Design Science Research in Information Systems

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ABSTRACT

Information Systems are purposefully designed human-machine artifacts that significantly impact people, organizations, and society. Two paradigms characterize research in this discipline: behavioral (or natural) science and design science. Whereas the behavioral science paradigm seeks to discover and verify laws or principles that explain or predict human or social behavior, the design science paradigm seeks to extend the boundaries of human and social capabilities by creating new and innovative artifacts. Such artifacts can so affect human and organizational behavior that previously posited behavioral laws are rendered irrelevant or inapplicable. We develop a framework for understanding, executing, and evaluating design science research in the Information Systems field and present guidelines for its conduct and evaluation. Recent exemplars are used to demonstrate the utility of these guidelines. We conclude with a call for an effective integration of the design science paradigm into the Information Systems research community.

Keywords: Information Systems research methodologies, design science, design artifact, business environment, technology infrastructure, search strategies, experimental methods, creativity

ISRL Categories: AI01, AI02, AI03, AC03, FB04, IB01, IB02

Design Science Research in Information Systems

1. INTRODUCTION

Design science plays a central role in the development and management of information technologies and systems (Glass 1999; Winograd 1996; Winograd 1997). It embodies the creative, artistic, and goal oriented spirit within which purposeful artifacts are created (Simon 1996; Brooks 1996). Thus it reaches to the very core of what information systems practitioners and researchers do – create, apply, evaluate, and improve information technology (IT) artifacts[1]. These artifacts are human-machine systems whose purpose is to "support operations, management, analysis, and decision-making functions in an organization" (Davis and Olson 1985, p. 6). They can result in a transformation of the organization itself.

Research in IT that uses a behavioral (natural) science paradigm is fundamentally reactive. Its goal is to identify and codify emergent properties and laws governing human and organizational behavior as it affects and is affected by existing information technologies. Research in IT that uses a design science paradigm is fundamentally proactive. Its goal is to create innovative artifacts that extend human and social capabilities and aim to achieve desired outcomes. These artifacts often define the object of study in behavioral IT research.

Natural science has become the paradigm of choice for research published in the *MIS Quarterly*. However, this paradigm fails to adequately address the design science imperative of improving performance or even of demonstrating how discovered properties and laws can be used to improve performance (Venkatesh 2000; Orlikowski and Iacono 2001). A notable exception is action research which may implement an innovative IT artifact (e.g. system or methodology) within an organizational setting for the purpose of demonstrating its effects on a specific process.

We argue that design science is an applicable and necessary paradigm for IT research (Denning 1997). Important problems in the theory and practice of information

[1] We use the terms Information Systems (IS) and Information Technology (IT) throughout the paper to represent and identify the field of research and practice that applies computer and communication technologies to solving business problems.

systems will be resolved only by a combination of design and natural science paradigms. The construction of new, innovative artifacts can have far reaching impacts on organizations. Although such artifacts have no dispensation from laws or principles governing human and organizational behavior, they may so change the environment that previously posited laws or principles are rendered irrelevant or inapplicable. That, in fact, is the goal of design science, "to solve problems by introducing into the environment new artifacts, the availability of which will induce their spontaneous employment by humans and thus, coincidently, cause humans to abandon their previous problem-producing behaviors and devices" (Fuller 1992).

Informed by prior behavioral and design science knowledge, IT researchers must create innovative IT artifacts that address important problems, demonstrate the capabilities of such artifacts, and evaluate and predict their potential benefits and risks. IT managers must be cognizant of these artifacts and their potential for transforming business strategies and processes even as they emerge from research laboratories. They must understand the fundamentals of how these artifacts work, even if they are not concerned with their details. Ultimately the properties and laws discovered and verified by behavioral studies must have significance for the design and implementation of information systems thus completing the research cycle.

Business organizations are in dire need of new and innovative IT artifacts that enable globalization, integration, increased productivity, and rapid adaptation (Madnick 1992). However, simply creating a new IT artifact for extant organizational problems does not necessarily constitute good research. Hence, it is important to develop guidelines for conducting and criteria for evaluating design science research in IT.

To be relevant for a managerial audience the presentation of design science research must demonstrate its potential for significantly impacting business practice or organizational capabilities. There is a larger body of IT design science research focused on computer science or operations research that may not be suitably presented for a managerial audience. The primary purposes of informing an MIS audience about design science research are to enable it to anticipate the effects, manage the deployment, and participate in the utilization, evaluation, and improvement of IT artifacts (Zmud 1997).

Following Klein and Meyers (1999) the remainder of this paper is organized as follows. The next section presents a framework for understanding design science research in IT. From this framework, we derive guidelines for conducting and evaluating design science research, specifically addressing the fundamental notions of *relevance* and *rigor*. We demonstrate the utility of these guidelines by applying them to recent exemplar papers published in the IS literature. Finally, we conclude with a call for an effective integration of the design science paradigm into the IS research community.

2. A DESIGN SCIENCE FRAMEWORK FOR IT RESEARCH

Organizations and the information systems that support them are among the most complex artifacts designed by human intention. Figure 1 illustrates the essential alignments between business and information technology strategies and between organizational and information systems infrastructures (Henderson and Venkatraman 1993). The effective transition of strategy into infrastructure requires extensive design activities on both sides of the figure – organizational and technological. The information systems profession focuses on IS design activities but is actively involved in the related issues of organizational design.

Hence information systems and the organizations they support are artificial, purposefully designed, and interdependent artifacts (Bunge 1985; Simon 1996). Information systems enable and constrain the design and implementation of an organization (Orlikowski and Barley 2001). They are a significant factor in the strategies that guide organizational activities. Cutting edge information systems allow organizations to engage new forms and new structures -- to change the way they "do business" (Drucker 1988, 1991; Orlikowski 2000).

To achieve a true understanding of and appreciation for design activities, an important dichotomy must be faced. Design is both a process and a product. Respectively, design is both a verb and a noun. It describes the world as acted upon (*processes*) and the world as sensed (*artifacts*). This Platonic view of design supports a problem-solving paradigm that continuously shifts perspective between creating design processes and building design artifacts for the same complex problem.

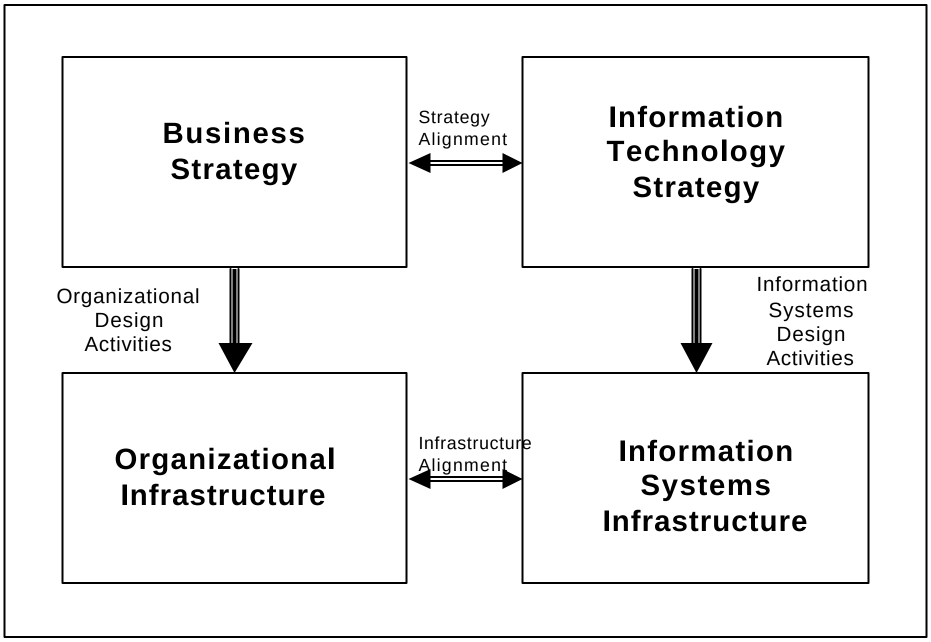

Figure 1: Organizational Design and Information Systems Design Activities

March and Smith (1995) identify two processes and four products of design science. The two processes are build and evaluate. The products are constructs, models, methods, and instantiations. Purposeful artifacts are built to address heretofore unsolved problems. Their performance can be evaluated with respect to the utility provided in solving those problems. Constructs provide the language in which problems and solutions are defined and communicated. Models aid in understanding the real world and enable exploration of the effects of design decisions and changes in the real world. Methods provide guidance on how to solve problems. Instantiations demonstrate feasibility, provide empirical evidence that an artifact is suited to its intended purpose, and enable researchers to learn about the real world and how an artifact affects it.

Figure 2 presents a framework for understanding, executing, and evaluating design science research in IT. The environment defines the problem space (Simon 1996) in which reside the phenomena of interest. It is composed of Business (organizations) and Technology. In it are the problems, opportunities, organizational context, and business processes that define business needs. It also contains the existing infrastructure, information systems, applications, and communications architecture that must be replaced by or integrated with any new artifact. These too are "part of the problem." Implementation of an artifact within that environment is the acid test of relevance for design science research.

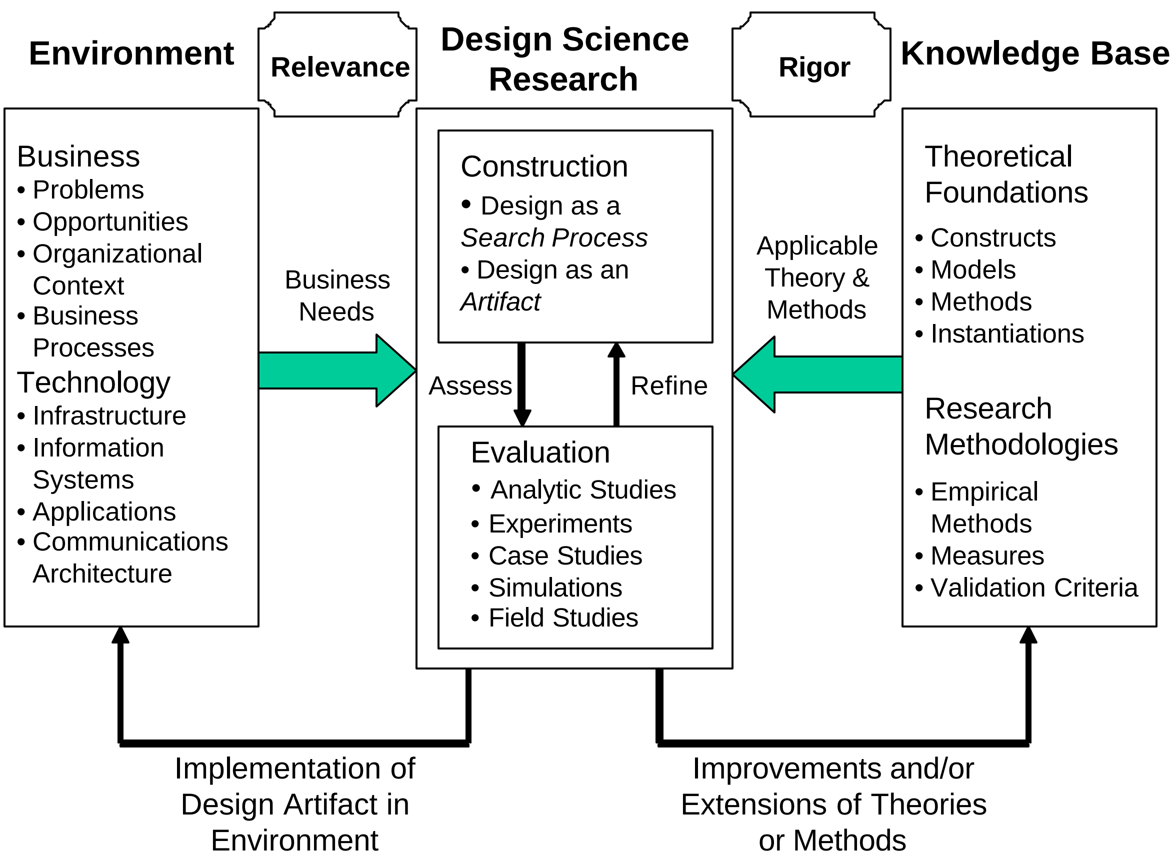

Figure 2: Design Science Research Framework

The knowledge base provides the materials from and through which artifacts are constructed and evaluated. It is composed of Theoretical Foundations and Research Methodologies. Prior research provides a starting point and benchmark for new artifacts. Existing constructs, models, methods, and instantiations must be brought to bear. Rigor is achieved by appropriately applying existing theory and methods, typically utilizing mathematical formalisms. The resulting artifacts are assessed as they improve and extend the content of the knowledge base for further research and practice.

What differentiates "routine design" from design science research is the nature of the problems and solutions. Routine design is the application of existing knowledge to organizational problems, such as constructing a financial or marketing information system using "best practice" theory from the knowledge base. Design science research addresses important unsolved problems in unique or innovative ways. Design science research must differentiate routine from innovative design - thus the importance of evaluation. Design science research must demonstrate its contribution to the knowledge base.

In the early stages of a discipline each new artifact is "an experiment" that "poses a question to nature" (Newell and Simon 1976, p 114). Existing theory is used where appropriate; however, often such theory is nonexistent or at least not well understood. Reliance on creativity and trial and error search are characteristic of such efforts. Design science research results in new or improved theories and methods that eventually form "best practice" for the discipline. Design then becomes the routine application of the knowledge base. Design science research moves on to address important problems for which the knowledge base is inadequate.

3. DESIGN SCIENCE RESEARCH GUIDELINES

Design activities are endemic in many professions. In particular, the engineering profession has produced a considerable literature on design (Dym 1994; Pahl and Beitz 1996; Petroski 1996). However, even after centuries of experience in many diverse fields, design is still considered a *wicked problem* (Rittel and Webber 1984). The wicked nature of design is typically characterized by:

- Unstable requirements and constraints based upon ill-defined environmental contexts,
- Complex interactions among subcomponents of the problem,
- Inherent flexibility to change design processes as well as design artifacts (i.e., malleable processes and artifacts),

- A critical dependence upon human cognitive abilities (e.g., creativity) to produce effective solutions, and
- A critical dependence upon human social abilities (e.g., teamwork) to produce effective solutions.

These characteristics are clearly evident in IT design science research (Brooks 1987, 1996). As a result we agree with Simon (1996) that a theory of design in information systems, of necessity, is in a constant state of scientific revolution (Kuhn 1996). Technological advances are the result of innovative, creative design science processes. If not "capricious" they are at least "arbitrary" (Brooks 1987). Innovations, such as database management systems, high-level languages, personal computers, software components, intelligent agents, object technology, the Internet, and the World Wide Web, have had dramatic impacts on the way in which information systems are designed, implemented, and managed and consequently on the information processing capabilities of organizations. Hence, the guidelines we present below are, of necessity, adaptive and process oriented.

3.1 Guideline 1: Problem Relevance

The objective of design science research in information systems is to develop technology-based solutions to important and relevant business problems.

A problem can be defined as the differences between a goal state and the current state of a system and problem solving as a search process using actions to reduce or eliminate the differences (Simon 1996). This definition implies an environment that imposes goal criteria as well as constraints upon a system. Referring to Figure 2, business organizations are goal-oriented entities existing in an economic and social setting. Economic theory often portrays the goals of business organizations as being related to profit (utility) maximization. Hence, business problems and opportunities often relate to increasing revenue or decreasing cost through the design of effective business processes. The design of organizational and inter-organizational information systems plays a major role in enabling effective business processes to achieve these goals.

The relevance of any design science research effort is with respect to a constituent community. For IS researchers that constituent community is the practitioners who plan, manage, design, implement, operate, and evaluate information systems. To be relevant to this community, research must address the problems faced and the opportunities afforded by the interaction of people, organizations, and information technology. Organizations spend billions of dollars annually on IT only too often to conclude that those dollars were wasted (Keil 1995; Keil et al. 1998; Keil and Robey 1999). This community welcomes proven artifacts that enable solutions to such problems -- constructs by which to think about them, models by which to explore or optimize them, methods by which to address them, and instantiations that demonstrate how to affect them.

Criteria for assessing relevance focus on *representational fidelity* and *implementability*. Artifacts must accurately represent the business and technology environments used in the research, information systems themselves being models of the business. These artifacts must be "implementable," hence the importance of instantiating design science artifacts. Beyond these, however, the research must demonstrate a clear contribution to the business environment, solving an important, previously unsolved problem. For a managerial audience, this contribution must be communicated in such a manner that its implications for the organization are apparent.

3.2 Guideline 2: Research Rigor

Design science research requires the application of rigorous methods in both the construction and evaluation of the design artifact. Often empirical methods are needed to evaluate the artifact as part of a complete human-machine system.

In natural and behavioral science rigor is often assessed by adherence to appropriate data collection and analysis techniques. Overemphasis on rigor in behavioral IS research has often resulted in a corresponding lowering of relevance (Lee 1999). In design science, rigor is often assessed by mathematical formalism and deductive logic. Again, an overemphasis on rigor can lessen relevance. We argue, along with behavioral IS researchers (Applegate 1999), that it is possible and necessary for all IS research paradigms to be both rigorous and relevant.

Rigor addresses the way in which research is conducted. Design science is a creative, and often iterative, problem-solving process that builds and evaluates purposeful artifacts. Rigor is derived from the effective use of the design science knowledge base -- theoretical foundations and research methodologies (Figure 2). Design success is predicated on the researcher's skilled selection of the right construction techniques and evaluation methods to produce the most effective artifact.

Design science rightly relies on mathematical formalism since design is inherently a mathematical science. However, the environments in which IT artifacts must perform and the artifacts themselves may defy excessive formalism. Or, in an attempt to be "rigorous," important parts of the problem may be abstracted or "assumed away." In particular, with respect to the construction activity, rigor must be assessed with respect to the *applicability* and *generalizability* of the artifact.

Claims about artifacts are typically dependent upon performance metrics. Even formal mathematical proofs rely on evaluation criteria against which the performance of an artifact can be measured. Design science researchers must constantly assess the appropriateness of their metrics and the construction of effective metrics is an important part of design science research.

Design science artifacts are often components of a human-machine problem-solving system. For such artifacts, empirical work is necessary to enable construction and evaluation. Constructs, models, methods, and instantiations must be exercised within appropriate environments. Appropriate subject groups must be obtained for such studies. Issues that are addressed include comparability, subject selection, training, time, and tasks. Methods for this type of evaluation are not unlike those for justifying or testing behavioral theories. However, the aim is to determine *how well* an artifact works, not to theorize about or prove anything about *how* or *why* the artifact works. This is where design science and behavioral science researchers must come together. Since design science artifacts are often the "machine" part of the human-machine system constituting an information system, it is imperative to understand why an artifact works or does not work to enable new artifacts that exploit the former and avoid the latter.

3.3 Guideline 3: Design as a Search Process

> The search for an optimal design is often intractable for realistic information systems problems. Heuristic search strategies produce feasible, good designs that can be implemented in the business environment. Decomposition of complex problems is an effective heuristic in the search for effective designs.

Design is essentially a search process to discover an effective solution to a problem. This search is an integral part of construction. Problem solving can be viewed as utilizing available means to reach desired ends while satisfying laws existing in the environment (Simon 1996). Abstraction and representation of appropriate means, ends, and laws are crucial components of design science research. These factors are problem and environment dependent and invariably involve creativity and innovation. Means are the set of actions and resources available to construct a solution. Ends represent goals and constraints on the solution. Laws are uncontrollable forces in the environment. Effective design requires knowledge of both the application domain (e.g., requirements and constraints) and the solution domain (e.g., technical and organizational) (Curtis et al. 1988).

Design science research often simplifies a problem by explicitly representing only a subset of the relevant means, ends, and laws or by decomposing a problem into simpler sub-problems. Such simplifications and decompositions may not be realistic enough to have a significant impact on practice but may represent a starting point. Progress is made iteratively as the scope of the design problem is expanded. As means, ends, and laws are refined and made more realistic the design artifact becomes more relevant and valuable. The means, ends, and laws for IS design problems can often be represented using the tools of mathematics and operations research. Means are represented by decision variables whose values constitute an implementable design solution. Ends are represented using a utility function and constraints that can be expressed in terms of decision variables and constants. Laws are represented by the values of constants used in the utility function and constraints.

The set of possible design solutions for any problem is specified as all possible means that satisfy all end conditions consistent with identified laws. When these can be formulated appropriately and posed mathematically, standard operations research techniques can be used to determine an optimal solution for the specified end conditions. Given the wicked nature of many information system design problems, however, it may not be possible to determine, let alone explicitly describe the relevant means, ends, or laws. Even when it is possible to do so, the sheer size and complexity of the solution space will often render the problem computationally infeasible. For example, to build a "reliable, secure, and responsive information systems infrastructure" (Brancheau, Janz, and Wetherbe 1996) a designer must represent all possible infrastructures (means), determine their utility and constraints (ends), and specify all cost and benefit constants (laws). Clearly such an approach is infeasible.

In such situations, the search is for satisfactory solutions, *satisficing* (Simon 1996), without explicitly specifying all possible solutions. The design task involves the creation, utilization, and assessment of *heuristic search* strategies. That is, constructing an artifact that "works" well for the specified class of problems. It may or may not be clear *why* it works; it simply qualifies as "credentialed knowledge" (Meehl 1986, p. 311). While it is important to understand why an artifact works, the critical nature of design in IS makes it important to establish *that* it works and to characterize the environments *in which* it works even if we cannot explain why it works. This enables IS practitioners to take advantage of the artifact to improve practice.

The use of heuristics to find "good" design solutions opens the question of how goodness is measured. Different mathematical representations may provide varying techniques for measuring how good a solution is. One approach is to prove or demonstrate that a heuristic design solution is always within close proximity of the optimal solution.

3.4 Guideline 4: Design as an Artifact

The designed artifact must be effectively represented, enabling implementation and application in an appropriate environment.

The result of a design science research effort is, by definition, an artifact, i.e. a construct, a model, a method, or an instantiation. It must be represented and presented in such a way as to enable evaluation and comparison with existing artifacts created for the same purpose. Orlikowski and Iacono (2001) call the IT artifact the “core subject matter” of the IS field. Weber (1987) argues that a theory of "long-lived" artifacts is fundamental to the IS discipline. Such a theory must explain how IS artifacts are created and adapted to their changing environments and underlying technologies.

Constructing an artifact demonstrates feasibility. One of the central questions in computer science is, “What can be (efficiently) automated?” Constructing an artifact definitively answers that question. The critical nature of design science research in IS lies in the identification of new information technology capabilities, resulting in the expansion of IS into new realms. Such a result is significant IS research only if there is a serious question about the ability to construct such an artifact, there is uncertainty about its ability to perform appropriately, and the automated task is important to the IS community.

Prior to the construction of the first expert system (artifact), for example, it was not clear if such a system *could* be constructed or *how well* it would perform. Once feasibility was demonstrated, subsequent research in expert systems focused on demonstrating significant improvements in the product or process of construction (Tam 1990; Trice and Davis 1993). Similar examples exist in requirements determination (Bell 1993; Bhargava et al. 1998), individual and group decision support systems (Aiken et al. 1991; Basu and Blanning 1994), database design and integration (Dey et al. 1998; Dey et al. 1999; Storey et al. 1997), and workflow analysis (Basu and Blanning 2000) - to name a few important areas of IS design research.

Representation of the artifact has a profound impact on design work. The field of mathematics was revolutionized, for example, with the representations of Arabic numbers, zero, and place notation. The search for an effective problem representation is crucial to finding an effective design solution. In fact, Simon (1996, p. 132) states, "solving a problem simply means representing it so as to make the solution transparent."

The design science knowledge base contains many techniques for representing IT problems so as to facilitate the discovery of effective solutions. These include analytical modeling, simulation, grammars, set-theoretic and formal logic, and architectural representations. Such techniques provide rigor in design science research. They serve to distinguish "rigorous" research from ad hoc "system building" or application development work.

3.5 Guideline 5: Design Evaluation

The quality and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods. Good designs embody a style that is aesthetically pleasing to both the designer and the user.

Design is inherently an iterative and incremental activity with no well-defined stopping rules. A design artifact is complete and effective when it satisfies the requirements and constraints of the problem it was meant to solve. The design evaluation phase, as shown in Figure 2, provides essential feedback to the construction phase as to the quality of the design process and the design artifact under development. Simon (1996) describes the nature of the design process as a Generator/Test Cycle (Figure 3).

Since the goal of design science research is utility, evaluation is a crucial component of the design process. The business environment establishes the requirements upon which the evaluation of the artifact is based. The technology within the environment (Figure 2) is incrementally built by the implementation of each new design artifact. Thus, another aspect of evaluation is the fit of the artifact within the technical infrastructure of the business environment. Evaluation requires the definition of appropriate metrics and the gathering and analysis of appropriate data. IT artifacts can be evaluated in terms of functionality, completeness, consistency, accuracy, performance, reliability, usability, and other relevant quality attributes.

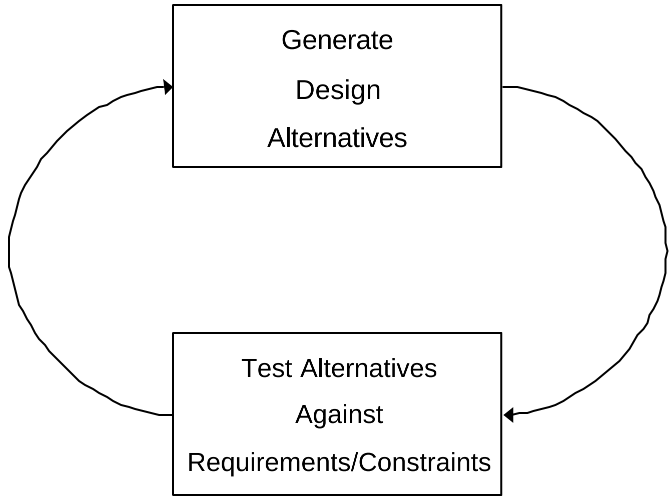

Figure 3: The Generate/Test Cycle

The effective evaluation of design artifacts requires the use of a knowledge base of research methodologies (Figure 2). These are summarized in Table 1. The selection of evaluation method must be matched appropriately with the design artifact and the evaluation metrics. The goodness and efficacy of an artifact can then be rigorously demonstrated (Basili 1996; Kleindorfer et al. 1998; Zelkowitz and Wallace 1998).

As a key component of evaluation, we must recognize the creative nature of design. Csikszentmihalyi (1997, p. 28) describes creativity as:

> Creativity occurs when a person, using the symbols of a given domain such as music, engineering, business, or mathematics, has a new idea or sees a new pattern, and when this novelty is selected by the appropriate field for inclusion into the relevant domain.

Design, in all of its realizations (e.g. architecture, landscaping, art, music), has style. Given the means, ends, and laws of an IS design problem, there remain sufficient degrees of freedom to express a variety of forms and functions in the artifact that is aesthetically pleasing to both the designer and the user. Good designers bring an element of style to their work (Norman 1988). Thus, we posit that design evaluation should include an assessment of the artifact's style and inherent creativity.

While difficult to define, style in IS design is widely recognized and appreciated (Kernighan and Plauger 1978; Winograd 1996). Gelernter (1998) terms the essence of style in IS design *"machine beauty."* He describes it as a marriage between simplicity and power that drives innovation in science and technology. Machine beauty is visceral.

> The sense of beauty is a tuning fork in the brain that hums when we stumble on something beautiful. We enjoy the resonant hum and seek it out. Strangely enough, beauty is also a truth-and-righteousness meter and science and technology could not exist without it. Its tuning fork hum guides scientists toward truth and technologist toward stronger and more useful machines. It leads the way forward. (Gelernter 1998, p. 1)

Table 1: Design Evaluation Methods

1. Observational	*Case Study* – Study Artifact in Depth in Business Environment
	Field Study – Monitor Use of Artifact in Multiple Projects
2. Analytical	*Static Analysis* – Examine Structure of Artifact for Static Qualities (e.g., Complexity)
	Architecture Analysis – Study Fit of Artifact into Technical IS Architecture
	Dynamic Analysis – Study Artifact in Use for Dynamic Qualities (e.g., Performance)
3. Experimental	*Controlled Experiment* – Study Artifact in Controlled Environment for Qualities (e.g., Usability)
	Simulation – Execute Artifact with Artificial Data
4. Testing	*Functional (Black Box) Testing* – Execute Artifact Interfaces to Discover Failures and Identify Defects
	Structural (White Box) Testing – Perform Coverage Testing of all Execution Paths in the Artifact

Effective application of this principle calls for design science researchers to have broad knowledge and training in the creative arts. Analytical skills must be combined with talents of a creative artist (i.e., left brain – right brain synergy) to produce beautiful designs. In addition to a thorough grounding in mathematics, Gelernter (1998, p. 9) lists the attributes of a good designer as taste, good judgment, aesthetic gifts, brains, and sheer intellectual aggressiveness.

Simon (1996) also notes the importance of style in the design process. The ability to creatively vary the design process, within the limits of satisfactory constraints, challenges and adds value to designers who participate in the process.

3.6 Guideline 6: Research Contributions

Effective design science research must provide clear contributions in the areas of the design artifact, design construction knowledge, and/or design evaluation knowledge.

The ultimate assessment for any research is "What are the new and interesting contributions?" Design science research holds the potential for three types of research contributions. One or more of these contributions may be found in a given research project.

1. *The Design Artifact* - Most often, the contribution of design science research is the artifact itself. The new construct, model, method, or instantiation must be clearly identified and validated as a new research contribution. As shown in Figure 2 by the left-facing arrow at the bottom of the figure from Design Science Research to the Environment; exercising the artifact in the environment produces significant value to the constituent IS community. The artifact enables the solution of heretofore unsolved problems.

2. *Theoretical Foundations* - The creative development and use of new constructs, models, methods, or instantiations that extend and improve existing theoretical foundations in the design science knowledge base are important contributions. The right-facing arrow at the bottom of the figure from Design Science Research to the Knowledge Base in Figure 2 indicates these contributions.

3. *Evaluation Methodologies* - Finally, the creative development and use of evaluation methods (e.g., experimental, analytical, observational, and testing) and new evaluation metrics may provide a design science research contribution. Metrics in particular are a crucial component of design science research. The right-facing arrow at the bottom of the figure from Design Science Research to the Knowledge Base in Figure 2 also indicates these contributions.

3.7 Presentation of Design Science Research to a Managerial Audience

The above guidelines focus on design science research in IT. However, as noted earlier not all such research is appropriately presented for a managerial audience. A technical audience is concerned about the details of the artifact and how it works. A managerial audience is concerned about the implications of the artifact for developing and managing organizational information processing capabilities. Presentation of design science research for a managerial audience must address these implications while still presenting the artifact in a convincing manner.

While the essential nature of design science research is based in mathematical rigor, we believe that it is necessary and possible to present such research with a clear focus on relevant business and managerial implications. This challenging requirement provides an important distinction between the design science research reported in the computer science / management science literature and that reported in the MIS literature (Zmud 1997). The next section explores these issues through the use of exemplars. Our goal is to develop an understanding of how to conduct, evaluate, and present design science research to IS researchers and practicing business managers.

4. APPLICATION OF THE DESIGN SCIENCE RESEARCH GUIDELINES

To illustrate the application of the design science guidelines to IS research, we have selected four exemplars articles for analysis, two from *MIS Quarterly* and two from *Decision Support Systems*. Each has strengths and weaknesses when viewed through the lens of the above guidelines and management presentation requirements. Our goal is not to perform a critical evaluation of the quality of the research contributions, but rather to illuminate the design science guidelines and presentation requirements. The articles are:

- Tillquist, King, and Woo (2002) present a formalism and method for conceptually modeling an information system within its organizational context.
- Baskerville and Stage (1996) use action research to explore the use of risk analysis as an approach to managing projects that use a prototyping development methodology.
- Gavish and Gerdes (1998) develop techniques for implementing anonymity in Group Decision Support Systems (GDSS) environments.
- Rao and Turoff (2000) design a flexible component-based GDSS architecture to support collaborative decision-making in a medical environment.

The fundamental questions for design science research are, "What utility does the new artifact provide?" and "What demonstrates that utility?" Evidence must be presented. That is the essence of design science. Contribution springs from utility. If existing approaches are adequate then design science research creating a new artifact is unnecessary (it is irrelevant). If the new artifact does not map adequately to the real world (rigor) then it cannot provide utility. If the artifact does not solve the problem (search, implementability) then it has no utility. If utility is not demonstrated (evaluation) then there is no basis upon which to accept the claims that it provides any contribution (contribution). Furthermore, if the problem, the artifact, and its utility are not presented in a manner such that the implications for practice are clear, then it is not appropriate for a managerial audience.

4.1 Tillquist, King, and Woo (2002)

This paper proposes a formalism (constructs) called Dependency Network Diagram (DND) and methods for conceptually modeling an information system within an organizational context using that formalism. The constructs in the DND are based on Resource Dependence Theory from organizational behavior literature. The paper presents rules and construction algorithms for DND's and evaluates the formalism and methods using a case study.

Problem Relevance

Information systems development is central to IT research and practice. Tillquist, King, and Woo argue that organizational interaction and process coordination must be explicitly taken into consideration in order to develop effective information system but that none of the existing formalisms have appropriate constructs to adequately represent them. This research is specifically aimed at incorporating the concept of inter and intra-organizational dependence relations into the conceptual model of an information system. The problem is important and relevant to IT managers, project managers, system developers and to the customer base they serve. Failure to adequately represent such organizational dependencies can result in information systems that do not interoperate effectively and therefore do not adequately meet the needs of the business organization.

Research Rigor

The constructs that form a Dependency Network Diagram (DND) are Activity, Resource, Role, Goal, Dependency, and Governance Control. They are grounded in Resource Dependence Theory, a well-established theory in the Organizational Behavior literature (Pfeffer and Salancik 1978). Each construct is defined in text and depicted graphically using a symbol. The methods include rules and construction algorithms for DND's. However, the presentation lacks rigor in the sense that the constructs are not formally defined. There is no evidence provided to prove theoretically or demonstrate empirically that these constructs are necessary or sufficient for modeling process coordination and dependence relations. There is no reference to or comparison with other system development constructs or formalisms. Similarly while the paper claims that the algorithm and construction rules guarantee completeness and parsimony of a DND, it does not provide any proof nor does it explain how this is the case.

Design as a Search Process

The paper proposes a new representation technique called DND. While other techniques such as DFD's, ER models, state transition diagrams, and process diagrams are acknowledged as alternative techniques for modeling information systems, the paper does not attempt to compare the DND with any of these either explicitly or implicitly. In fact the DND in many parts appears very similar to the DFD and hence a comparison would have added much by explicitly pointing out the shortcomings of DFD's as compared to the DND.

<u>Design as an Artifact</u>

The artifacts presented in this research are the DND constructs and methods (construction algorithm and rules). These enable the development of a model for conceptually representing an information system design with process interactions. The artifact does not currently have any automated support tools.

<u>Design Evaluation</u>

Evaluation is addressed via a case study using DND's in the development of an automated collision repair estimation system for a Canadian auto insurance company. The company diagnosed several problems in their existing procedures for repair estimation and made efforts to overcome these in automating the process. The case study demonstrates the utility of the DND in understanding the nature and dynamics of organizational dependencies that resulted from the process of developing an information system. While the case study is useful and interesting, it is not clear why the study was conducted in the selected organization. It is also not clear whether the same kind of understanding could have resulted from the use of other representational schemes such as DFD's and ER diagrams.

<u>Research Contributions</u>

The contributions of this paper are: the DND (constructs, algorithm, and rules), a demonstration of its practical application, and a case study to demonstrate its utility. It is also the first attempt to approach the design of a conceptual modeling formalism from an organization theory perspective. To strengthen its design science contribution, however, the paper must precisely and formally define the constructs within the DND and its associated construction and evaluation methods and demonstrate their utility compared to other approaches. Existing objective and subjective metrics such as those used in assessing existing system development formalisms (e.g., Wand and Weber 1993, Sinha and Vessey 1999) may or may not be adequate for this demonstration. New metrics that more specifically address organizational issues may need to be developed.

Summary

This paper is aimed at a managerial audience familiar with the organizational issues inherent in information system development. It is not aimed at a technical audience charged with implementing the artifact within an organization. As such the lack of rigor and formalism in the presentation of the artifacts and their evaluation is not surprising. Use of a case study is familiar to a managerial audience and provides sufficient grounding for a convincing argument of utility. Details of how the artifact would be implemented or how it would be integrated with existing system development artifacts are excluded. We argue that these are important issues even for a managerial audience and suggest that the paper would be more valuable if they were addressed.

4.2 Baskerville and Stage (1996)

This paper uses an action research paradigm to assess the effects of a risk management approach on a manager's ability to control information system development projects that use prototyping as a development methodology. A single project illustrates the approach in a descriptive sense.

Problem Relevance

Project management is a significant problem for IT managers and developers and their customers (users). Techniques are needed to enable IT managers to more effectively control expenditures and resources allocated to IT development projects. Baskerville and Stage argue that existing project management approaches are inadequate for projects that use prototyping. Such projects often spiral out of control, they claim, resulting in significant cost and time overruns.

Research Rigor

The approach is not formally presented nor is it systematically assessed with respect to existing project management approaches. The approach is applied to a single development project. While the authors argue that the project is typical there is no basis for measuring if or how well the approach worked or under what conditions it should be applied.

Design as a Search Process

Assessing risk factors is an important element of any system development methodology. Project managers must be aware of factors that can affect the success or failure of a project. However, this research does not describe how risk factors can be determined. No mathematical formalism is proposed for the task environment (problem or solution space) or for the means engaged to construct a solution. Prior approaches are not identified or used to construct the proposed approach. There is no generalization of when or how to use the approach in practice.

Design as an Artifact

Two distinct artifacts are proposed: an explicit risk mitigation model and a management process (method). The model is not represented in any formal mathematical or logical way; there is no presentation of "constituent parts" or representations of the problem or solution space or of the relationships among problem and solution elements. The process (method) is described informally as it was applied in a specific situation. No attempt is made to compare the performance of the proposed method against existing methods. There is no attempt to automate any of the process.

Design Evaluation

The proposed approach is illustrated using an action research approach. Baskerville and Stage argue that the discovery of risk factors early in the project improves the prospects of success; however, no evaluation metrics are defined and the approach is not evaluated in any theoretical (absolute) way. Its performance was not compared with any existing methods.

Research Contributions

The contribution of this work is the demonstration that a risk analysis approach (method) is an effective mechanism for managing the prototype project studied. One could conclude that risk analysis should be part of the foundation theory in control of prototyping projects. However, from a design science perspective, the artifact is not unique or innovative. Risk analysis is a well-known technique and should be applied in any situation where risk factors could jeopardize a project, regardless of the nature of the project. Hence the contribution is not, by its nature, one to design science but rather one to practice -- well-known techniques for managing risk are appropriate for managing prototyping projects which often have significant risk.

Summary

Applying the above guidelines, this work would be greatly strengthened by (1) more formally defining the problem space for management of system development projects, (2) comparing the nature of the proposed approach with existing approaches to establish its novelty (constructs and methods), (3) defining or using appropriate metrics for assessing its utility, and (4) gathering and analyzing evidence to demonstrate its effectiveness relative to those existing approaches. This is not to diminish the contribution of the action research paradigm or the demonstration that, for the project studied, managers found risk assessment to be effective in identifying and dealing with certain types of problems. The authors themselves point out the limitations of active research in assessing the benefits of the approach. However, a design science contribution must articulate an important problem and build an innovative artifact that addresses it. This paper does not make such a contribution. It does not argue convincingly that "control of prototyping projects" is, in fact, a serious problem different from the control of any type of IT project nor does it present or evaluate a novel approach to resolving control problems in project management.

4.3 Group Decision Support Systems (GDSS) Research

The study of group decision support systems (GDSS) has been and remains one of the most visible and successful research streams in the IS field. The use of information technology to effectively support meetings of groups of different sizes over time and space is a real problem that challenges all business organizations. Recent GDSS literature surveys demonstrate the large numbers of GDSS research papers published in the IS field and, more importantly, the wide variety of research paradigms applied to GDSS research (see, e.g., (Nunamaker et al. 1996; Fuermestad and Hiltz 1998; Dennis and Wixom 2001)). However, only a small percentage of GDSS papers can be considered to make true design science research contributions. The vast majority of these papers assume the introduction of a new information technology or process in the GDSS environment and then study the individual, group, or organizational implications using natural science (e.g., behavioral) research paradigms. Several such GDSS papers have appeared in MISQ, e.g., (Jarvenpaa et al. 1988; Dickson et al. 1993; Sengupta and Te'eni 1993; Gallupe et al. 1998).

The central role of design science in GDSS is clearly recognized in the early foundation papers of the field. The University of Arizona Electronic Meeting System group, for example, states the need for both *developmental* and *empirical* research agendas (Dennis et al. 1988; Nunamaker et al. 1991). Developmental, or design science, research is called for in the areas of process structures and support and task structures and support. Process structure and support technologies and methods are generic to all GDSS environments and tasks. Technologies and methods for distributed communications, group memory, decision-making methods, and anonymity are a few of the critical design issues for GDSS process support needed in any task domain. Task structure and support are specific to the problem domain (e.g., medical decision making, software development) under consideration by the group. Task support includes the design of new technologies and methods for managing and analyzing task-related information and using that information to make specific, task-related decisions.

We have selected GDSS research papers that demonstrate use of the design science paradigm. Based on the six research guidelines we discuss the strengths and weaknesses of each paper as design science research and critique the effectiveness of its presentation to a managerial audience.

4.3.1 Anonymity in GDSS - Gavish and Gerdes (1998)

The issue of anonymity has been studied extensively in GDSS environments. Behavioral research studies have shown both positive and negative impacts on group interactions. On the positive side, GDSS participants can express their views freely without fear of embarrassment or reprisal. However, anonymity can encourage free-riding and antisocial behaviors. While the pros and cons of anonymity in GDSS are much researched, there has been a noticeable lack of research on the design of techniques for implementing anonymity in GDSS environments. Gavish and Gerdes address this issue by designing five basic mechanisms to provide GDSS procedural anonymity.

<u>Problem Relevance</u>

The amount of interest and research on anonymity issues in GDSS testifies to its relevance. Field studies and surveys clearly indicate that participants rank anonymity as a highly desired attribute in the GDSS system. Many individuals state that they would refuse to participate in or trust the results of a GDSS meeting without a satisfactory level of assured anonymity (Fuermestad and Hiltz 1998).

<u>Research Rigor</u>

Gavish and Gerdes base their GDSS anonymity designs on past research in the fields of cryptography and secure network communication protocols (e.g. Chaum 1981; Schneier 1996). These research areas have a long history of formal, rigorous results that have been applied to the design of many practical security and privacy mechanisms. Appendix A of the paper provides a set of formal proofs that the claims made by the authors for the anonymity designs are correct and draw their validity from the knowledge base of this past research.

<u>Design as a Search Process</u>

The authors motivate their design science research by identifying three basic types of anonymity in a GDSS system – *environmental*, *content*, and *procedural*. After a definition and brief discussion of each type, they focus on the design of mechanisms for procedural anonymity; the ability of the GDSS system to hide the source of any message. This is a very difficult requirement since standard network protocols typically attach source information in headers to support reliable transmission protocols. Thus, GDSS systems must modify standard communication protocols and include additional transmission procedures to ensure required levels of anonymity.

The design science process employed by the authors is to state the desired procedural anonymity attributes of the GDSS system and then to design mechanisms to satisfy the system requirements for anonymity. Proposed designs are presented and anonymity claims are proved to be correct. A thorough discussion of the costs and benefits of the proposed anonymity mechanisms is provided in Section 4 of the paper.

Design as an Artifact

Gavish and Gerdes design a GDSS system architecture that provides a rigorous level of procedural anonymity. Five mechanisms are employed to ensure participant anonymity:

- All messages are encrypted with a unique session key.
- The sender's header information is removed from all messages.
- All messages are re-encrypted upon retransmission from any GDSS server.
- Transmission order of messages is randomized.
- Artificial messages are introduced to thwart traffic analysis.

The procedures and communication protocols that implement these mechanisms in a GDSS system are the artifacts of this research.

Design Evaluation

The evaluation consists of two reported activities. First, in Appendix A, each of the mechanisms is proved to correctly provide the claimed anonymity benefits. Formal proof methods are used to validate the effectiveness of the designed mechanisms. Second, a thorough cost-benefit analysis is presented in Section 4. It is shown that the operational costs of supporting the proposed anonymity mechanisms can be quite significant. In addition, the communication protocols to implement the mechanisms add considerable complexity to the system. Thus, the authors recommend that a cost-benefit justification be performed before determining the level of anonymity to implement for a GDSS meeting.

The authors do not claim to have implemented the proposed anonymity mechanisms in a prototype or actual GDSS system. Thus, the design artifacts remain to be evaluated in an operational GDSS environment.

Research Contributions

The design science contributions of this research are the proposed anonymity mechanisms as the design artifacts and the evaluation results in the form of formal proofs and cost-benefit analyses. These contributions advance our understanding of how best to provide participant anonymity in GDSS meetings.

Summary

Although the presentation of this research is aimed at an audience familiar with network system concepts such as encryption and communication protocols, the paper also contains important and useful information for a managerial audience. Managers should have a good understanding of the implications of anonymity in GDSS meeting. This understanding must include an appreciation of the costs of providing desired levels of participant anonymity. While the authors provide a thorough discussion of cost-benefit tradeoffs toward the end of the paper, the paper would be more accessible to a managerial audience if it included a stronger motivation up front on the important implications of anonymity in GDSS system development and operations.

4.1.2 A GDSS Architecture to Support Medical Decision-Making - Rao and Turoff (2000)

Rao and Turoff adapt GDSS methods and tools to the arena of medical decision-making (MDM). Their goal is to produce a flexible component-based GDSS architecture to support collaborative MDM.

Problem Relevance

Medical decision-making is a critically important activity that has received a tremendous amount of attention both in research and practice. Recent advances in this field have introduced intelligent tools and collaborative processes into MDM. It is natural to investigate what past research in GDSS has to offer to improve collaborative MDM tools and processes. Thus, the authors make a convincing argument that research on GDSS for collaborative MDM is highly relevant.

Research Rigor

The authors draw from a vast knowledge base of past research on diagnostic reasoning, decision-making, and group cognition. A goal in the design of the GDSS architecture is to support a wide range of diagnosis methods and decision-making techniques and tools. They propose to integrate these various methods and tools via hypermedia support in the GDSS architecture. The result of this research is a conceptual GDSS architecture design that relies upon the effective integration of rigorous, well-understood methods and tools for diagnosis and decision-making. However, the conceptual architecture itself is simply presented as a graphic design with little formal representation or rigorous evaluation.

Design as a Search Process

A clear step-by-step process is used in this research to design the GDSS architecture for MDM. First, the authors survey the MDM literature to identify essential decision-making features, such as timing issues, multiple criteria tradeoffs, individual decision-making styles, and group cognition support. Second, the GDSS literature is surveyed to find system structures and procedures to support the MDM requirements. Finally, a GDSS architecture is designed to integrate all GDSS elements required to support MDM.

Design as an Artifact

The artifact resulting from this research is the conceptual GDSS architecture to support collaborative MDM. It is represented graphically in four inter-related sections:

- GDSS Architecture Inputs – Input categories are technology, task, context, and group characteristics.
- GDSS Architecture Structures – The two classes of structures in the GDSS are cognitive-aid and group process support structures.

- Cognitive Appropriation Mechanisms – These mechanisms support the integration of medical information with the relevant diagnosis and decision-making methods and tools.
- GDSS Group Outcomes – This section presents the results of the MDM process.

In particular, the authors discuss how a commercial tool, MEDICALWARE, can be implemented into the architecture as a component to provide much of the needed MDM functionality.

<u>Design Evaluation</u>

The authors attempt to evaluate the design artifact in three ways. First, a coverage argument is made that the GDSS architecture supports all of the required MDM features. However, this is simplistic argument since the architecture was designed to support these features in the first place. Next, the authors discuss how a clinical algorithm for the evaluation and care of heart failure patients can be supported by the GDSS architecture. While some interesting observations are made, this is a single example of application. Finally, the authors comment that the GDSS architecture can be prototyped and field-tested. However, this activity is not reported in this paper. Thus, evaluation of the design science artifact is a clear weakness of this research.

<u>Research Contributions</u>

The major contribution of this research is the well-defined and exhaustive design science process performed to develop the GDSS architecture for MDM. The authors have done an outstanding job of surveying the GDSS and MDM literatures to identify the GDSS methods and tools to effectively support MDM features and requirements. The proposed GDSS architecture for collaborative MDM is comprehensive and consistent with their findings. However, without more convincing evaluation evidence, no claims to the quality and effectiveness of the designed architecture can be made.

<u>Summary</u>

An audience of health care professionals and managers would find the premise and motivation for this research to be compelling. The research contributions of the paper, however, are not mature enough for the managerial implications to be well articulated. The missing evaluation methods of prototyping and field testing, as identified by the authors, are required before this design science research could be presented effectively to a managerial audience.

6. DISCUSSION AND CONCLUSIONS

Philosophical debates on how to conduct IS research, e.g., positivism vs. interpretivism, have been the focus of much recent attention. The major emphasis of such debates lies in the epistemologies of research, the underlying assumption being one of natural science – that somewhere some *truth* exists and somehow that truth can be extracted and codified. The natural science paradigm seeks to find "what is true." In contrast, the design science paradigm seeks to create "what is effective," more closely addressing the concerns of IT practitioners. While it can be argued that utility relies on truth, the discovery of truth may greatly lag the application of its utility. We argue that both design science and natural science paradigms are needed to insure the relevance and effectiveness of IS research.

Given the artificial nature of organizations and the information systems that support them, the design science paradigm can play a significant role in resolving the fundamental dilemmas that have plagued IS research, rigor, relevance, discipline boundaries, behavior, and technology (Lee 2000). We suggest the above guidelines for IT researchers concerned with these issues. To be applicable to an MIS audience the managerial implications of the designed artifact for developing and managing organizational information processing capabilities must be clearly described. Examples dealing with information system development, project management, and decision support technologies were used to illustrate these guidelines and how they can be used to improve the design science contribution of a research project.

Information systems research lies at the intersection of management and engineering (Madnick 1992; Orlikowski and Barley 2001). It relies on and contributes to cognitive science, organizational theory, management sciences, and computer science. It is both an organizational and a technical discipline being concerned with the construction, deployment, utilization, evaluation, and management of information system artifacts in organizational settings. The design science research paradigm focuses on the creation and evaluation of innovative IT artifacts that enable organizations to address important information related tasks. While the danger of a design science paradigm is an overemphasis on technological artifacts and a failure to maintain an adequate theory base, the danger of a behavioral science research paradigm is relegating IT research to a reactive mode, discovering laws and principles for outdated technologies as organizations choose to implement technologies "that work." We argue strongly that IT research must be both proactive and reactive. It needs a complete research cycle where artifacts are created for specific information problems based on relevant behavioral science theory and behavioral science research anticipates and engages in the created IT artifacts.

Hence we reiterate the call made earlier by March, Hevner and Ram (2000) to align IS design science research with real-world production experience. Results from such industrial experience can be framed in the context of our six guidelines. These must be assessed not only by IS design science researchers but also by behavioral IS researchers who can validate the organizational problems and anticipate the impacts of created artifacts. Thus, we encourage collaborative industrial / academic research projects and publications based on such experience. Such publications will help accelerate the development of domain independent and scalable solutions to large-scale information systems problems within organizations.

We recognize that there is a lag between academic research and its adoption in industry. We also recognize the possible ad hoc nature of technology oriented solutions developed in industry. The latter gap can be considerably reduced by developing and framing the industrial solutions based on our proposed guidelines. It is also important to distinguish between “system building” efforts and design science research. Guidelines 2 (Rigor), 3 (Search Process) and 5 (Evaluation) are especially important in providing this distinction. The underlying formalism required by these guidelines helps develop models that lead to domain independent and scalable solutions to IS problems.

There exist a number of exciting challenges facing the design science research community in IS. A few are summarized below.

- There is an inadequate theoretical base upon which to build an engineering discipline of information systems design (Basili 1996). This is still a very young field without the cumulative theory development found in other engineering fields. The immature nature of the theory base is illustrated by the recent abortive ACM-IEEE effort to define a Common Body of Knowledge for the field of Software Engineering. It is important to demonstrate the feasibility and utility of such a theoretical base to a managerial audience which must make technology adoption decisions that can have far reaching impacts on the organization.
- Insufficient sets of constructs, models, methods, and tools exist for accurately representing the business / technology environment. Highly abstract representations (e.g. analytical mathematical models) are criticized as having no relationship to 'real-world' environments. The trade-offs between relevance and rigor are clearly problematic; finding representational techniques with an acceptable balance between the two is very difficult.
- The existing knowledge base is often insufficient for design purposes and designers must rely on trial and error methods. A constructed artifact itself embodies the designer's knowledge of the problem and solution and the artifact itself represents an experiment. In its execution, we learn about the nature of the problem, the environment, and the possible solutions -- hence the importance of developing and implementing prototype artifacts (Newell and Simon 1976).
- Design science research is perishable. Rapid advances in IT can invalidate design science research results before they are effectively implemented in the business environment. Just as important to IS researchers, design results are often overtaken by technology before they appear in the research literature.
- Rigorous evaluation methods are extremely difficult to apply in design science research (Tichy 1998; Zelkowitz and Wallace 1998). For example, the use of a design artifact on a single project may not generalize to different environments.

We believe that design science will play an increasingly important role in the IS profession. IT managers in particular are actively engaged in design activities -- the creation, deployment, evaluation, and improvement of purposeful IT artifacts that enable organizations to achieve their goals. The challenge for design science researchers in IT is to inform managers of the capabilities and impacts of new IT artifacts.

Much of the research published in MISQ uses a behavioral science paradigm. It is reactive with respect to technology, seeking or assessing theories that explain or predict the effects of technological artifacts on people and organizations. Its focus is on describing the implications of an artifact - its impact on individuals, groups, and organizations. It regularly includes studies that examine how users employ a technology, or report on the benefits and difficulties encountered when a technology is implemented within an organization, or discuss how managers might facilitate use of a technology. Design science is proactive with respect to technology, engaging in the creation of technological artifacts that impact people and organizations. Its focus is on problem solving. As stated earlier, the design of an artifact, its formal specification, and an assessment of its utility, often by comparison with competing artifacts, are integral to design science research. The effective presentation of design science research in IS journals, such as MISQ, will be an important step for achieving a true integration of the design and behavioral science paradigms in IS research.

We close with a quote from Simon (1996, p. 138) that reflects our aim in this article:

> If I have made my case, then we can conclude that, in large part, the proper study of mankind is the science of design, not only as a professional component of a technical education but as a core discipline for every liberally educated person.

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