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A Taxonomy of Business Process Modeling and Information Systems Modeling Techniques

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Abstract. Modeling always has been at the core of both organizational design and information systems (IS) development. Models enable decision makers to filter out the irrelevant complexities of the real world, so that efforts can be directed toward the most important parts of the system under study. However, both business analysts and IS professionals may find it difficult to navigate through a maze of theoretical paradigms, methodological approaches, and representational formalisms that have been proposed for both business process modeling (BPM) and information systems modeling (ISM). This paper sets out to put an order to this chaos by proposing an evaluation framework and a novel taxonomy of BPM and ISM techniques. These findings, coupled with a detailed review of BPM and ISM techniques, can assist decision makers in comparatively evaluating and selecting suitable modeling techniques, depending on the characteristics and requirements of individual projects.

Key Words:

1. Introduction: IS-enabled business process change

According to Davenport and Short (1990), although business process design and information technology are natural partners, their relationship has never been fully exploited in practice. The authors define this relationship as a recursive pattern. One the one hand, it naturally is expected that the choice of a particular way of conducting business in an organization will influence the design and structure of the information systems to support this process. On the other hand, advances in information technology can generate completely new opportunities for organizations and thus influence the design of specific business process layouts.

Such recursive relationships imply that organizations should align the design of information systems with the design of the corresponding business processes, if maximum benefits from their synergy are to be achieved (van Meel, Bots, and Sol, 1994; Grover, Fielder, and Teng, 1994; Teufel and Teufel, 1995). Although the benefits of aligning the design of business processes with the design of their corresponding information systems should be apparent in theory, such integrated design strategies rarely have been the case in practice. Business analysts and IS professionals traditionally had distinct roles within organizations, each equipped with his or her own tools, techniques, skills, and even terminology (Earl, 1994). There seems to be very limited support for predicting the consequences that changes in one organizational facet (business processes or information systems) will have on the other (MacArthur, Crosslin, and Warren, 1994).

This distinction is reinforced when the issue of *modeling* business processes and information systems is addressed. Most current approaches concentrate too heavily on one end of the scale, usually leaving the question of business/IS alignment outside their scope. This observation spawned the research that culminated in this paper: to develop an evaluation framework for studying and positioning BPM and ISM techniques, to review a selection of popular techniques based on this framework, and to propose a novel taxonomy that would assist prospective modelers in choosing appropriate modeling techniques, depending on the requirements of a particular problem. In section 2 we introduce the concepts of business process modeling and IS modeling in the context of organizational design, while in section 3 we postulate an evaluation framework for BPM/ISM techniques. Using this theoretical basis, we provide a detailed review of a number of techniques for BPM (section 4) and ISM (section 5). We conclude by synthesising these findings into a taxonomy of BPM/ISM techniques, proposing avenues for further research into the subject.

2. Organizational change and IS development as design problems

Process-based thinking in the context of organizational change, it can be argued, primarily is a *systems design problem* (Earl, 1994; Davenport and Stoddard, 1994). According to the *information processing* (Tushman and Nadler, 1978) and *decision making* (Huber and McDaniel, 1986) paradigms of organizational design, processes can be viewed as collections of decision models, each of which is identified by a type of decision and contains a sequence of processing tasks (Moore and Whinston, 1986). These tasks are the smallest identifiable units of analysis, and their optimum arrangement is the critical design variable determining the efficiency of the resulting structures (Orman, 1995). According to this model management approach, complex design decisions need to be made that may affect different, but interacting and interrelated, dimensions of an organization: its processes, its people, its strategy, its environment, its culture, and its information systems, to name but a few. A change in one aspect may have unknown or unexpected consequences on the others.

Based on these theoretical foundations, we can deduce that techniques that allow for modeling business process components, experimenting with alternative configurations and process layouts, and comparing diverse proposals for change would be highly suitable for organizational design and business engineering.

Coupled with the widely studied problems of IS design and development, this “model management” approach presents an opportunity for addressing the “business/IS fit” problem by means of modeling. The importance of the modeling process for organizational change has been heavily emphasized in the literature (for example, in Curtis, Kellner, and Over, 1992; Hansen, 1994; Tsalgatidou and Junginger, 1995; Blyth, 1995). The term *business process modeling* is used to incorporate all activities relating to the transformation of knowledge about business systems into models that describe the processes performed by organizations (Scholz-Reiter and Stickel, 1996). The term *information systems modeling* (ISM) is used in a similar fashion to denote approaches “seeking to make our abstractions of information systems look more like the real-world systems they represent” (Sol and Crosslin, 1992).

Figure 1 illustrates how the concept of modeling techniques fits within a hierarchical decomposition of modeling elements (the same line of thought was followed by Kettinger, Teng, and Guha, 1997). According to this decomposition, modeling, in general, can be thought of as supported by one or more methodologies. *Methodologies* are taken to refer

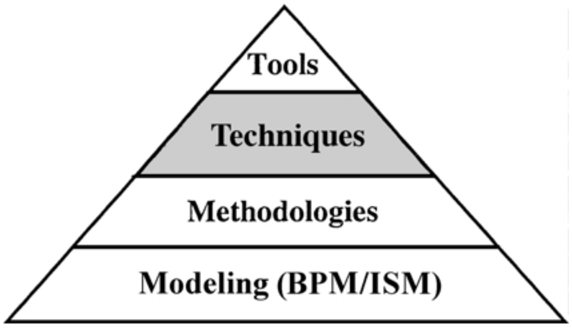

Figure 1. Modeling methodologies, techniques, and Tools.

to modeling paradigms (for example, data focused, object oriented, and so on) and are outside the scope of this paper. Modeling methodologies are supported by a number of *techniques* that provide the main analytical focus of our research. *Techniques* are taken to refer to diagrammatic or other notations for studying and analyzing modeled systems. Specific techniques, as well as their underlying methodologies, can be supported (and, in most cases, are supported) by software modeling *tools*, such as CASE tools, Workflow Management Systems, process modeling software, and others. Like methodologies, the study of modeling tools falls outside the scope of this paper.

Due to the complex and dynamic nature of organizations, carefully developed models are necessary for understanding their behavior to design new systems or improve the operation of existing ones (Bhaskar et al., 1994; Gladwin and Tumay, 1994; Liles and Presley, 1996). However, this very complexity of business processes and information systems can make modeling and experimentation an arduous and problematic task (Streng, 1994), especially when there is a need to combine BPM and ISM in an integrated activity. Since most BPM and ISM techniques have been developed with no reference to such integration, a fundamental research question would involve studying current approaches to modeling with the view of developing a novel taxonomy for their positioning, comparison, and evaluation. To this end, the next section discusses the development of an evaluation framework for studying BPM/ISM techniques. Drawing on this framework, a number of selected modeling techniques are reviewed and classified, providing the foundation on which a taxonomy is proposed in the following sections of this paper.

3. A framework for evaluating BPM/ISM techniques

Business process models and IS models can be used in a variety of contexts; for example, business process engineering, IS design and development, and investment evaluation. The goals and objectives of a particular study necessarily have an impact on the uses to which a model will be put and therefore influence the requirements posed on the process representation formalisms to be employed (Liles and Presley, 1996). Table 1 illustrates typical BPM/ISM goals and objectives, along with associated requirements for modeling techniques in each case (Curtis et al., 1992).

Table 1. BPM/ISM goals and requirements (adapted from Curtis et al., 1992).

Modeling Goals and Objectives	Requirements for Modeling Techniques
Support human understanding and communication	Comprehensibility, communicability
Support process improvement	Model process components, reusability, measurability, comparability, support technology selection and incorporation, support process evolution
Support process management	Support reasoning, forecasting, measurement, monitoring, management, and coordination
Support process development	Integrate with development environments, support for process documentation, reusability
Support process execution	Automate process tasks, support co-operative work, automate performance measurement, check process integrity

To accommodate the aforementioned goals and objectives, a model must be capable of providing various information elements to its users. Such elements include, for example, what activities constitute the process, who performs these activities, when and where the activities are performed, how and why they are executed, and what data elements they manipulate. Modeling techniques differ in the extent to which their constructs highlight the information that answers these questions. To provide this information, a modeling technique should be capable of representing one or more of the following "process perspectives" (Curtis et al., 1992):

1. The *functional perspective* represents *what* process elements (activities) are being performed.
2. The *behavioral perspective* represents *when* activities are performed (for example, sequencing) as well as aspects of *how* they are performed through feedback loops, iteration, decision-making conditions, entry and exit criteria, and so on.
3. The *organizational perspective* represents *where* and *by whom* activities are performed, the physical communication mechanisms used to transfer entities, and the physical media and locations used to store entities.
4. The *informational perspective* represents the informational entities (*data*) produced or manipulated by a process and their interrelationships.

The combination of modeling goals and objectives with the perspectives of modeling can provide the basis of an evaluation framework for studying, analyzing, and comparing current and new BPM and ISM techniques. This framework is illustrated in figure 2. The framework suggests three evaluation variables to classify and evaluate modeling techniques: breadth (the modeling goals typically addressed by the technique), depth (the modeling perspectives covered), and fit (typical projects to which the technique can be fitted). The analytical power of the framework lies in its ability to match project characteristics to the modeling goals and the perspectives typically associated with them. For example, with reference to figure 2, a typical BPR project aims at delivering *process improvement* and concentrates more than anything else on the *behavioral* aspects of modeling. It is worth repeating that the emphasis

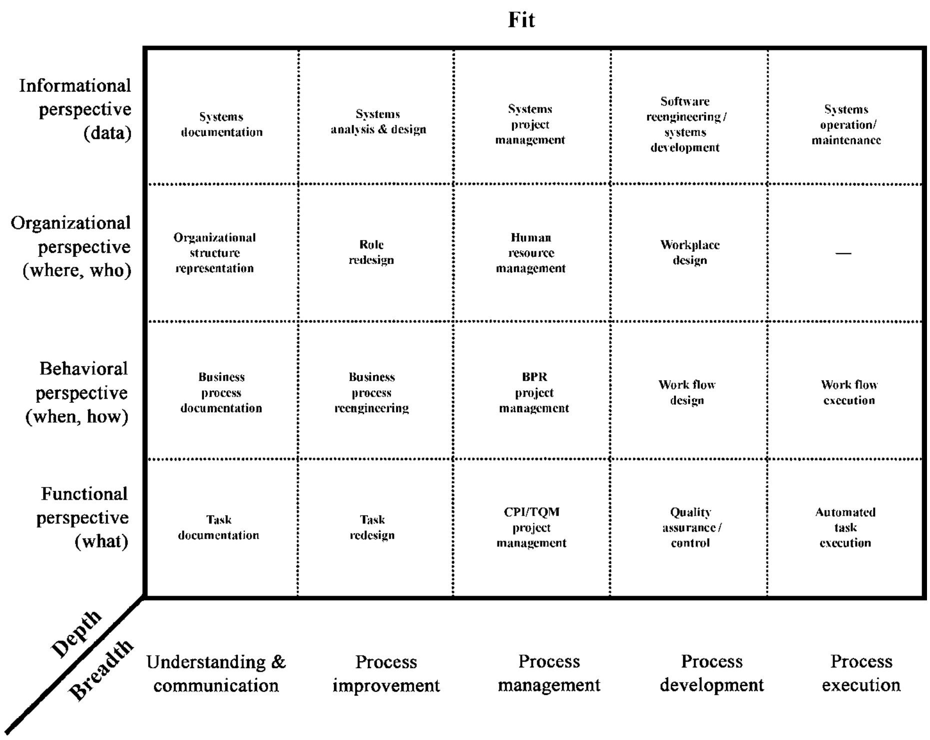

Figure 2. An evaluation framework for BPM/ISM techniques.

is on modeling goals and perspectives *typically* associated with projects, rather than laying out strict guidelines for the selection of modeling techniques.

By studying the framework in more detail, we can note the following:

1. The *horizontal flow* of projects within a modeling perspective is consistent with theoretical approaches to systems analysis and design. For example, in the *informational* perspective (top row in the framework) one easily can identify a sequence of steps that resembles closely the systems development life-cycle paradigm (Avison, 1997): documentation, analysis and design, development, and operation/maintenance.
2. The *vertical integration* of projects within a given modeling goal points toward the need for combining business and IS modeling in the context of projects that spread across the boundaries of individual modeling perspectives. For example, in a modeling project aimed at improving the understanding of a business system (first column in the framework), one might need to employ all modeling perspectives to grasp the wider system picture: functional modeling to document the detail of individual tasks, behavioral modeling to identify how individual tasks interact with each other to produce the whole process, organizational modeling to examine user roles within the process, and

Table 2. BPM/ISM techniques reviewed.

Business Process Modeling Techniques	IS Modeling Techniques
BPM-1. Flowcharting	ISM-1. Data flow diagramming
BPM-2. IDEF techniques (IDEF0, IDEF3)	ISM-2. Entity-relationship diagramming
BPM-3. Petri nets	ISM-3. State-transition diagramming
BPM-4. Simulation	ISM-4. IDEF techniques (IDEF1x)
BPM-5. Knowledge-based techniques	ISM-5. UML
BPM-6. Role activity diagramming	

informational modeling to document the details of information systems that support process execution.

It is worth mentioning that the boundaries between the individual project types depicted in the framework in reality are much more blurred than this theoretical classification might imply. For example, work flow execution and automated task execution may be inseparable activities in real-life situations. However, the framework classification allows isolating the different goals and perspectives of an overall project's steps. Hence, it can provide a solid foundation on which BPM and ISM techniques can be positioned and integrated more easily. In other words, although the framework possesses enough explanatory and analytical power on its own, its real value can be harnessed if it is expanded to show how current BPM and ISM techniques are positioned within the framework dimensions. To this end, in the remainder of the paper, a selected number of popular BPM and ISM techniques are reviewed. The overview presented in the following sections is not intended to be exhaustive but rather to assist in the development of a generic taxonomy of modeling techniques to which other techniques easily can be added at a later stage. The techniques reviewed in this paper are summarized in table 2.

4. Business process modeling techniques

4.1. Flowcharting

Flowcharting is among the first graphical modeling techniques, dating back to the 1960s (Schriber, 1969). The advantages of flowcharts center on their ability to show the overall structure of a system; to trace the flow of information and work; to depict the physical media on which data are entered, produced, and stored; and to highlight key processing and decision points (Jones, 1986).

Flowcharting initially was intended to represent computer program logic, but due to its generic nature, it has been used in many other application areas as well, including business process modeling. Despite its advantages (familiarity and ease of use), flowcharting no longer is a dominant modeling technique, because it can provide only basic facilities in representing processes. Therefore, flowcharts nowadays typically are used as a simple, graphic means of communication, intended to support narrative descriptions of processes when the latter become complicated and difficult to follow.

4.2. IDEF techniques (IDEF0, IDEF3)

The IDEF family of modeling techniques was developed as a set of notational formalisms for representing and modeling process and data structures in an integrated fashion. The IDEF suite consists of a number of independent techniques, the most well-known being IDEF0 (function modeling), IDEF1*x* (data modeling), and IDEF3 (process description capture). In this section, we describe IDEF0 and IDEF3, since they relate primarily to business process modeling. IDEF1*x* is considered later, along with other techniques related to information systems modeling.

The IDEF0 method is designed to model the decisions, actions, and activities of an organization or other system, and as such, it is targeted mostly toward the functional modeling perspective (Mayer et al., 1995). As a communication tool, IDEF0 aims at enhanced domain expert involvement and consensus decision making through simplified graphical devices. Perhaps the main strength of IDEF0 is its simplicity, as it uses only one notational construct, the ICOM (input-control-output-mechanism; see figure 3). IDEF0 supports process modeling by progressively decomposing higher-level ICOMs into more-detailed models that depict the hierarchical decomposition of activities.

Despite its advantages, IDEF0 has a number of limitations that may render the technique unsuitable for process analysis. More specifically, IDEF0 models are static diagrams with no explicit or even implicit representation of time. Even the sequence of ICOMs is not meant to depict the temporal relations among activities. As such, IDEF0 models cannot represent the *behavioral* or *informational* modeling perspectives.

IDEF3 was developed to overcome some of the limitations of IDEF0 models. IDEF3 describes processes as ordered sequences of events or activities. As such, IDEF3 is a scenario-driven process flow modeling technique, based on the direct capture of precedence and causality relations between situations and events (Mayer et al., 1995). The goal of an IDEF3 model is to provide a structured method of expressing the domain experts' knowledge about *how* a particular system or organization works (as opposed to IDEF0, which is concerned mainly with *what* activities the organization performs).

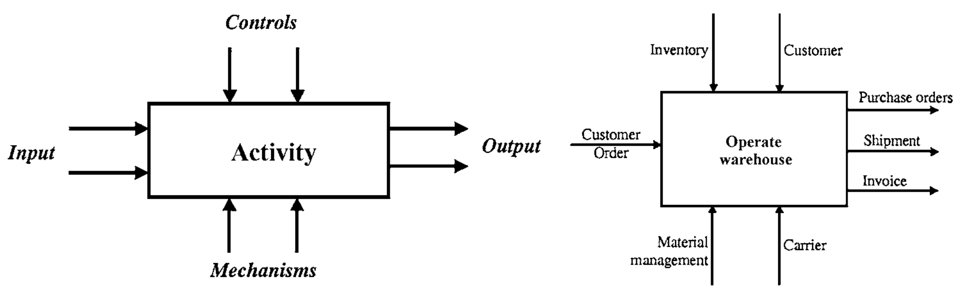

Figure 3. IDEF0 notation (ICOM) and example diagram.

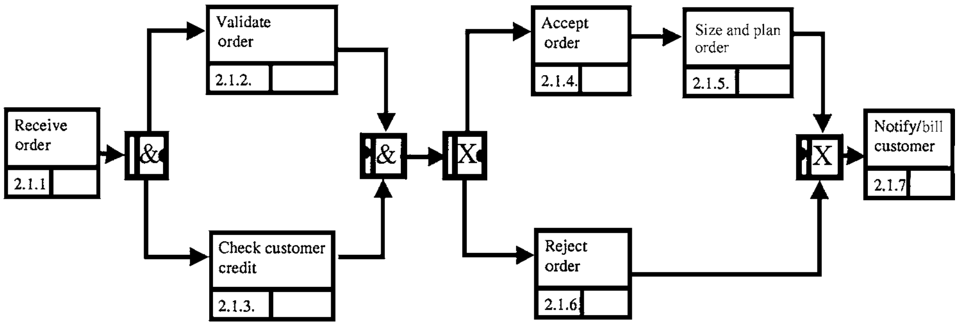

Figure 4. IDEF3 example (process flow diagram).

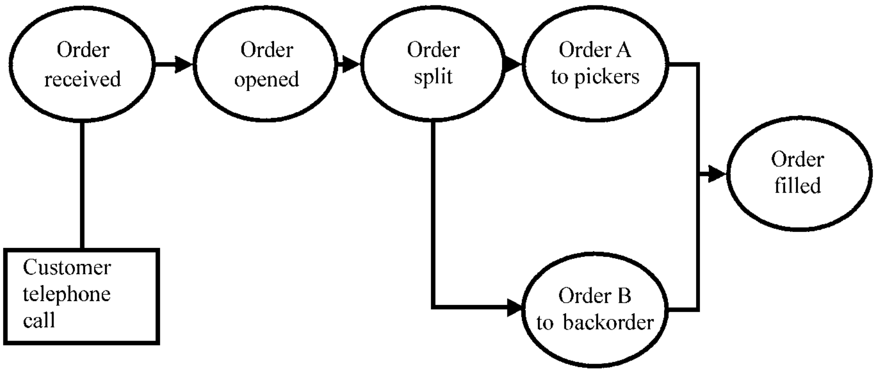

Figure 5. IDEF3 example (object-state transition diagram).

IDEF3 uses two complementary diagrammatic representations of process models. *Process flow diagrams* (Figure 4) depict the flow of activities within a process, while *object-state transition diagrams* (Figure 5) represent the different states of entities as they flow through the process.

4.3. Petri nets

Strictly speaking, Petri nets are not a business process modeling technique, since they originated from and traditionally are used for systems modeling. However, among the systems modeling techniques, the Petri nets perhaps has received the most attention as a potential candidate for business process modeling as well (Reising, Muchnick, and Schnupp 1992). Basic Petri nets are mathematical/graphical representations of systems, aiming at assisting the analysis of the structure and dynamic behavior of modeled systems, especially systems with interacting concurrent components (Peterson 1981). A basic Petri net graph is composed of a set of *states* and a set of *transitions*. Figure 6 illustrates an example of a basic Petri net.

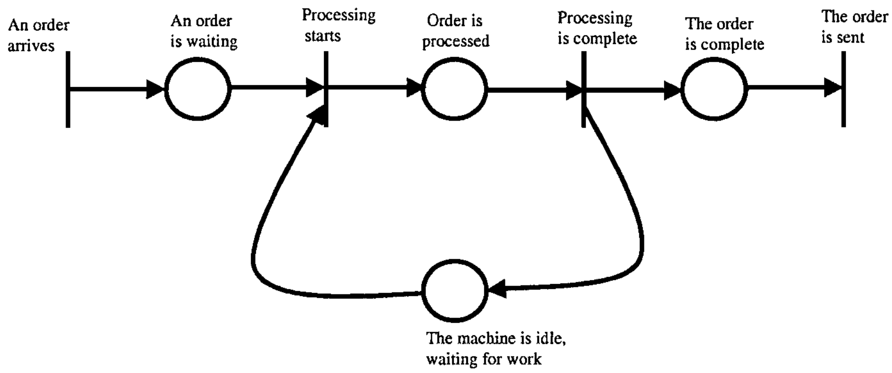

Figure 6. Petri net example (Peterson 1981).

Basic Petri Nets, it has been recognized, are not succinct and manageable enough to be useful in modeling high-level, complex business processes (Leymann and Altenhuber 1994). To this end, a number of extensions to the basic Petri net formalism (usually to include the notions of color, time, and hierarchy) have been proposed. These extensions collectively are referred to as *high-level Petri nets* (van der Aalst and van Hee, 1996) and include, for example, generalized stochastic Petri nets (GSPN; Marsan et al., 1995) and colored Petri nets (CPN; Jensen, 1996).

4.4. Simulation

The basic idea behind simulation is simple (Doran and Gilbert, 1994). We wish to acquire knowledge and reach some informed decisions regarding a real-world system, but the system is not easy to study directly. We therefore proceed indirectly by creating and studying another entity (the simulation model) that is sufficiently similar to the real-world system that we are confident that some of what we learn about the model will be true of the system. Simulation can have many forms (for example, discrete-event simulation, continuous simulation, system dynamics, Monte Carlo simulation, and qualitative simulation). Discrete-event simulation and system dynamics seem to have received most attention, in relation to BPM and ISM, and are reviewed here.

Discrete-event simulation. Shannon (1975) defined discrete-event simulation as

> the process of designing a model of a real system and conducting experiments with this model for the purpose, either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system.

Practical simulation modeling usually originates in a management perception of a problem requiring some decision or understanding (Paul and Doukidis, 1987). The problem may concern or involve the operation of some complex system on which direct experimentation may be impractical due to cost, time, or some human restriction.

The very definition of simulation reveals its theoretical potential as a tool for BPM. Indeed, simulation modeling of an organization's processes can help towards understanding the behaviour of the existing business system, identifying problematic tasks, and making experimentation with alternative processes easier, directly comparable and less risky. However, relatively less research or application has been directed towards addressing the more specific problems associated with the potential of simulation for ISM. Even in the few published articles that deal with the matter (for example, Warren et al., 1992), the simulation of Information Systems is treated at the level of technical system specifications rather than the level of organizational performance impact.

System Dynamics. System dynamics (SD) was developed during the 1950s at MIT (Forrester, 1961) as a set of tools for relating the structure of complex managerial systems to their performance over time via the use of simulation. Systems dynamics models are based on cause and effect diagrams (known as *causal loop* or *influence diagrams*) and *pipe diagrams*. The purpose of these diagrams is to make explicit mental models about system structure and strategies. The word *structure* is taken to imply the information feedback structure of the system; hence, system dynamics models often are described as taking a feedback perspective of a situation, the underlying premise being that the feedback structure of a system is a direct determinant of its behavior. Figure 7 illustrates typical examples of notational conventions used in pipe diagrams and shows an example of such a diagram created using the iThink software (HPS, 1997). By quantifying the relationships implied

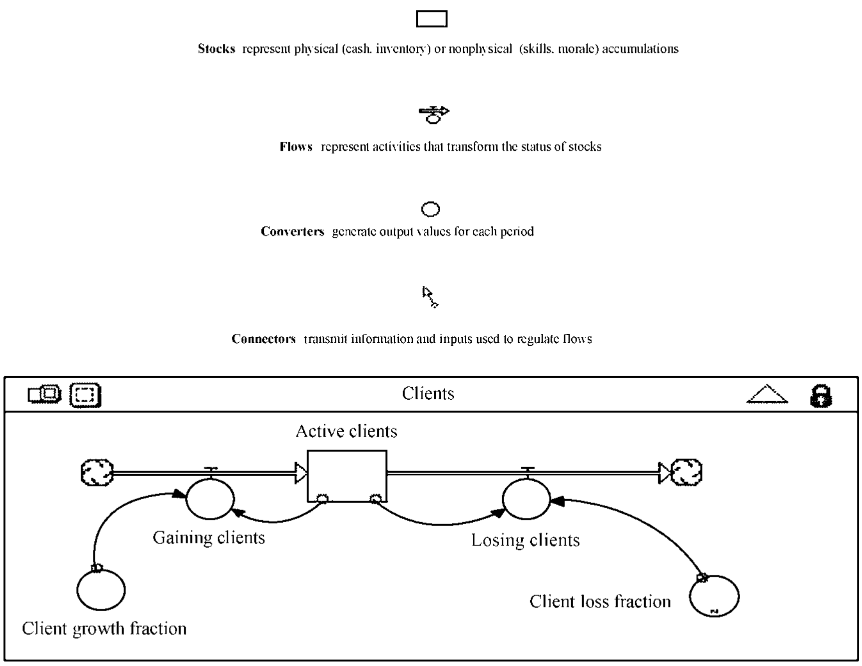

Figure 7. System dynamics notation and example (pipe diagram).

by the links in a system dynamics model, it is possible to simulate the model and gain quantitative information on model dynamics.

Despite its advantages, the application of system dynamics as a BPM/ISM technique may present a number of limitations. First, it places much emphasis on feedback and control processes, which may be of limited importance in many practical situations of business/IS modeling. Second, modeling essentially is deterministic and hence unable to cope with the stochastic elements so frequent in real-world business processes. Finally, according to Wolstenholme, Henderson, and Gavine (1993), "the technique's limited range of primitive analytical constructs compels the analyst to adopt a specific (usually high-level) approach which can sometimes limit the scope of analysis achievable."

4.5. Knowledge-based techniques

In the last few years, techniques based on artificial intelligence (AI) have started to appear as building blocks in business process modeling applications (Hedberg 1996). These techniques are targeted mainly to the issue of linking business processes to organizational rules and business objectives in a formal manner (Yu, Mylopoulos, and Lesperance, 1996). Among the AI techniques proposed, knowledge-based systems (KBS) and qualitative simulation seem to have attracted the most attention by researchers and are reviewed here.

Knowledge-based systems. Ba, Lang, and Whinston (1997) present a knowledge-based enterprise modeling framework to support organizational decision making in the context of strategic change. This framework bases its reasoning about a particular organization on a "library of knowledge," representing significant organizational phenomena from different perspectives and at different levels of detail. The authors also present an Intranet-based prototype implementation of their framework to illustrate its ideas and concepts.

In a similar vein, Compatangelo and Rumolo (1997) advocate the use of knowledge-based techniques, with emphasis on automated reasoning, to address enterprise modeling at the conceptual level. They claim their approach could form the foundation of a framework for the development of computer-aided modeling tools endowed with automatic reasoning capabilities. The authors present the concepts of the $EDDL_{DP}$ language, which is a concept language based on description logics, and discuss (on the basis of a practical example) how the language could be used to create an enterprise knowledge base.

Qualitative simulation. Nissen (1994, 1996) follows a similar approach and employs the AI technology of qualitative simulation to develop models of organizational processes for informing the process of analysis and redesign. Qualitative simulation is a technology of the commonsense reasoning branch of AI and exploits the use of knowledge to support "intelligent" reasoning about modeled phenomena. Qualitative simulation enables entities and relationships to be modeled and codified even with only minimal understanding or information regarding them. The output of qualitative simulation is an "envisionment," in other words, a description of all possible behaviors for the modeled process.

Despite its potential advantages, qualitative simulation also presents a number of severe limitations. Its inherently qualitative nature makes it more suitable for modeling general

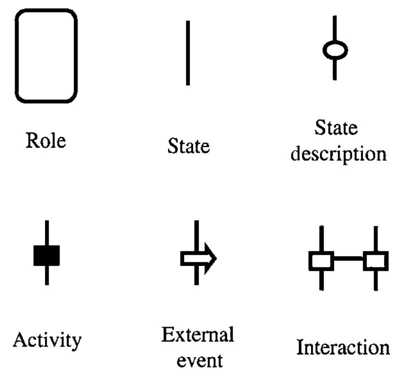

Figure 8. RAD notation.

classes of phenomena than specific instances. Nissen (1996) recognizes that qualitative and quantitative simulations should complement each other if a comprehensive picture of the organizational processes is to be drawn. The author also recognizes that "the envisionment . . . suffers from considerable ambiguity, and provides nowhere near the level and amount of information we would expect from a quantitative simulation model." Moreover, the simulation generates a very large state space, even for simple processes, and therefore its development and use may represent a complex and laborious endeavor in practice.

4.6. Role activity diagramming

Role activity diagrams (RADs) are diagrammatic notations that concentrate on modeling individual or group *roles* within a process, their component activities, and their interactions, together with external events and the logic that determines what activities are carried out and when (Huckvale and Ould, 1995). Figure 8 illustrates the basic constructs of RAD notation.

RADs differ from most other process diagrammatic notations in that they adopt the *role*, as opposed to the *activity*, as the primary unit of analysis in the process model. Due to this focus, they are suitable mostly for organizational contexts in which the human element is the critical organizational resource addressed by that process change. However, they cannot accommodate the explicit depiction of and experimentation with other organizational perspectives (for example, *functional* or *informational*), restricting their role to being mostly complementary in the context of business engineering.

5. Information systems modeling techniques

5.1. Data flow diagramming

Data flow diagramming (DFD) is a technique for graphically depicting the flow of data among external entities, internal processing steps, and data storage elements in a business process (Kettinger et al., 1997). DFDs are used to document systems by focusing on the flow of data into, around, and outside the system boundaries. In that respect, DFDs are comparable to flowcharts, differing from them basically in the focus of analysis (DFDs focus on data instead of activities and control).

DFDs have been widely used for data modeling and have become the standard notation for traditional systems analysis and design (Yourdon, 1989). However, they present a number of limitations. First, they focus exclusively (or at least primarily) on data and provide no modeling constructs on which to base representation of work flow, people, events, and other business process elements. Second, they provide no information on decisions and event sequences (temporal or precedence relationships). Finally, DFDs have no beginning or end points, nor execution paths. In other words, they are static representations of a system and the system's functions that involve data manipulation; therefore, they do not lend themselves easily to analysis or decision making. To facilitate such analysis, data flow diagramming sometimes is complemented by structured textual descriptions of procedures in which data are to be used; these descriptions are called *process specifications* (Yourdon, 1989).

5.2. Entity-relationship diagramming

Entity-relationship (ER) diagrams are another widely used data modeling technique. ER diagrams are network models that describe the stored data layout of a system (Yourdon, 1989). ER diagrams focus on modeling the data in a system and their interrelationship in a manner entirely *independent* of the processing that may take place on that data. Such separation of data and operations may be necessitated in cases where the data and their interrelationships are sufficiently complex. For the system analyst, ER diagrams have another advantage: They highlight relationships between data stores in the DFD that otherwise would be visible only in the (textual) process specification.

For business process modeling, ER diagrams pose limitations similar to DFDs. More specifically, they focus too much on data and their interrelationships and, hence, provide no constructs for modeling other process elements. Even more important, they provide no information about the functions depicted that create or use these data (as DFDs do). Finally, they are entirely static representations, providing no time-related information that could drive analysis and measurement.

5.3. State-transition diagramming

State-transition (ST) diagrams originate from the analysis and design of real-time systems. ST diagrams attempt to overcome the limitations arising from the static nature of DFDs and ER diagrams by providing explicit information about the time-related sequence of events within a system. The notation used by standard ST diagrams is very simple, consisting of only rectangular boxes that represent states and arrows that represent changes in state (transitions).

Although ST diagrams overcome some limitations of the other IS modeling techniques (such as DFDs and ER diagrams), they still focus primarily on the data portion of a system, ignoring aspects of work flow, control, decision making, and so on. Therefore, ST diagrams continue to be applicable mainly in systems design and are rather inappropriate mechanisms for capturing business process modeling aspects, let alone the wider-encompassing area of integrated BPM/ISM.

5.4. IDEF techniques (IDEF1x)

IDEF1*x* was designed as a technique for modeling and analyzing data structures for the establishment of information systems requirements (Mayer et al., 1995). IDEF1*x* differs from traditional data modeling techniques in that it does not restrict modeling in the data elements being manipulated by computers but extends its application to modeling manual-handled data elements as well. IDEF1*x* utilizes simple graphical conventions (see figure 9) to express sets of rules and relationships between entity classes in a fashion similar to entity-relationship diagrams.

The power of IDEF1*x* diagrams for integrated BPM/ISM can be harnessed when these diagrams are combined with IDEF0 and IDEF3 business models. Since they belong to the same family of techniques, IDEF models complement each other effectively and, when combined, can provide a holistic perspective of a modeled system. However, this facility comes at a potentially high complexity of developing and maintaining many different models for a single system, as discussed earlier.

5.5. Unified modeling language

Introduced in 1997 and supported by major industry-leading companies, the unified modeling language (UML) rapidly was accepted throughout the object-technology community as the standard graphical language for specifying, constructing, visualizing, and documenting software-intensive systems (Booch, Rumbaugh, and Jacobson, 1999). UML utilizes a wide array of diagrammatic notations, including

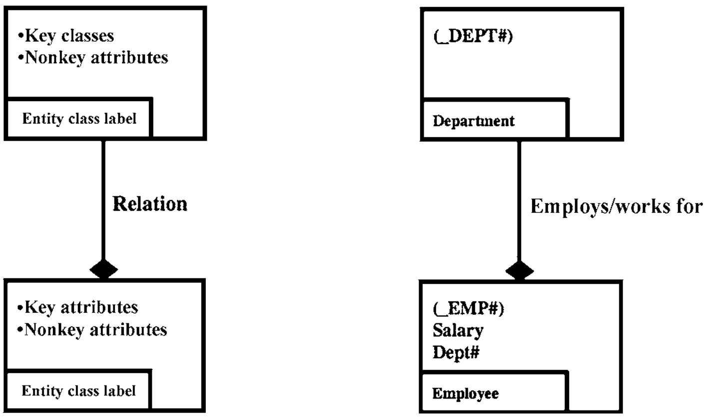

Figure 9. IDEF1*x* notation and example.

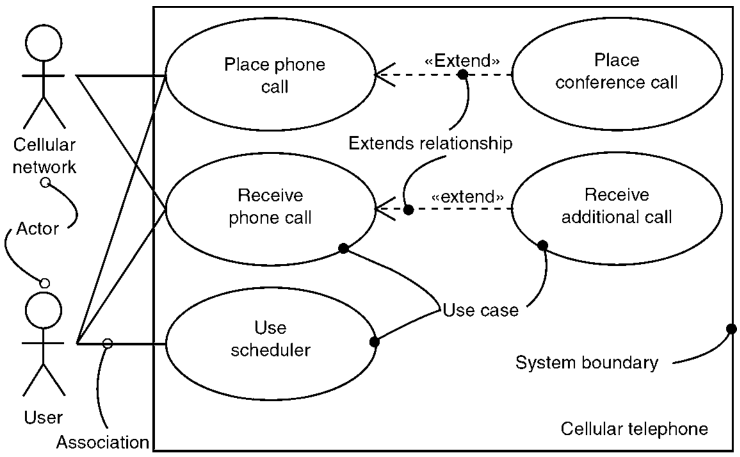

Figure 10. Use case diagram (example).

1. *Use case* diagrams, which capture system functionality as seen by the users (see figure 10).
2. *Class* diagrams, which capture the vocabulary of the system.
3. *Behavior* diagrams (for example, *statechart*, *activity*, and *interaction* diagrams).
4. *Implementation* diagrams (for example, *component* and *deployment* diagrams).

The underlying reason for the development of the language is simple: Although a wide variety of notational languages have long existed for the representation of software systems, most languages are aligned with a particular analysis and design method. This wide variety can be a source of complexity and problems of incompatibility among languages. UML attempts to address this gap by being a "universal" language, covering everything from business process representation to database schema depiction and software components modeling. According to its developers, UML

> will reduce the degree of confusion within the industry surrounding modeling languages. Its adoption would settle unproductive arguments about method notations and model interchange mechanisms, and would allow the industry to focus on higher leverage, more productive activities. (UML, 1997).

As far as BPM and ISM are concerned, UML is targeted mostly to systems modeling, although an "extension for business modeling" also has been developed. Furthermore, some may argue that the language is based heavily on the object-oriented paradigm and hence may not be applicable in situations where the modelers follow a more traditional modeling approach.

6. Conclusions: A taxonomy of modeling techniques

The preceding review of techniques used in modeling business processes and information systems can lead to some interesting observations. First, the various techniques differ

Table 3. Depth of BPM/ISM techniques (modeling perspectives).

	Modeling Perspectives (Depth)			
BPM/ISM Techniques	Functional	Behavioral	Organizational	Informational
Flowchart	Yes	No	No	Limited
IDEF0	Yes	No	Limited	No
IDEF3	Limited	Limited	No	Limited
Petri nets	Yes	Yes	No	No
Discrete event simulation	Yes	Yes	Yes	Limited
System dynamics	Limited	Yes	Yes	Limited
Knowledge-based techniques	No	Yes	No	No
Role activity diagram	No	Limited	Yes	No
Data flow diagram	Yes	No	Limited	Yes
Entity-relationship diagram	No	No	No	Yes
State-transition diagram	No	Limited	No	Limited
IDEF1*x*	No	No	No	Yes
UML‘	Yes	Limited	Limited	Yes

significantly in the extent to which they provide the ability to model different business and system perspectives. Some techniques focus primarily on functions, others on roles, and yet others on data. Ideally, what might be needed is the development of a single, holistic technique that could effectively represent all modeling perspectives in a rigorous and concise fashion and hence be applicable in all modeling situations.

However, the multiplicity of possible modeling goals and objectives might render the development of such a modeling technique impossible or at least impractical. Such a technique probably would generate complex models, reducing the ease of use for any single particular application (Curtis et al., 1992). To deal with this problem of complexity, each of the techniques reviewed chooses to concentrate on a subset of modeling perspectives and, therefore, provides support for specific modeling goals and objectives.

To assist in technique evaluation and selection, depending on the characteristics of individual projects, in this section, we combine the characteristics of the modeling techniques reviewed earlier, with the evaluation framework of figure 2, to develop a taxonomy of BPM/ISM techniques. As a starting point, Table 3 illustrates the degree to which the techniques reviewed represent the process modeling perspectives of the evaluation framework (*depth* of modeling).

Based on these findings, figure 11 proposes a classification of BPM/ISM techniques in terms of the evaluation framework of figure 2. The taxonomy is not intended to be rigid, since the lines between modeling depth and breadth by definition are blurred and cannot be subjected to strict separation. However, the taxonomy is helpful, as it can provide the basis for selecting appropriate techniques to use depending on either their *fit* with individual projects (as depicted in figure 2) or the *depth* and *breadth* required in a specific modeling exercise. For example, in a typical business process documentation project (or any

Depth \ Breadth	Understanding & communicating	Process improvement	Process management	Process development	Process execution
Informational (data)	(Flowchart) (IDEF3) DFD Entity relationship State transition IDEF1*x* UML	(Simulation) DFD Entity relationship State transition IDEF1*x* UML	Simulation DFD Entity relationship State transition IDEF1*x* UML	Simulation DFD Entity relationship State transition IDEF1*x* UML	Simulation DFD Entity relationship State transition IDEF1*x* UML
Organizational (where, who)	(IDEF0) (Simulation) System dynamics RAD	(IDEF0) Simulation System dynamics RAD	(IDEF0) Simulation System dynamics RAD	Simulation (UML) (RAD)	—
Behavioral (when, how)	(IDEF3) Simulation System dynamics RAD	(IDEF3) Simulation System dynamics RAD	(IDEF3) Simulation System dynamics RAD	Petri nets Simulation System dynamics Knowledge based (State transition)	Petri nets Simulation Knowledge based (State transition)
Functional (what)	Flowchart IDEF0 (IDEF3) Simulation (System dynamics) DFD (UML)	Flowchart IDEF0 (IDEF3) Simulation System dynamics DFD (UML)	Flowchart IDEF0 (IDEF3) Simulation	IDEF0 Petri nets Simulation DFD UML	Petri nets Simulation DFD UML

Figure 11. A taxonomy of BPM/ISM techniques.

similar endeavor aiming at improving human understanding and focusing on the behavioral aspects of modeling), the following modeling techniques seem more appropriate to use (with reference to figure 11): simulation, system dynamics, role activity diagram, and (to a lesser degree, indicated by the parentheses) IDEF3. Of course, nothing prevents modelers from using a different technique. The taxonomy merely suggests modeling techniques better fitted (due to the constructs they provide) than others to the characteristics of the problem under investigation.

Both the evaluation framework of figure 2 and the taxonomy of figure 11 present the additional benefit of being completely open. New project types and BPM/ISM techniques can be added without affecting the validity of the structure and the information presently included. To this end, further research could be directed toward

1. Enhancing the evaluation framework by adding new project types to the *fit* dimension.
2. Reviewing other modeling techniques and adding them to the taxonomy.
3. Validating the framework and the taxonomy in an empirical fashion by testing the fit of individual techniques in the field (i.e., in real-world organizational modeling projects).
4. Further enhancing the framework and the taxonomy by addressing the issue of *integration* between project steps and modeling techniques, an issue of paramount importance in the face of the arguments discussed in the earlier sections of this paper. Figure 12 illustrates

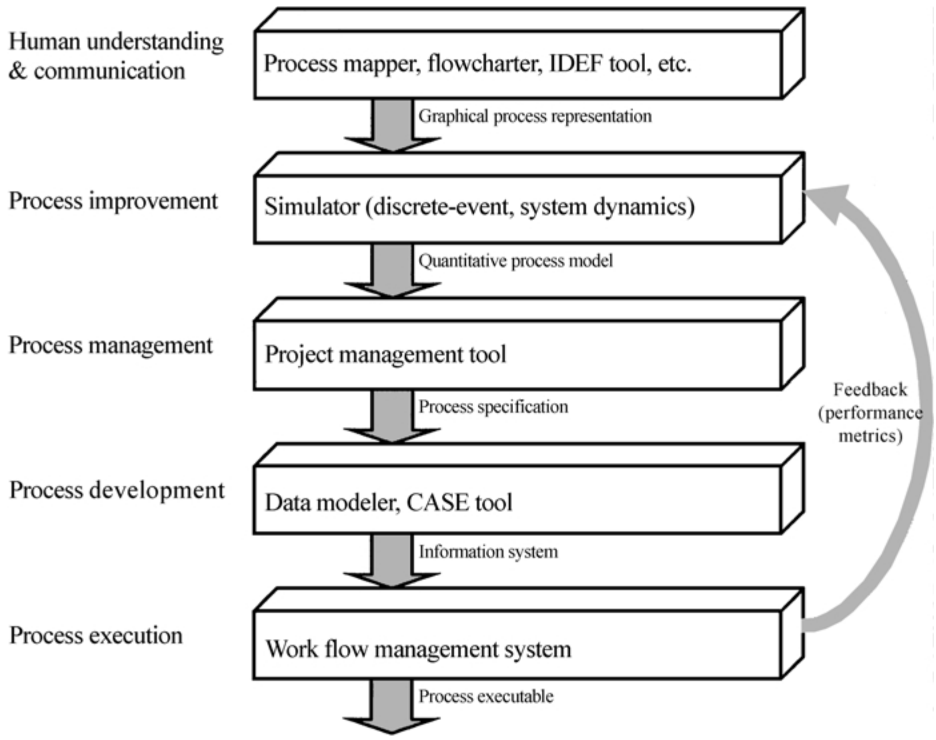

Figure 12. Organizational design workbench architecture.

a potential arrangement of software modeling tools (and, therefore, the techniques they support) into an organizational design workbench (Paul, Giaglis, and Hlupic, 1999).

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