussion.*** Participants addressed both the content and process of the event. The discussion of content focused on what people felt they had learned. The discussion of process focused on the characteristics of a flexible learning environment. (Details of participants' comments during these discussions are presented in the case study web-journal at http://www.psych.lse.ac.uk/dreams).

## 5.2 Evaluation of the Event by the Participants

An online forum for event evaluation was set up during the event, where participants could post evaluative comments. GDACS, to be effective and comprehensive, should nurture the entire decision hedgehog: its rhizomic body-without-organs, as well as its decision spines. The evaluation comments were generally very positive, but all the comments both positive and critical confirmed that the design and implementation process for the event had, in fact, succeeded in doing this. Here are two representative comments from participants:

> "It was the most innovative way of learning, creating and reflecting ideas I had ever heard about. [Previously] when we had talked about it in class I could never imagine that it would be so productive—I had thought it was just a waste of time. I wish the company I will work for will create an environment like this in order to foster ideas …"
> "It was the most attractive learning environment I have ever experienced. I found students willing to share their opinions, information, sources of learning in that relaxing atmosphere, and it is good to have this kind of bbs [bulletin board system] to get more feedback afterwards because sometimes we feel more about what we think afterwards …"

# 6 Implications for Group Decision and Communication Support

The language of the design process has emerged as a means whereby groups socially construct outcomes at every level of GDACS. Such language is used to enable the design of procedures for creative decision-making in the long term—nurturing the decision hedgehog and thus enriching context—as well as providing frames within which the decisions may be manifest—supporting rapid iterative cycles of decision-making, anchored within artifacts leading, in turn, to rapid cycles of reflection and reaction.

The convergence, in GDACS, of the processes shown in Figure 6 raises challenges for how we organize our work in groups, the environments we construct for ourselves to work in, the organization of our knowledge systems, and how we organize ourselves to achieve desired outcomes. We propose that the languages of authorship and production in multimedia revealed in this chapter provide a rich set of constructs for collaborative authoring of outcomes, *showing* as well as *telling* about *what is* and *what could* be.

In GDACS, the fundamental challenge of effective foraging still confronts us: how to construct and navigate the rhizome that comprises the body-without-organs of the decision hedgehog, in such a way that traversing its spines can enable effective contact with the real?

Specific implementations of GDACS must also address the questions:

- How do we ensure our decision-making is not taking place in isolation?
- How do we ensure that we are not the developers of redundant and expensive collective fantasy?
- How do we engage the attention of the communities affected by our decision making to ensure acceptance and activities of implementation?

## 7 Conclusion

The shift to the knowledge economy and the rise in real-time interactive systems—whose users can explore, show, and tell—provide opportunities for the crafting of complex narratives from the vast amounts of knowledge available. In such a condition, the collaborative construction of the rhizome, the visualization of desired outcomes, and the design of pathways to and through decision-spines enable groups to navigate and author the decisions that lead to desired consequences. This is the foraging territory of the decision-hedgehog.

For Deleuze & Guattari (1988), the symbolic acts as a constraint on the imaginary. GDACS attempts to provide sufficient encounters between these planes to enable sensemaking. The use of multimedia in Collaborative Authoring of Outcomes causes a doubling to take place that enables us to make sense of the real and the symbolic.

Collaborative Authoring of Outcomes is predicated on an understanding that the real is to be endured, embraced, and incorporated into the narrative structures of our personal and group story-authoring, in order for it to lead to sustainable change in our own behaviors. Rapid co-authoring of contingent, framed artifacts enables the unspeakable to be sufficiently present in deciding how to “prick the real," and thus to inform the proceeding cycles of authorship of stories that serve to enrich context within the rhizome.

We have shown how effective sharing of context goes beyond issues of semantic representation, but can be enhanced through rich audio-visual language and multiple modes of representation, as was evident in the foregoing case study. Combining rich and restrictive languages in multi-media has been shown to have a strong impact on creative and innovative decision-making (Humphreys and Brezillon, 2002). The richness of the metaphors, labels, and platitudes (Weick and Meader, 1993) that describe context in linguistic, visual, and other media can have a powerful impact on the sharing of contextual understanding. This is not to say the volume of external knowledge is increased, rather that the construction and accessibility of plateaus of contextual knowledge is improved within the rhizome—a process we call "nurturing the decision hedgehog."

Collaborative authoring of outcomes relies, for its success, on the understanding that GDACS must not presume the elimination of external knowledge in order to bind "the decision problem" within a restricted frame of proceduralized contextual knowledge. GDACS involves also the co-authoring, within the interaction context, of entirely new contextual knowledge, which may or may not be a synthesis of pre-existing contextual knowledge. The generation of this new contextual knowledge, and improvement of its accessibility, at the level of the group, becomes useful beyond the immediate moment in time. It becomes regenerated itself as it moves through time, and is available for proceduralization as the decision-making context shifts.

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# CHAPTER 70
# Creativity Support Systems

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Creativity support systems (CSSs) aid companies in finding ways to differentiate themselves by examining their current paradigm and improving or modifying the paradigm in a fundamentally new way. The four key factors involved in the execution of creative acts are the four Ps: person, process, press, and product. Each of these four factors plays an active role in how CSSs should be designed and utilized. The cognitive process of creativity starts in the mind of individuals to formulate the problem and produce ideas. At the individual level, a CSS can be used to present a variety of stimuli to the individual in an effort to break cognitive inertia and to help stimulate dissimilar memory chunks or frames. Various creative processes and techniques can be supported and implemented in a CSS. The creative press or environment is the context in which creative ideas are produced and explored. When a CSS is introduced to the creative process, it brings in its own internal environment comprising of the technology's spirit and its structural features. The creative product can be measured by the quality, the novelty, degree of originality, feasibility, appropriateness, or usefulness of the idea. As organizations strive to produce creative products, CSS tools, with their potential to enhance or modify the creative output of an individual or group, become increasingly called upon to aid in this goal.

**Keywords:** Creativity; Creative output; Creativity support systems; Four Ps

## 1 Introduction

Most believe that we are no longer in the era of manufacturing and industrialization, but are instead in the era of knowledge creation (Drucker 1993, Boland and Tenkasi 1995, Quinn et al. 1996) where a corporation's competitive advantage stems from the ideas of its management and employees. With the rapidly changing business environment and the globalization of many economies, businesses are also constantly searching for ways to differentiate themselves from their competition. Creativity aids a company in differentiating itself from its competitors by helping the company examine its current paradigm and consider ways to improve within this paradigm or to modify the paradigm in fundamentally new ways. Creating ideas that help a company differentiate itself from its competitors can be challenging. Many companies are tapping into the creativity of their employees in an attempt to find a new competitive edge. For corporations, understanding how to tap into the various creative abilities and styles of their employees could lead to new ways of competing in the marketplace.

Information technology has been used as one tool that can aid a company in leveraging and enhancing the creative powers that lie within its employees. Information technology features and creativity techniques have been found to enhance an individual's ability to develop more-creative solutions to problems (Massetti 1996, MacCrimmon and Wagner 1994, Couger et al. 1993, Satzinger et al. 1999, Garfield et al. 2001). Creativity support systems (CSSs) are computer-based systems that support individual- and group-level problem solving in an effort to enhance creative outcomes. This chapter looks at the creative process and the components of creativity support systems that impact the creative process and product within an organization.

## 2 Creativity and the Creative Process

The creative process can be broken into five steps as shown in Figure 1: problem presentation, preparation, idea generation, idea evaluation, and idea selection (Amabile 1983). The problem that one works on can be either internally or externally stimulated. Once the problem is picked, the second step is to prepare to solve it by recalling information and processes relevant to the problem. Next, a set of alternative approaches to solving the problem are generated; then they are evaluated and finally one or more is selected. The implementation of the selected creative idea is often times considered part of the innovation process (Amabile et al. 1996).

Research in the interdisciplinary field of creativity suggests that there are four key factors involved in the execution of creative acts (Rhodes 1961, Couger 1995). These are the four Ps shown in Figure 2: person, process, press, and product. Each of these four factors impacts all five of the steps in the overall creative process.

Creative people are responsible for bringing the creative product into being, whether directly (e. g., by formulating the problem at hand, generating the idea for a design, or evaluating and selecting the idea to solve the initial problem) or indirectly (e. g., managers and supervisors supporting and encouraging subordinates who are more directly responsible for the creative product). Creative processes are procedures or methods used by individuals and groups to bring creative ideas to life. The creative press or environment is the context in which creative products are generated and explored. The creative product is the thing or object that draws praise or appreciation. It could be an idea, a new design, a strategy, or a plan. Each of the four Ps influences one another (Rhodes 1961, Fellers and Bostrom 1993).

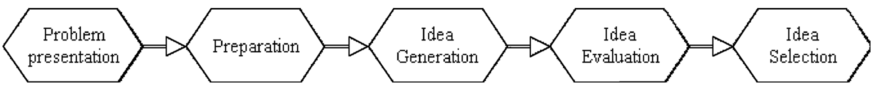


**Figure 1.** The creative process (adapted from Amabile 1983)

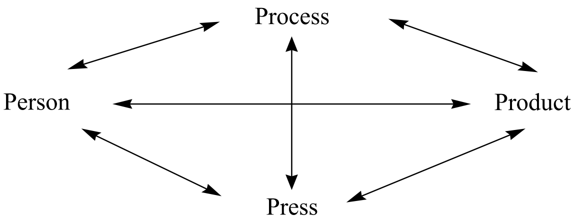


**Figure 2.** Creativity research framework, adapted from Fellers and Bostrom (1993

The remainder of this chapter examines each of the four Ps and discusses how CSSs can influence them.

## 2.1 Person

The cognitive process of creativity starts in the minds of individuals (Van de Ven 1986) as they formulate the problem and produce ideas. ACT* theory (Anderson 1983, 1987) argues that cognitive behavior is controlled by production rules—rules specifying the steps of cognition—that produce ideas when activated. Production rules are activated automatically by stimuli, without conscious control (Anderson 1992). A stimulus will activate a rule, or set of rules, each of which has its own weight (i. e., likelihood of being activated), based on past experiences and inherent tendencies. Individuals tend to recall, and cluster or bundle, information together (into frames) that they have encoded in similar ways (Meyer 1970, Santanen et al. 2004). As activation spreads through memory, rules related to the stimuli and to each other have the greatest strength and thus are most likely to be activated (Dennis et al. 1996). Familiar stimuli tend to activate familiar paths in an individual's cognitive network (Santanen et al. 2004), which can lead to cognitive inertia.

Other variables such as task motivation, domain-relevant skills, and creativity-relevant processes also play significant roles in an individual's ability to produce creative products (Amabile 1983, Amabile 1996, Conti et al. 1996). The type of task motivation that appears to have the largest impact on the individual is intrinsic task motivation; motivation to engage in a task for its own sake (Ruscio et al. 1998). Intrinsic task motivation occurs when one believes that one is in control of the way that one engages in the task at hand (Elam and Mead 1990). Domain-relevant skills are related to an individual's familiarity with factual knowledge of the domain in question, as well as the scripts used for solving problems in this domain (Schank and Abelson 1977, Ruscio et al. 1998). Creativity-relevant skills relate to an individual's ability to undertake lateral, associative, and/or divergent thinking, leading to idea generation that does not follow preexisting paths of cognition (Elam and Mead 1990). By increasing an individual's creativity- and domain-relevant skills and by triggering intrinsic motivation, an individual can increase their ability to produce creative products.

While the creative process can start within the mind of an individual, in most cases people do not work in isolation; they often work with others, as part of formal or informal groups, teams, or organizations (Drazin et al. 1999, MacCrimmon and Wagner 1994). Not all ideas that are produced in a participant's mind are actually contributed; the individual must choose to contribute or share a particular idea. One of the most fundamental theories of human behavior is the theory of reasoned action (Ajzen and Fishbein 1980, Fishbein and Ajzen 1974). This theory—and its successors such as the theory of planned behavior (Ajzen 1991)—argues that the decision to behave in a certain manner is affected by the relative importance of an individual's own attitude toward a behavior and the individual's understanding of the subjective norms toward a behavior. Therefore, the decision to contribute an idea is influenced by the individual's attitude toward the idea and his/her perceptions about the subjective norms of others towards the contribution of the idea (Ajzen and Fishbein 1980, Fishbein and Ajzen 1974). As members work together they establish structures or traditions that constrain how they act by defining normal and unacceptable behaviors (Gersick and Hackman,1990) and thus impact the likelihood that an individual will share an idea with his/her group, team, or organization (e. g., community, network, firm).

Various aspects of the group/team/organization can also have a significant impact on its creative output. For instance, group diversity, conflict, and leadership have been shown to impact group creativity. Group diversity can increase creativity by giving the group a range of perspectives (Amabile 1988), but it may also decrease creativity in the beginning of a group's life, due to the group members' limited shared experiences (although over time the group's members will create shared experiences). Group conflict generally limits creativity, but it can increase it if it is task based (i. e., if the conflict is focused on disagreements of opinion on specific work issues, Kurtzberg and Amabile 2001). Team leadership has also been shown to play a valuable role in a team's creative output. Groups that have transformational leaders tend to be more creative than groups that have transactional leaders (Jung 2001). Team creativity also increases through autonomy of work, openness of ideas, constructive challenge to ideas, shared goals, and commitment to the team (Amabile et al. 1996). However, team creativity decreases with group think (Janis 1972), social loafing (Latane et al. 1979), evaluation apprehension, and production blocking (Diehl and Stroebe 1987). Therefore, the composition of the group and the manner in which it interacts plays a significant role in a team's ability to produce creative products.

### 2.1.1 Ways a CSS Impacts the Person

While some argue that creativity is too ambiguous a process to be formalized in a way that can be captured by a system, this paper contends that not only can a person express their creative ideas while interfacing with a system, but that a system can enable people to be more creative than they would be without using a system. A CSS can not only enhance both an individual's creativity, but can also enhance the creativity of a group. One way to enhance creativity and reduce cognitive inertia is to bring together external stimuli that are not typically brought together, thus increasing the probability of lateral associations (Kurtzberg and Amabile 2001, Satzinger et al. 1996). At the individual level, a CSS can be used to present a variety of stimuli to the individual in an effort to break cognitive inertia and help stimulate dissimilar memory chunks or frames. Furthermore, a CSS can be used to capture ideas from an external source, an individual, or group of individuals, and then be used to display these ideas to an individual or group. Feedback in the form of ideas from other group members or external sources will also impact the ideas generated by an individual (Dennis and Valacich 1994), leading an individual to generate ideas similar to those to which they are exposed (Satzinger et al. 1996). Hence, it is possible to design a CSS to guide an individual's cognitive network towards different pathways than they typically activate. The CSS can also be used to jolt an individual or team by introducing structures or stimuli that help unconventional ways of thinking (Rickards and Moger 2000).

Furthermore, a CSS can be used to help individuals establish or maintain weak ties to other individuals. Strong ties are more easily maintained due to their very nature (i. e., people tend to see each other often, have a level of trust, and are emotionally close). Weak ties often bring together people that are part of different social groups. When this occurs there is often an increase in diverse perspectives and ways to approach problems. This diversity should enhance creativity (Perry-Smith and Shalley 2003). A CSS can also be used to enhance an individual's domain-relevant skills by providing her/him with access to relevant material and/or training. Furthermore, by utilizing entertaining and inventive work processes via the CSS, an individual's intrinsic motivation can be enhanced.

A CSS can also be used in a variety of ways to improve a group process. For instance, using anonymity in a system can reduce evaluation apprehension which, in turn, can result in more ideas being produced as well as ideas that do not fit social norms within the group. There is a large stream of literature that targets this specific area of CSS in the group decision support system (GDSS) work. See Dennis et al. (2001) and Benbasat and Lim (1993) for metastudies of GDSS effects.

### 2.1.2 Measuring a Person's Creativity

People can be classified using instruments that identify an individual's creativity level or style based on some criteria for which all people can be ranked. There are many different ways to measure an individual's creativity aptitude. Some of these measurement tools are:

- The creative thought and innovative action inventory (CTI, Hellriegel and Slocum 1992)
- The Kirton adaptive innovator (KAI) scale (Kirton 1976, 1989)
- Associative and bisociative problem-solving scales (Jabri 1991, Scott and Bruce 1994)
- The Myers–Briggs type indicator (Myers and Briggs 1952, Myers 1987)
- Adjective checklists (Gough and Heilburn 1983)

See Eysenck (1994) for a more-thorough listing of such methods.

The CTI (Hellriegel and Slocum 1992) helps to identify barriers that an individual faces when they attempt to produce creative thoughts. If such barriers are low (i. e., a low CTI score), then the individual is less likely to encounter a significant amount of difficulty when attempting to generate creative ideas.

The KAI score identifies a person's preferred cognitive style, on a continuum from adaptive to innovative (Kirton 1976). This style manifests itself in the way a person approaches and solves a problem. Those who tend to use adaptive approaches in problem solving seek to do things better by using standard rules. Innovators, on the other hand, look to do things differently by reorganizing a problem when it is presented, looking for a new way to view the problem.

Jabri's tool identifies two types of thinkers. Some individuals tend to be systematic thinkers, building on ideas and facts in the problem and focusing on rationality and logic, while others rely more heavily on intuition and imagery, looking beyond current rules, boundaries, and rational logic (Jabri 1991, Scott and Bruce 1994). Jabri's tool is not a single scale, but rather two subscales that measure the associative and bisociative characteristics of a person.

The Myers–Briggs type indicator (MBTI, Myers 1987, Myers and Briggs 1952) has four subscales, two of which are of particular interest to creativity (Garfield et al. 2001). The sensor–intuitor (S–N) subscale assesses the extent to which individuals view reality in terms of data and facts without considering alternative meanings. At the other end of the scale are those who rely more on the general context or atmosphere, using intuition to see beyond objective reality to the subtle inner relationships (N: intuitors). The thinker–feeler (T–F) subscale assesses the extent to which individuals use a rational, systematic process to understand reality through analysis and logical inference (thinkers), versus those who emphasize images and feelings (feelers). While the MBTI is used by many people in industry, its theoretical and statistical stability has been challenged.

The adjective checklist is an instrument that assesses individual creativity by having a subject indicate which adjectives (out of 300) describe them. Each subject then receives a score based on the creative personality scale developed by Gough (1979).

This section identifies and briefly discusses several tools that can be used to assess an individual's creativity level and/or style. There are many other tools that can be used for this purpose as well. The selection of any particular tool should be made with the theoretical underpinnings of a specific study in mind. Matching the theory to the tool is critical in understanding how various CSSs impact the creative output of an individual or group/team/organization. While it can be argued that we can measure an individual's innate creativity level, it has also been shown that, in fact, creativity can be learned just as memory can be learned.

## 2.2 Process

In order for a person to display creativity, they must engage in a creative process. Many different creativity techniques have been developed to focus and enhance creativity (VanGundy 1988). These can be classified by the cognitive processes they attempt to induce. Couger (1995) classifies techniques as analytical or intuitive. Analytical techniques generate logical patterns of thought that "tend to follow a linear pattern or sequence of steps" (Miller 1987, p. 66). Intuitive techniques "rely on a single image or symbol to provide a whole answer all at once … to arrive at solutions by a leap" (Miller 1987, p. 66). One powerful creativity technique is the use of analogies (Hender et al. 2002) or metaphors to aid in the generation of ideas to solve a problem. "The choice of a technique in a given context should be dictated by its performance with respect to the nature of the desired outcomes" (Nagasundaram and Bostrom 1994, p. 95).

A CSS can be designed to support a single or a set of different CSS techniques that emulate specific creativity-inducing techniques. Not only can creativity techniques be embedded in a CSS, but the creative process itself can be altered through the use of software tools (MacCrimmon and Wagner 1994). Individuals that use a CSS in place of pen and paper have been shown to be more creative, even though it is unclear how the use of a CSS led to this result (Massetti 1996). However, we do know that if a CSS is too cumbersome or confining, it will not be effective in the quest to accelerate and enhance the creative ability and product of a group or individual. Very little work has been done in this area and more research would help us better understand the role of CSSs on the process component of the creative framework (Nagasundaram and Bostrom 1994).

## 2.3 Press

The creative press or environment is the context in which creative ideas are produced and explored. The press may include such environmental and cultural factors as evaluation, surveillance, competition, and restricted choice (Amabile et al. 1990). In any given organization, there can be a variety of cultures and subcultures that may be homogenous in some aspects, but can vary drastically in other aspects. These cultures can be associated with different levels of an organization, different functional areas, or different geographical locations. The different cultures can have differing impacts on the creative process. Identifying the cultural level to measure an environment's creative atmosphere can have on impact on observed outcomes. However, if we are only interested in the external environment's impact on an individual's ability to be creative, the organizational level from which the influence comes is of low importance.

If a person feels that his/her workplace is not open to new ideas, it is important to identify those feelings regardless of which level of the organization is responsible for the individual's perceptions. For an environment to be conducive to creativity, the workplace should be encouraging of creativity (at the organizational, supervisory, and group levels) by

- giving employees a high degree of autonomy
- allocating resources in terms of equipment, facilities, and time to the projects of interest

- providing sufficiently challenging work
- avoiding high workload pressure on employees
- being free from organizational strife or other impediments to the creative output of employees (Amabile et al. 1996, Scott and Bruce 1994).

### 2.3.1 CSS and the Press

When a CSS is introduced into the creative process, it brings with it its own internal environment. This environment is comprised of the technologies' spirit and structural features. A CSS can affect the way in which teams work through both its structural features and its spirit.

The structural features are the specific components of the CSS, their capabilities, and the "specific types of rules and resources, or capabilities, offered by the system" (DeSanctis and Poole 1994, p. 126). For example, structural features such as anonymity can significantly influence how information is discussed, and thereby impact members' interaction. The spirit of the technology is the general intent of its structural features, and is broadly defined to include the system design, its features, user interface, and training materials (DeSanctis and Poole 1994).

Some CSSs are more restrictive in nature than others, which may cause users to perceive the technical environment in which they are working as restrictive and thus less conducive to the creative process. Furthermore, the fit between the technical environment of the CSS and the organizational environment in which it is used will greatly impact the outcomes of the system use. Not only must we be aware of the structural and spiritual components of the CSS, but also the organizational environment in which it will be placed. The same system can be adapted and used in a variety of ways and the individuals using the system and the environment in which the system is used will impact the outcomes of the system use.

### 2.3.2 Measuring the Press

Amabile and colleagues developed the KEYS tool to assess the climate for creativity in the work environment. "KEYS was designed to assess perceptions of all of the work environment dimensions that have been suggested as important in empirical research and theory on creativity in organizations" (Amabile et al. 1996, p. 1155). This tool assesses the way in which individuals perceive aspects of their work environment that influence their own creative behavior.

## 2.4 The Product

Creative products are the outcome of the creative process and can be categorized in a variety of manners. In the past, the creativity level of an idea has been measured by the quality, novelty, degree of originality, feasibility, appropriateness, or usefulness of the idea (de Bono 1970, Gallupe et. al. 1992, Durand and VanHuss

1992, Amabile 1983, Elam and Mead 1990, Marakas and Elam 1997, Mullen et al. 1991, Barron 1968). The *type* of creativity present in an idea has been categorized in terms of the paradigm-relatedness of the idea (Satzinger et al. 1996). The way in which we choose to measure the creative level, or type of the creative product, is often governed by the goal of the creative process. In some cases, the goal is to create a large quantity of ideas, while in other cases the goal is to create a few high-quality ideas (de Bono 1970, Gallupe et al. 1992).

### 2.4.1 Measures of the Creative Product – Quality

Clearly, one does not want to produce low-quality products when trying to solve a potential problem. However, determining if a product is of high or low quality can be very subjective. The overall quality of an idea is often assessed based on a panel of content experts who have extensive knowledge of the problem domain. This panel will then rate each idea generated via the creative process being studied (Ruscio et al. 1998).

### 2.4.2 Measures of the Creative Product – Novelty/Originality

The study of creativity has emphasized the generation of novel ideas that are different from what has come before (Amabile et al. 1996, Oldham and Cummings 1996, Woodman et al. 1993, MacKinnon 1962, Rickards and Moger 2006). In this sense, idea novelty represents the rareness or uniqueness of an idea; more-obvious (i. e., less-novel) ideas will be generated more often, and more-novel ideas will occur less often. Idea novelty can be particularly desirable because it can be important in distinguishing a firm from its competitors (Woodman et al. 1993). There are two ways to measure novelty: to calculate the frequency with which an idea is expressed within a given set of data, or use raters to rate the novelty of each idea based on their preconceived notions of the solution set for the problem at hand.

### 2.4.3 Measures of the Creative Product – Degree of Feasibility

When a creative product is rated for feasibility, one must take into consideration the environment in which the creative product is to be implemented. For instance, if the creative product would be difficult to implement due to resource constraints, then the idea would be rated lower in feasibility than other ideas that would be easier to implement.

### 2.4.4 Measures of the Creative Product – Appropriateness

The appropriateness of an idea is assessed by its fit with the organizational goals. Some ideas may be novel and feasible, but inappropriate. For instance, if the problem is how a restaurant can attract more business, an idea that is both novel and feasible, but not appropriate, is to have the restaurant become notorious due to having a member of its staff murdered.

### 2.4.5 Measures of the Creative Product – Usefulness

An idea is useful if it helps solve the problem at hand and can be implemented. This measure is typically used to identify creative products that will move from the idea generation stage of creativity to the assessment stage. If an idea is not useful, it may be excluded from further examination. Comments about the creative process may fall into this category, as well as side discussions by group participants.

### 2.4.6 Measures of the Creative Product – Paradigm Relatedness

Ideas and other creative products can also be classified in a way that highlights the differences between them, without making a judgment about the extent to which they are creative. This allows for different types of ideas to be equally creative, although different in form. One such classification scheme reflects how closely an idea conforms to the overriding paradigm of the problem or situation presented (Gryskiewicz 1987, Nagasundaram and Bostrom 1994). In this classification scheme, an idea is mapped onto a continuum based on the extent to which it supports or challenges the existing paradigms or habitual routines that constrain individual and organizational behavior (Ford 1996, Kirton 1976). A paradigm in this context refers to the fundamental elements of a problem and the relationships among them (Gryskiewicz 1987). Paradigm-preserving (PP) ideas support or extend the existing paradigm; they are evolutionary in that they adapt elements of the existing paradigm, working within the underlying assumptions of the problem. Paradigm-modifying (PM) ideas are revolutionary in that they redefine the problem or its elements (Gryskiewicz 1987, Kirton 1976, Kirton 1989). Because an idea can alter the underlying paradigm and assumptions of a presented problem to varying degrees, this scheme is a continuum.

## 3 Conclusion

As organizations strive to develop creative products, CSS tools will become increasingly called on to aid in achieving this goal. These tools have the potential to greatly enhance the creative output of an individual, group, or organization. When selecting or designing a CSS, we need to consider the press that is present within the system, as well as the external environment in which it will be used, the people or groups that will use the system, and the creative processes embedded in the system. Much work has been done to understand ways in which the four Ps impact creative output. However, we must take a better look at how technology, and CSSs in particular, can impact all four Ps. CSSs brings to the table another dimension through which creativity can be enhanced. It is our job to understand better how CSSs can enhance each of the five steps in the creative process. We need further research to gain additional insight into the components of a CSS and how they impact on creative output.

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# CHAPTER 71
# Systems for Strategic Learning

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An important decision support system component is machine learning/data mining. Classical machine learning methods implicitly assume that attributes of instances under classification do not change to acquire a positive classification. However, in many situations these instances represent people or organizations that can proactively seek to alter their characteristics to gain a positive classification. We argue that the learning mechanism should take this possible strategic learning into consideration during the induction process. We call this strategic learning. In this chapter we define this concept, summarize related research, and present a number of future research areas.

**Keywords:** Discriminant analysis; Principal-agent; Strategic gaming; Data mining; Machine learning

## 1 Introduction

Today's highly computerized environment makes it possible for researchers and practitioners to collect and store virtually any kind or amount of information easily in electronic form. As a result, an enormous amount of data in many different formats is available for analyses. This increase in the availability and ease of access to data enables many companies constantly to look for ways to make use of their vast data collections to create competitive advantage and keep pace with the rapidly changing needs of their customers. This strong demand to utilize the available data has created a recent interest in applying machine-learning algorithms to analyze large amounts of corporate and scientific data, a practice commonly called data mining. Here we use the terms data mining and machine learning interchangeably.

Recently, a new paradigm has evolved that we believe will be an important new area for research and practice in data mining. This paradigm considers certain data mining tasks that involve classification over intelligent agents. We call this concept strategic learning. Traditional data mining methods use training data as-is without questioning the future usage of the induced function. More specifically, none of these algorithms take into account the possibility that any future observed cases might have attributes deliberately modified by their source when that source is a human or collection of humans. They fail to anticipate that people (and collections of people) might play the system and alter their attributes to attain a preferred classification.

In Sections 3 and 4 we present a review of recent literature on strategic learning and then move onto a discussion of potential research areas of possible interest to the decision support system (DSS) community in general. Before undertaking our review, in Section 2 we lay out the fundamental components of this area and discuss the strategic importance of the approach.

## 2 Data Mining and Supervised Learning Paradigm – Strategic Learning

An important type of machine learning commonly used in data mining tasks is called supervised learning, which is performed by making use of information collected from a set of examples called a training set. The training set usually takes the form $\mathrm{S} = \left(\left(\mathrm{x}_1, \mathrm{y}_1\right), \ldots, \left(\mathrm{x}_\ell, \mathrm{y}_\ell\right)\right)$, where $\ell$ is the total number of available examples. Each example (also called a labeled instance) is denoted by $x_i = (x_{i1}, \ldots, x_{in})$ which is the vector of $n$ attributes for the instance. The set of all instances is denoted by $\mathrm{X} \subseteq \Re^{\mathrm{n}}$. The label for each instance is denoted by $\mathrm{y}_{\mathrm{i}}$ and is assumed to be known for each example, which is why supervised learning is sometimes referred to as learning with a teacher. Given this setting, we are interested in choosing a hypothesis that will be able to discriminate between classes of instances. A wide range of algorithms have been developed for this task, including decision trees (Quinlan 1986), neural networks (Bishop 1995), association rules (Agrawal et al. 1993), discriminant functions (Fisher 1936), and support vector machines (Cristianini and Shawe-Taylor 2000). Throughout this chapter, we particularly focus on binary classification where $\mathrm{y}_{\mathrm{i}} \in \{-1, 1\}$. Informally, we are interested in the classification of two classes of instances, which we call the negative class and positive class, respectively. We choose a collection of candidate functions as our hypothesis space. For example, if we are interested in a linear classifier, then the hypothesis space consists of functions of the form $w'x + b$. Under these circumstances, the goal is to learn a linear function $f : X \subseteq \Re^n \rightarrow \Re$ such that $f(x) = w'x + b \geq 0$ if $\mathrm{x} \in \mathrm{X}$ belongs to the positive class and $f(x) < 0$ if it belongs to the negative class.

As an example of strategic learning for the binary classification problem, consider the credit-card approval scenario where each instance, $x \in X$, (i.e., a credit applicant) is described by a vector of attributes (such as age, marital status, checking account balance, number of existing credit cards, etc.). $w'x$ is often called a credit score and an applicant is awarded credit if $f(x) = w'x + b \geq 0$. There are hundreds of websites that purport to help applicants increase their credit score by offering legal ways to manipulate their information prior to the credit application.

In Abdel Khalik and El-Sheshai (1980) the underlying concept is described as "firms that won't default or go bankrupt." Financial attributes, such as the firm's ratio of retained earnings to total tangible assets, were used in this study.

Also, as a more-extreme case, the case of a terrorist trying to get through airline security is another vivid example of how certain individuals might try to act proactively in order to stay undetected under certain classification systems where a decision maker determines functions such as $f$ to be able to classify between classes of individuals. Throughout this chapter, we will speak collectively of these yet to be classified individuals as agents and the decision maker as the principal.

Until now most researchers have assumed that the observed data are not generated by a strategic process, which implicitly assumes that the attributes of the agents are not subject to modification in response to the eventual decision rule. However, this type of strategic behavior is usually observed in many real-world settings, as suggested by the above examples. Thus, it is reasonable to think that individuals or companies might try to play classification systems. Strategic learning aims to develop a model for this specific type of classification setting where the instances that are the subject to classification are known to be self-interested, utility maximizing, and intelligent decision-making units.

We start our literature review by looking at a related area of machine learning where the discovery process considers economic issues such as cost and utility. In utility-based data mining, the principal is a utility-maximizing entity who considers not just classification accuracy in learning but also various associated costs. We briefly review this area before reviewing strategic learning.

## 3 Economic Machine Learning – Utility-Based Data Mining

Utility-based data mining (Provost 2005) is closely related to the problem of strategic learning. This area explores the notion of economic utility and its maximization for data mining problems, as there has been a growing interest in addressing economical issues that arise throughout the data mining process. It has often been assumed that training data sets were freely available and thus many researchers focused on objectives such as predictive accuracy. However, economical issues come into play in data mining since, over time, data acquisition may become costly. Utility-based methods for knowledge induction incorporate data-acquisition costs and trade these off against predictive accuracy to maximize the overall principal utility. Hence these methods become more meaningful and reflective of real-world usage.

Utility-based data mining is a broad topic that covers and incorporates aspects of economic utility in data mining and includes areas such as cost-sensitive learning, pattern-extraction algorithms that incorporate economic utility, effects of misclassification costs on data purchase, and types of economic factors. Simply, all machine-learning applications that take into account the principal's utility considerations fall into this category of data mining research. Researchers in this area are primarily focused on two main streams. One stream focuses on cost-sensitive learning (i. e., cost assigned to misclassifications) (Arnt and Zilberstein 2005, Ciraco et al. 2005, Crone et al. 2005, Holte and Drummond 2005, McCarthy et al. 2005, Zadrozny 2005). The other stream focuses on the costs associated with the collection of data (i. e., data acquisition cost) (Kapoor and Greiner 2005, Melville et al. 2005, Morrison and Cohen 2005). In the following section we will look at these two streams of research.

## 3.1 Cost-Sensitive Learning

The first type of utility-based data mining explores the problem of optimal learning when different misclassification errors incur different penalties. This area has been revisited many times (Elkan 2001) and has a long history in statistics and data mining. Cost-sensitive classification is a growing area of research and aims to minimize the expected cost incurred in misclassifying the future instances rather than focusing on improving the predictive accuracy, which is usually measured by the number of correctly classified instances. This shift of focus from predictive accuracy to the cost of misclassifications is maintained by assigning penalties for misclassified instances based on the actual label of the instance. For example, in medical diagnosis domains, identifying a sick patient as healthy is usually more costly than labeling a healthy patient as sick. Likewise, in the spam filtering domain, false misclassification of a non-spam email is significantly more costly than misclassifying a spam email. Arnt and Zilberstein (2005) examine a previously unexplored dimension of cost-sensitive learning by pointing to the fact that it is impractical to measure all possible attributes for each instance when the final result has time-dependent utility, and they call this problem time- and cost-sensitive classification.

Holte and Drummond (2005) review the classic technique of classifier performance visualization, the receiver operating characteristic (ROC) curve, which is a two-dimensional plot of the false-positive rate versus the true-positive rate. They argue that this approach is inadequate for the needs of researchers and practitioners as they do not allow any of the questions to be answered such as: What is the classifier's performance in terms of expected cost? Or, at what misclassification costs does the classifier outperform others? They demonstrate the shortcomings of ROC curves and argue that the cost curves overcome these problems. In this respect, the authors point to the fact that cost-sensitive measurement of classifier performance should be utilized since misclassification costs should be an important part of classifier performance evaluation.

## 3.2 Data-Acquisition Costs

The second area of utility-based data mining, the cost of data acquisition, is an important area that has potential implications for real-world applications and thus is a topic that receives positive attention from industry as well as academia. For example, for large, real-world inductive learning problems, the number of training examples must often be limited due to the costs associated with procuring, preparing, and storing the training examples and/or the computational costs associated with learning from them (Weiss and Provost 2003). In many classification tasks, training data have missing values that can be acquired at a cost (Melville et al. 2005). For example, in the medical diagnosis domain, some of the patient's attributes may require an expensive test to be conducted. To be able to build accurate predictive models, it is important to acquire these missing values. However, acquiring all the missing values may not always be possible due to economical or other type of constraints. A quick solution would be to acquire a random subset of values, but this approach may not be most effective. Melville et al. (2005) propose a method called *active feature-value acquisition*, which incrementally selects feature values that are most cost-effective to improve the model's accuracy. They represent two policies, sampled expected utility and expected utility, which acquire feature values for inducing a classification model based on an estimation of the expected improvement in model accuracy per unit cost. Other researchers investigate the same problem under the scenario where the number of feature values that can be purchased is limited by a budget (Kapoor and Greiner 2005).

Whereas utility-based data mining incorporates a principal's utility, strategic learning additionally considers the possibility that the objects of classification are self-interested, utility-maximizing, intelligent decision-making units. We believe that strategic-learning considerations encompass utility-based data mining. Strategic learning looks at problems where different classes of instances with different misclassification costs and utility structures can act strategically when they are subject to discrimination. In the next section, we cover the details of strategic learning.

# 4 Strategic Learning

As was mentioned before, we look into a certain class of problems in which a decision maker needs to discover a classification rule to classify intelligent agents. The main aspect of this problem that distinguishes it from standard data-mining problems is that we acknowledge the fact that these agents may engage in strategic behavior and try to alter their characteristics in order to achieve a favorable classification. We call this set of learning problems strategic learning. In this type of data mining, the key point is to anticipate the agents' strategic behavior in the induction process. This has not been addressed by any of the standard learning approaches.

Depending on the type of application, the agent can be thought of as any type of intelligent decision-making unit capable of acting strategically to maximize its individual utility function. The following are some examples of strategic agents and the corresponding principals under different real-world settings:

- a credit-card company (the principal) decides which people (agents) get credit cards.
- an admissions board at a university (the principal) decides which applicants (agents) are admitted.
- an auditing group (principal) tries to spot fraudulent or soon to be bankrupt companies (agents).
- an anti-spam package (the principal is the package creator) tries to correctly label and then screen spam (which is agent-created).
- airport security guards (the principals) try to distinguish terrorists from normal passengers (agents).

Apparently, in each of these settings and in many others not mentioned here, if agents know or have some notion of the decision rules that the principal use, they can try to modify their attributes to attain a positive classification by the principal.

In most cases, the attributes used by a principal for classification are obvious and many people can discern which of these might be changed for their benefit. In the credit approval case, it is likely that an increase in one's checking account balance or getting a job will be beneficial. Thus, it is reasonable to anticipate that the agents will attempt to manipulate their attributes (either through deceit or not) whenever doing so is in their best interest. This gaming situation between the agents and the principal leads to a need to anticipate this kind of strategic behavior and incorporating it into the standard learning approaches. Furthermore, if instead one just uses classical learning methods to classify individuals when they are strategic decision-making units, it might eventually be possible for some agents to play the system.

To date, very few learning methods incorporate the strategic-learning paradigm. The closest we have found is called adversarial classification, which we review below. Another related area is called reinforcement learning. This area has some aspects of strategic learning that we also discuss below.

## 4.1 Adversarial Classification

Dalvi et al. (2004) acknowledge the fact that classification should be viewed as a game between the classifier (which we call the principal) and the adversary (which we call the agent) for all the reasons that we have discussed so far. They emphasize the fact that the problem is observed in many domains such as spam detection, intrusion detection, fraud detection, surveillance, and counter-terrorism. In their setting, the adversary actively manipulates the data to find ways to make the classifier produce a false decision. They argue that the adversary can learn ways to defeat the classifier that would result in a degrading of its performance, as the classifier needs to modify its decision rule every time the agents react by manipulating their behaviors. Clearly, this leads to an arms race between the classifier and the adversary, resulting in a never-ending game of modifications on both sides, since the adversary will react to the classifier's strategy in every period and the classifier will need to adjust accordingly in the next period. This poses an economical problem as well since in every period more human effort and cost are incurred to modify the classifier according to the latest strategy of the adversary.

They approach the strategic-learning problem from a micro perspective by focusing on a single-shot version of the classification game where only one move by each player is considered. They start by assuming that the classifier initially decides on a classification rule when the data are not modified by the adversary. However, knowing that adversary will deploy an optimal plan against this classification rule, the classifier instead uses an optimal decision rule that takes into account the adversary's optimal modifications. They focus on a Bayesian classification method.

Although their approach is quite explanatory, it is an initial effort since their goal was only to be able to explain one round of the game. However as they discuss, the ultimate solution is one that solves the repeated version of this game. However, by viewing the problem as an infinite game played between two parties, they tend to encourage modifications rather then prevent these modifications. This leads to a key question that needs to be answered: is there an optimal strategy for the classifier that can prevent an adversary from evolving against the classifier round after round when this strategic gaming is pursued infinitely? Or is it possible to prevent an agent's actions by anticipating them beforehand and taking corrective action, rather than reacting to the outcome after the game is played? These points are addressed by strategic learning, which formulates the problem as the well-known principal-agent problem where the principal anticipates the actions of agents and uses that information to discover a foolproof classifier that takes into account the possible strategic behavior. In that sense, the strategic-learning approach is more of preventive than reactive. Also, it involves many strategic agents acting towards one principal as opposed to a two-player game setting.

## 4.2 Multi-Agent Reinforcement Learning

Another related area of research is reinforcement learning, which involves learning through interactions (Samuel 1959, Kaelbling et al. 1996). We briefly discuss this area and point out its relevance to strategic learning. Reinforcement learning is a field of machine learning in which agents learn by using the reward signals provided from the environment. Essentially, an agent understands and updates its performance according to its interactions with the environment. In reinforcement-learning theory, an agent learns by considering every unique configuration of the environment. An agent acts according to a policy that is essentially a function that tells the agent how to behave by taking in information sensed from the environment, and outputting an action to perform. Depending on the action performed, the agent can go from one state to another and the reward function assigns a value to each state the agent can be in. Reinforcement-learning agents are fundamentally reward-driven and the ultimate goal of any reinforcement-learning agent is to maximize its accumulated reward over time. This is generally achieved through a particular sequence of actions to be able to reach the states in the environment that offer the highest reward (Sutton and Barto 1998).

A strategic-learning agent is quite similar to a reinforcement-learning agent as the former also aims to maximize its utility while attempting to reach a preferred classification state. Also, the environment can be thought of as analogous to the principal, who essentially sets the reward function (the classifier).

However, there are clear differences between the two learning situations. First, the learner in reinforcement-learning problems is the agent whereas strategic learning is concerned with the principal's learning. Second, the interaction in a strategic setting is usually adversarial in contrast to the obvious cooperation between the environment and the learner in reinforcement learning. Third, strategic learning operates on supervised learning whereas reinforcement learning is at best semi-supervised since the reward is only a proxy for the label of action. Fourth, most strategic settings assume that all parties involved possess some knowledge that will help them act optimally in self-interest. At best a reinforcement-learning agent can aim to learn some of that knowledge through experimentation.

Even though there are differences between the two learning paradigms it is possible to use reinforcement learning in competitive settings mostly because the learner is a utility (reward)-maximizing agent. Creative use of this idea can be seen in leader-follower multi-agent systems (Bhattacharyya and Tharakunnel 2005, Littman 1994) where both the leader and the follower(s) are learners. In these systems, which have a number of applications such as monitoring and control of energy markets (Keyhani 2003), e-business supply chain contracting and coordination (Fan et al. 2003), modeling public policy formulation in pollution control, taxation etc. (Ehtamo et al. 2002), a leader decides on and announces an incentive to induce the followers to act in a way that maximizes the leader's utility, while the followers maximize their own utilities under the announced incentive scheme. This is similar in many ways to our principal-agent terminology, as the leader acts as the principal and tries to identify and announce the ultimate decision rule that would maximize his/her own objective while the agents act as followers who seek to maximize their own utilities.

Bhattacharyya and Tharakunnel (2005) apply this kind of a sequential approach for repeated game leader-follower multi-agent systems. One of the interesting contributions of their work is the introduction of nonsymmetric agents with different roles to the existing multi-agent reinforcement-learning research. This is analogous to our asymmetric setting where both the principal and agents are self-interested, utility-maximizing units, with the exception that the principal has a leading role in setting the classifier to which the agents react. This is similar to the interaction between the leader and the followers in their work.

However, a key difference between the two is the sequential nature of the decisions made by the leader and the followers. In the leader-follower setting, the learning takes place progressively from period to period as the leader and the followers interact with each other according to the ideas of trial-and-error learning. Essentially, the leader announces his/her decision at specific points in time based on the aggregate information gained from the earlier rounds and the followers make their decisions according to the incentive announced at that period. In this scenario, the leader aims to learn an optimal incentive based on the cumulative information from the earlier periods while the followers try to learn optimal actions based on the announced incentive. Learning is achieved over successive rounds of decisions with information being carried from one round to the next.

Even though the leader-follower approach has similarities with strategic learning, there are fundamental differences. First, strategic learning is an anticipatory approach. In other words, in strategic learning, learning is achieved by anticipating strategic behavior by agents and incorporating this anticipation in the learning process rather than following an after-the-fact reactive approach. Second, strategic learning does not involve periods based on the principles of principal-agent theory. Strategic learning results show that a sequential approach will often yield suboptimal results.

## 4.3 Learning in the Presence of Self-Interested Agents

A more-extensive approach to strategic learning was given by Boylu et al. (2005) and Aytug et al. (2006). Particularly, in Aytug et al. (2006), the authors introduce the problem under the name of learning in the presence of self-interested agents. and propose the framework for this type of learning that we briefly discuss in this section.

In supervised learning, one forms a training set by randomly drawing a sample of instances of size $\ell$ from $X$, and then determining the true label (−1 or 1) of each such instance. Using this sample, a machine-learning algorithm infers a hypothesis. A key consideration is the choice of sample size; whether it is large enough to control generalization error is of key importance.

Under our setting, the principal's goal is to determine a classification function $f$ to select individuals (for example, good credit applicants) or to spot negative cases (such as terrorists who try to get through a security line). However, each strategic agent's goal is to achieve a positive classification (e. g., admission to university) regardless of their true nature. To do this, they act strategically and take actions in such a way to alter their true attributes. In some cases it is possible for the agents to infer their own rules about how the principal is making decisions under $f$ and identify attributes that are likely to help produce positive classifications. Most classical learning methods operate using a sample from $X$, but under strategic actions this space may be altered (call it $\bar{X}$). This possible change from $X$ to $\bar{X}$ needs to be anticipated. Strategic learning does this by incorporating rational expectations theory into the classical learning theory. Figure 1 outlines the strategic-learning framework.

Figure 1 shows that, when strategic behavior is applied to the sample space, $X$, it causes it to change from $X$ to $\bar{X}$ (reflecting strategic behavior by the agents). Similarly, a new learning theory has to be developed on top of the classical learning theory if one takes into account rational expectations theory. This we call strategic

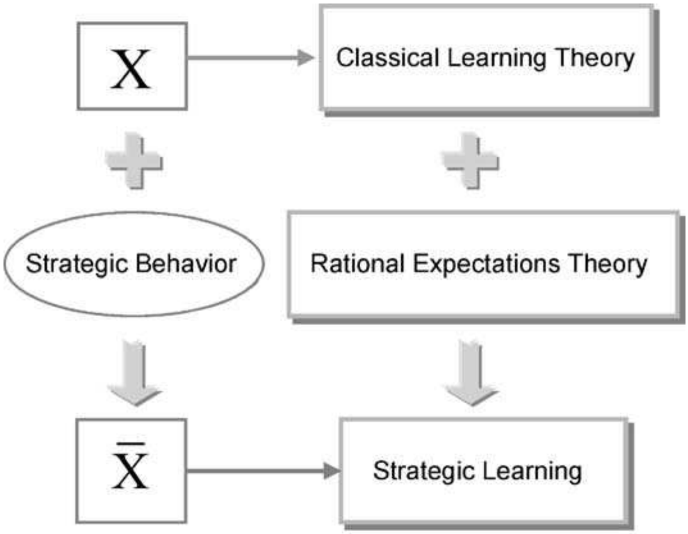


**Figure 1.** Strategic learning framework

learning. Also, classical learning theory operates on $X$ while strategic learning operates on all anticipated $\bar{X}$s.

## 4.4 Strategic Learning with Support Vector Machines

Boylu et al. (2005) consider strategic learning while inducing linear discriminant functions using support vector machines (SVMs). SVM is a popular algorithm based on statistical-learning theory (Vapnik 1998). In this section, we discuss some of their results to give a flavor of the ideas and methodology. In the strategic-learning setting, each agent $i$ has a utility function, a true vector of attributes $x_i$ and a true group membership (i. e., label) $y_i$. For linear utility, an agent has a vector of costs for modifying attributes $c_i$ and, for a given task, a reservation cost $r_i$. For the task of achieving a particular classification, the reservation cost can be viewed as the maximum effort an agent is willing to exert in order to be classified as a positive example, which we assume is desirable. On the principal's side, $C_{y_i}$ is assumed to be the penalty associated with misclassifications of a true type $y_i$.

SVMs are a computationally efficient way of learning linear discriminant functions as they can be applied easily to enormous data sets. In essence, SVMs are motivated to achieve better generalization by trading off empirical error with generalization error. This translates to the simple goal of minimizing the margin of the decision boundary of the separating hyperplane with parameters ($w$, $b$). Thus, the problem reduces to minimizing the norm of the weight vector ($w$) while penalizing for any misclassification errors (Cristianini and Shawe-Taylor 2000). An optimal SVM classifier is called a maximum-margin hyperplane. There are several SVM models, and the first model is called the hard-margin classifier, which is applicable when the training set is linearly separable. This model determines linear discriminant functions by solving

$$\begin{aligned} &\underset{w,b}{\text{Min}}\ w'w \\ &\text{s.t.}\quad y_i(w'x_i + b) \geq 1 \quad i = 1,\ldots,\ell \end{aligned} \tag{1}$$

This formulation produces a maximal-margin hyperplane when no strategic behavior is present. To illustrate how strategic behavior alters the above model. We start by introducing the agent's strategic move problem, which shows how rational agents will alter their true attributes if they knew the principal's SVM classifier. If the principal's classification function, $f(x_i) = w'x_i + b - 1$, was known by the rational agents, then each agent would solve what they call the strategic move problem to determine how they could achieve (or maintain) positive classification while exerting minimal effort in terms of cost. This is captured in the objective function (cost minimization). Thus the agent's strategic move problem can be modeled as

$$\begin{aligned} &\text{Min}\ c_i' d_i \\ &\text{s.t.}\ \ w'\left[x_i + D(w)d_i\right] + b \geq 1 \\ &\qquad d_i \geq 0 \end{aligned}$$

where $D(w)$ is a diagonal matrix defined by

$$D(w)_{j,j} = \begin{cases} 1 & w_j \geq 0 \\ -1 & w_j < 0 \end{cases}.$$

This problem finds a minimal-cost change of attributes, $D(w)d_i$, if feasible. This is the amount of modification that an agent needs to make to his/her attributes to be classified as a positive case. This would be undertaken if this cost does not exceed the agent's reservation cost, $r_i$. Let $d_i^*(w,b)$ be an optimal solution for the agent's strategic move problem [ $d_i^*(w,b)$ is zero if the strategic move problem is infeasible or if the agent lacks enough reservation]. Then the principal's strategic problem becomes the following

$$\begin{aligned} &\underset{w,b}{\text{Min}}\ \ w'w \\ &\text{s.t.}\quad y_i\left\{w'\left[x_i + D(w)d_i^*(w,b)\right] + b\right\} \geq 1 \qquad i = 1,\ldots,\ell \end{aligned} \tag{2}$$

When compared with the non-strategic SVM model, the difference is the term $D(w)d_i^*(w,b)$ that depends on the agent's problem. Basically, this term represents the principal's anticipation of a modification of the attributes by agent *i*. By incorporating this term into the principal's problem, this formulation makes it possible to prevent some misclassifications by taking corrective action beforehand

(i. e., before the principal determines a classification rule and incurs misclassification cost as agents make modifications). The essential idea is to anticipate an agent's optimal strategic move and use that information to infer a classification rule that will offset the agent's possible strategic behavior.

Boylu et al. (2005) derive a complete characterization for the solution of the principal's strategic problem under the base setting where all agents have the same known reservation and change costs (i. e., $r_i = r$ and $c_i = c$) and $S = ((x_1, y_1), \ldots, (x_\ell, y_\ell))$ is linearly separable. The authors provide a proof of Theorem 1, which states the following: $(w^*, b^*)$ solves (1) if and only if $\left(\frac{2}{2+t^*} w^*, \frac{2b^* - t^*}{2+t^*}\right)$ solves (2) where $t$ is given by $t^* = r \max_k |w_k^*| / c_k$ and

$$k = \arg \min_{j, w_j \neq 0} \frac{(c_i)_j \max(0, 1 - (b + w' x_i))}{|w_j|}.$$

In essence, Theorem 1 states that a principal, anticipating the strategic behavior of agents all having the same utilities and cost structures, will use a classifier that is parallel to the non-strategic SVM solution, $(w^*, b^*)$. The solution to the strategic SVM is a scaled [by $2/(2 + t^*)$] and shifted form of $(w^*, b^*)$. The margin of the strategic SVM solution hyperplane is greater than the non-strategic SVM solution and thus the probability of better generalization is greater. This scaling factor depends on the cost structure for altering attribute values, the reservation cost for being labeled as a positive case, and $(w^*, b^*)$.

Figure 2a shows a completely separable training set with a hyperplane using the nonstrategic SVM classifier (solid line) and the corresponding positive and negative margins (dotted lines) along with data points in two-dimensional space. In Theorem 1, the authors show that the negative agents will try to achieve a positive labeling by changing their true attributes if the cost of doing so does not exceed their reservation cost. This is indicated in Figure 2a by the horizontal arrows pointing out from some of the points for negative agents towards the positive side of the hyperplane. Clearly, these are the agents who have enough reservation cost and are willing to engage in strategic behavior to move to the positive side of the hyperplane. However, the principal, anticipating such strategic behavior, shifts and scales the hyperplane such that no true negative agent will benefit from engaging in such behavior. Figure 2b shows the sample space and the resulting strategic classifier. However, as Figure 2b shows, the negative agents would have no incentive to change their true attributes since they will not be able to move to the positive margin any more and hence would not exert any effort. Apparently, this shift may leave some marginally positive agents in danger of being classified as negative agents. Since they too anticipate that the principal will alter the classification function to cancel the effects of the expected strategic behavior of the negative labeled agents, they might undertake changes. In other words, they are forced to move as indicated by the arrows in Figure 2b. Thus, the ones who are penalized for engaging in a strategic behavior (i. e., must exert effort to attain a positive classification) are not the negative agents but rather the marginal positive agents.

Moreover, the resulting classifier has a greater margin and better generalization capability compared to the nonstrategic SVM learning results – all at the expense of marginal, positive agents.

In Figure 2c, the new strategic classifier with wider margins on each side and the resulting altered instances due to strategic behavior is shown. Notice that the margin of the resulting hyperplane is wider and is in fact a scaled and a shifted version of the hyperplane in Figure 2a and thus differs from nonstrategic SVM results.

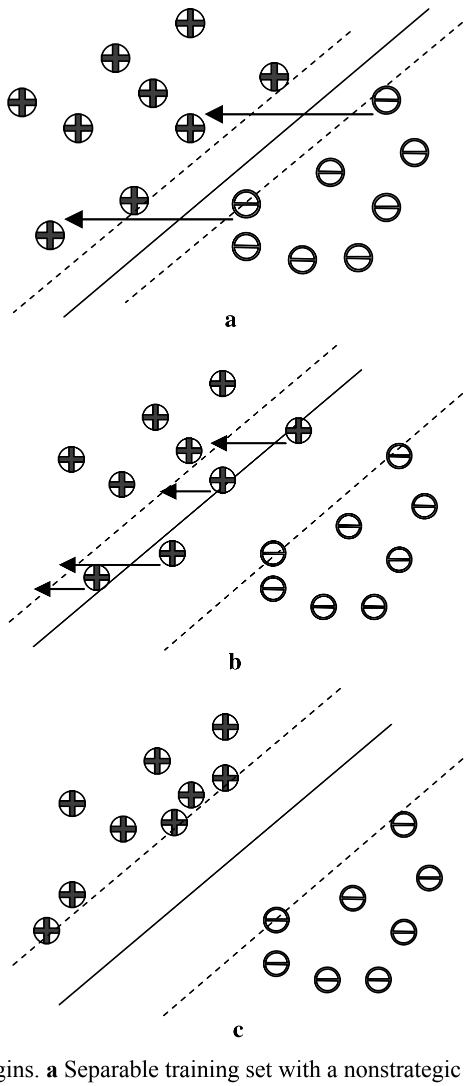


**Figure 2.** Wider margins. **a** Separable training set with a nonstrategic SVM classifier. **b** Sample space as the result of strategic behavior. **c** Strategic SVM classifier.

For nonseparable datasets, there are no results comparable to Theorem 1. However, for the case that $S$ is not linearly separable and all agents have their own reservation and change costs (i. e., $r_i$ and $c_i$), Boylu et al. (2005) derive a mixed integer programming model for the solution of the principal's strategic problem. The authors apply their results to a credit-card application and the results show that the strategic formulation performs better than its nonstrategic counterpart.

An interesting extension of strategic learning (Boylu et al. 2006) considers the cases when it is not realistic to let each attribute be modified unboundedly without posing any constraints on how much they can actually be modified. In other words, agents are constrained as to how much and in what way they can modify their attributes. Towards that end the authors look at a spam categorization problem where spammers (negative agents) are only allowed to make modifications in the form of addition or deletion of words with an upper limit on the number of modifications allowed. Essentially, they formulate the problem by allowing only binary modifications, which is an interesting constraint on the agent behavior. Clearly, agents can be constrained in many other ways such as upper and lower bounds or that the modifications have to belong to a certain set of moves (as in checkers or chess).

Interestingly, for the spam categorization problem, the authors point out that not all agents are strategic and in fact only the negative agents (spammers in their case) act strategically since it is not usually the case that legitimate e-mail users engage in strategic behavior and change the content of their emails to avoid spam filters. This distinguishes this application as it is a strategic-learning model for an environment where nonstrategic and strategic agents coexist.

# 5 Strategic Learning – Future Research Topics

The strategic-learning paradigm is new and many areas of research are possible. Immediately, relaxing the various assumptions mentioned above opens the door to new ideas and approaches. For example, the sort of strategic learning problem discussed in this chapter assumes that the only costs are misclassification costs and there is no cost associated with making the true positive agents alter their behavior. Including these costs would create a formulation that is equivalent to the social welfare concept common in economics literature.

Also, Theorem 1 is only applicable to separable datasets and an important contribution would be to develop a similar theoretical result for nonseparable datasets.

The current research assumes that both the principal and the agents know each other's parameters. In other words, the principal is well informed about the costs and the problem that the agent faces. One of the most interesting angles for future research would to remove this assumption. This is the issue on which economists focus their analysis of the principal-agent problem (Laffont and Martimort 2002). They most commonly consider cases where the principal is less omniscient. Also, in practice, it is usually the case that principal and agents will try to somehow roughly predict each others parameters. Boylu et al. (2005) provide several formulations for cases where the agent's utility parameters are not known with certainty. However, more work is needed in this area.

It is possible that the classifier that is developed when the agents do not collude may be suboptimal when the agents cooperate and act in a seemingly irrational way. For example, determining what happens in a scenario where agents collude and offer incentives to other agents to make suboptimal changes in their attributes to confuse the principal would make this problem more realistic and interesting.

Utility-based learning concentrates on the principal's utility. Strategic learning adds agent utilities that are self-interested, utility maximizing, intelligent decision making units. So far, the main concerns of utility-based learning (such as cost-sensitive learning and costs of data acquisition) have not been jointly investigated with the strategic learning issues discussed herein.

It is possible to reverse the strategic learning problem and use these ideas to create a classifier (or a policy) that promotes certain actions (rather than avoids them) or use these ideas as a what-if tool to test the implications of certain policies. For example, a board of directors could develop executive compensation policies for different performance classes to promote long-term value generation by anticipating how the chief executive officers (CEOs) can play the system to their advantage (which usually causes short-term gains at the cost of long-term value).

All discussion so far has focused on using SVMs as a classifier even though learning theory and rational expectations theory are independent of the implementation details. It would be very useful to determine the validity of these results independent of implementation and introduce the strategic-learning problem to the other classifiers such as decision trees, nearest neighbor, neural networks, etc. Essentially, strategic learning is a general problem that will arise in any learning situation involving intelligent agents, so it should be applied to other learning algorithms.

Another key area of future research is the application of domain knowledge to strategic learning. Kernel methods accomplish this by using a nonlinear, higher-dimensional mapping of attributes of features to make the classes linearly separable. It may be possible to compute an appropriate kernel that can anticipate and cancel the effects of strategic behavior. Such a kernel could be developed using agents' utility functions and cost structures, which are a form of domain-specific knowledge.

Current research on strategic learning only addresses static situations. However, it is possible that some exogenous factors such as the environment or the parameters being used change over time. For example, it might be possible that, over time, new attributes may be added to the data set or conversely some may become obsolete. This type of dynamic situation may need to be modeled in a way to accommodate these possible changes to determine classifiers that will adapt efficiently.

There is yet another angle to approach the problem, which is the game-theoretical point of view partially addressed by Dalvi et al. (2004). However, further investigation of this angle is an interesting and relevant task for future research in the area.

An important area of research in strategic learning is to find better algorithmic methods to solve the strategic learning problem. While mixed integer formulations exist, solution methods currently do not scale up like their nonstrategic counterparts.

This chapter attempted to introduce the reader to the concept of strategic learning and provide some recent results in this new field of research. We believe that this area, accompanied by many open research questions, qualifies as an interesting potential area of future DSS research.

One can argue that a key drawback of strategic learning is its effect on the marginal positive agents. For a principal trying to distinguish between positive and negative agents, it seems unfair that marginal positive agents need to exert effort to be labeled as positive. Negative agents are no worse off and the principal gains in two ways with this. Firstly, fewer true negative agents are labeled as positive, and secondly the principal gains an increase in the probability that the induced function generalizes more easily. However, this disadvantage to the true positive agents is not uncommon under adverse strategic behavior. For example, shoplifters increase the cost to honest purchasers as stores anticipate theft and increase prices to account for expected losses.

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# Keyword Index

*Page numbers in italics refer to Volume 2 of the Handbook.*

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