

## **Simulation of Business Processes**

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*Computer-based simulation models of business processes offer a powerful mechanism for modelling organizational structures and arriving at informed recommendations for change and improvement. In this article, the authors review the current status of the business process modelling (BPM) and business process simulation (BPS) domains, discuss some pertinent issues for their successful deployment, and suggest a number of research directions for organizational modelling.*

**It is becoming increasingly common** to see computer-based simulation being used as a vehicle for modeling and analysis in a wide number of application areas. Manufacturing and production systems are one of the most common areas of simulation use in industry, but simulation models have been used to assist decision making in such diverse applications as military operations, economic studies, health care, computer systems design, construction applications, transportation facilities, and even sociological analyses (Halpin, 1999).

Among the recently developing areas of simulation use is the modeling of and experimentation with business processes. The proliferation and widespread attention being paid to business change management paradigms, such as business process reengineering (BPR), has created a "market" for organizational-modeling techniques (Warren, 1996), and simulation has naturally emerged as a prominent application. However, due to the embryonic stage of research in business process modeling (BPM), little theoretical and methodological support has been provided to explain the dynamics of business systems and the consequent modeling requirements (Curtis, Kellner, & Over, 1992; Meel & Sol, 1996).

In this article, we present an organized overview of ongoing work in the area of business process simulation (BPS). The aim is to define the boundaries of the field, position it within the wider area of BPM, provide a roadmap to guide navigation through an uncharted territory, and suggest avenues for further research and development. To set the scene for this effort, the next section will provide a brief overview of existing theoretical and practical approaches to BPM in general. In the third section, we will concentrate on discrete-event simulation of

business processes and review the existing status of the field in detail. Finally, the fourth section will draw on earlier discussions to highlight areas for future research needed to further expand the field.

### **BPM**

Process-based organizational analysis implies a "systemic" view of organizations, characterized by identifiable components with complex relationships between them. Organizations can be viewed as collections of entities, which interact between themselves and with their external environment to achieve specific objectives. This view is in line with Schmidt and Taylor's (1970) definition of a system and implies that the techniques of systems analysis and simulation have the potential to address the problem of organizational design and business change management.

It can be argued that process-based organizational analysis for the purpose of business change is primarily a design problem (Giaglis, Paul, & Hlupic, 1999). According to the information processing (Tushman & Nadler, 1978) and decision making (Huber & 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 information processing tasks (Moore & Whinston, 1986). These tasks are the smallest identifiable unit 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, its information policies, to name but a few. A change in one of these aspects may have unknown or unexpected consequences on the others. For example, the adoption of an innovative information technology (IT) application or a new strategic direction may not be favored by the workforce and have detrimental effects on staff morale/productivity. It is therefore important that alternative organizational aspects be taken into account and aligned when changes are designed or introduced. This need makes the organizational design problem complex, demanding, and laborious.

Many authors argue that one of the major problems that contributes to a high failure rate in many real-life business change projects is a lack of tools for evaluating the effects of designed solutions before implementation (Paolucci, Bonci, & Russi, 1997; Tumay, 1995). Kettinger, Teng, and Guha (1997) conducted an empirical review of existing methodologies, tools, and techniques for business process change and developed a reference framework to assist in the positioning of tools and techniques that help in reengineering strategy, people, management, structure, and technology dimensions of business processes. The authors pointed to the lack of a comprehensive, scientifically grounded design

methodology to structure, guide, and improve organizational design efforts. Mistakes brought by business change can only be recognized once the redesigned processes are implemented, when it is usually difficult and costly to correct wrong decisions. Although the evaluation of alternative solutions is usually difficult, it is essential to reduce some of the risks associated with business change projects. This argument is in line with Meel and Sol (1996), who advocate the development of computer-based models of business processes as a crucial mechanism to support the process of experimentation with alternative business structures.

In light of the above, BPM has emerged as an important research and application area within organizational design. Business process models can be used to serve a wide number of applications, for example, to drive a strategic organizational analysis, to derive requirements and specifications for information systems (IS) design, or to support (semi) automated execution of processes (work flows).

#### **BPM OBJECTIVES, GOALS, AND REQUIREMENTS**

The goals and objectives of a particular study affect the uses to which a model will be put and therefore influence the requirements posed on the process representation formalisms to be employed. As a result, the context and objectives of a particular study may render some BPM methods more suitable than others. The design or choice of a particular process-modeling method needs to be evaluated against a set of criteria that will depend on the intended uses of a model. Clearly, the more criteria that a particular BPM technique satisfies, the more suitable it will be for a range of projects. However, the diversity of requirements posed by different modeling goals raises severe obstacles for the design of a "holistic" technique that will accommodate all BPM requirements. Table 1 illustrates this difficulty by matching basic categories of uses of process models against typical BPM requirements associated with each category.

The work presented in this article focuses on BPM as part of organizational change management and will therefore address mainly the first two categories of modeling objectives and goals. However, BPM techniques and modeling environments that support other modeling goals and objectives will also be briefly reviewed.

#### **MULTIPERSPECTIVE BPM**

To satisfy the needs and requirements of all possible users, a process model should be able to integrate and represent many forms of information. Due to the multiplicity of requirements, such a task would be extremely arduous and would probably result in very complex models, thus reducing the ease of use for any single particular application. To deal with this problem of complexity, process-modeling languages have traditionally concentrated on addressing specific parts

**TABLE 1: Business Process Modelling Goals and Requirements**

| <i>Process Modelling Objectives and Goals</i>    | <i>BPM Requirements</i>  |
|--|--|
| Facilitate human understanding and communication | Comprehensibility<br>Communicability<br>Completeness   |
| Support process improvement                      | Component identification<br>Reusability<br>Measurability<br>Comparability<br>Change impact assessment<br>Decision support<br>Evolution support |
| Support process management                       | Reasoning support<br>Forecasting support<br>Monitoring and coordination support  |
| Automated guidance in performing process         | Integration with development environments<br>Documentability<br>Reusability  |
| Automated execution support                      | Cooperative work support<br>Automated performance measurement support<br>Process integrity check support                                       |

SOURCE: Curtis, Kellner, and Over (1992).

of organizational design and providing support for specific modeling goals and objectives. This approach has resulted in different languages and techniques to support process depiction and understanding (for example, flowcharting methods), process improvement (for example, simulation environments), process management (project management tools), process development (computer-aided software engineering [CASE] tools), and process execution (work-flow management systems).

As a result, most process languages can effectively represent only a limited subset of the possible perspectives from which organizations may be analyzed. Curtis et al. (1992) have identified four different perspectives of process models:

- Functional perspective: what process elements are being performed and what flows of information entities are relevant to these process elements.
- Behavioral perspective: when process elements are performed as well as aspects of how they are performed, mainly in terms of policies and constraints.
- Organizational perspective: where and by whom in the organization are process elements performed; where are the physical locations relevant to the process elements.

Informational perspective: which informational entities are produced or manipulated by a process.

Liles and Presley (1996) argue that unless all views are included, a comprehensive enterprise model cannot be developed. At the same time, they argue that, because every model is initiated for some specific purpose, a model that includes only one or a few views might be sufficient for its intended use. Curtis et al. (1992) maintain the same idea and suggest that, when combined, the modeling perspectives produce an integrated, consistent, and complete model of the process analyzed. The authors conclude that approaches that integrate multiple representational paradigms are necessary for effective process modeling.

#### TOWARD A BUSINESS PROCESS ONTOLOGY

As stated earlier, process-modeling work is still young, and the span of the research agenda is still being formulated. Warren (1996) further supports this argument and points to the lack of a standardized terminology to describe processes as a result of the immaturity of existing work in the area.

Even the very definition of what constitutes a business process is not agreed on in the literature. For example, Hammer and Champy (1993), in one of the works that has greatly contributed to the proliferation of BPR, define a process as "a set of activities that, taken together, produces a result of value to a customer" (p. 35). In an equally influential work, Davenport (1993) defined a process as "a structured, measured set of activities designed to produce a specified output for a particular customer or market. It implies a strong emphasis on how work is done within an organization." (p. 12). According to Davenport and Short (1990), in an earlier article that is accredited with making a pioneering contribution to the BPR phenomenon, a business process is "a set of logically related tasks performed to achieve a defined business outcome." On the other hand, Earl (1994), in an article challenging the arguments of the BPR advocates, defined a process as "a lateral or horizontal form, that encapsulates the interdependence of tasks, roles, people, departments and functions required to provide a customer with a product or service." (p. 13).

Table 2 classifies a limited subset of the proposed business process definitions to highlight the differences in terminology used to describe what essentially is the same underlying phenomenon. Definitions are classified according to three variables: (a) the fundamental unit of analysis of a process (i.e., the smallest identifiable and independent element within a process), (b) the focus of a business process (i.e., the primary objectives anticipated by the process execution), and (c) the mechanisms that the process uses to transform its inputs into meaningful outputs.

The issue of a nonstandardized terminology for business processes extends beyond the definition of business processes to include all the component elements that are used in the representation of processes. If the lack of a

**TABLE 2: Business Process Definitions**

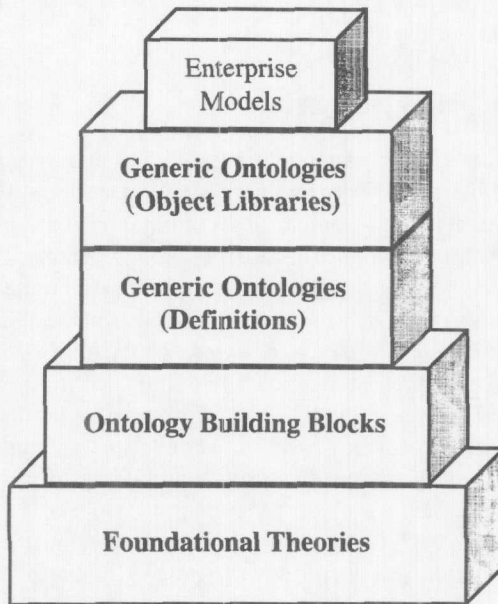
|                            | <i>Unit of Analysis</i> | <i>Focus</i>   | <i>Mechanisms</i>                                |
|----------------------------|-------------------------|--|--|
| Pall (1987)                | Work activity           | Produce a specified end result (work product)                  | People, materials, energy, equipment, procedures |
| Davenport and Short (1990) | Task                    | Achieve a defined business outcome                             | *  |
| Davenport (1993)           | Activity                | Produce a specified output for a particular customer or market | *  |
| Hammer and Champy (1993)   | Activity                | Produce value to the customer                                  | *  |
| Talwar (1993)              | Activity                | Achieve a prespecified type or range of outcomes               | *  |
| Earl (1994)                | *                       | Provide a product or service to a customer                     | Tasks, roles, people, departments, functions     |
| Omrani (1994)              | Activity                | Achieve a business objective                                   | *  |
| Ferrie (1995)              | Activity                | Satisfy an agreed customer need                                | *  |
| Ould (1995)                | *                       | Achieve a specific goal  | People, machines                                 |
| Alter (1996)               | Step or activity        | Create value for internal or external customers                | People, information, and other resources         |
| Saxena (1996)              | Work activity           | Produce specific outputs                                       | *  |

NOTE: \* Not specified in the definition.

standardized terminology is combined with the wide variety of applications that deal with the manipulation and representation of business processes as explained above, one can easily deduce a reason for the apparent difficulties in sharing understanding and information among different process-modeling applications. The lack of a generic representation of what is really the underlying concept of a "business process" may be one of the primary obstacles to such integration. To alleviate this problem, a number of research projects have studied the development of a generic "process ontology."

An ontology can be thought of as a sharable representation of knowledge that does the following:

- provides a shared terminology that various applications can jointly understand and use,
- defines the semantics of each term in a precise and unambiguous manner, and



**Figure 1: Process Ontology Structure**

SOURCE: Adopted from Gruninger, Schlenoff, Knutilla, and Ray (1997).

- implements the semantics in a set of axioms that allows one to automatically deduce the answer to many "commonsense" questions.

One of the projects that has addressed the issue of process ontologies is the Process Specification Language (PSL) project undertaken by the National Institute of Standards and Technology (NIST) in the United States with the collaboration of various research institutions and industry. Gruninger, Schlenoff, Knutilla, and Ray (1997) discuss preliminary results obtained within the first phase of PSL, which was concerned with determining the information requirements necessary to represent manufacturing processes. The authors argue that these requirements, although initially expected to serve as a basis for a process specification language, could also serve as a foundation for the development of a process ontology. The information requirements identified were categorized into four broad categories according to the degree of their pervasiveness in these manufacturing applications (core, outer core, extensions, and application-specific requirements). These requirements could serve as a strong foundation for the shared terminology and definitions for an ontology that describes the

process domain. The authors present a hierarchical structure of a generic ontology, as illustrated in Figure 1.

### PROCESS-MODELING TECHNIQUES

A wide variety of process-modeling techniques and approaches have been proposed in the literature. In line with the above discussion, almost all of these techniques are targeted to a limited subset of organizational-modeling projects and provide constructs suitable for satisfying the requirements associated with only particular modeling goals (see Table 1). In this section, we will provide a brief overview of some of these techniques, whereas in the next section, we will concentrate specifically on BPS and review the existing status of the field in detail. The overview presented herein is not intended to be complete, merely illustrative of the variety of modeling techniques being used.

Curtis et al. (1992) provide a review of various process-modeling paradigms, languages, and representations, focusing on modeling software processes. The approaches they discuss include programming models, functional models, plan-based models, petri-net models, and quantitative models based on system dynamics. The authors discuss the advantages and limitations of each approach in more detail and present examples of modeling languages that support each paradigm. However, their analysis is constrained by its definition (modeling of software processes) and is therefore limited to mostly formal techniques appropriate for modeling IS rather than business processes.

Compatangelo and Rumolo (1997) take a different approach and advocate the use of knowledge-based techniques, with emphasis on automated reasoning, to address enterprise modeling at the conceptual level. They present the concepts of the EDDL<sub>DP</sub> 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 for creating an enterprise knowledge base. Furthermore, they discuss the use of automatic deductive properties of the language as a means for eliminating conceptual errors that can be introduced in an enterprise domain model.

Knowledge-based representations of enterprise models may be valid mechanisms for representing knowledge and deductive argumentation about business systems. However, these approaches can represent only a partial view of an organizational system (single-perspective approach), and existing tools do not possess the necessary depth and breadth of reasoning to be of practical value in reasoning about complex, real-life enterprise models. Furthermore, knowledge-based techniques can accomplish only symbolic representation of processes. Therefore, they cannot accommodate requirements for process measurement and comparison that are integral to process improvement applications (see Table 1).

Nissen (1994a, 1996) follows a similar approach and employs the AI technology of qualitative simulation for developing a system (meta model) that the

author claims can overcome the limitations of extant computer-based (quantitative) simulation tools for business process analysis and redesign. Qualitative simulation is the fundamental technology of the commonsense reasoning branch of AI and exploits the use of knowledge to support "intelligent" reasoning about modeled phenomena.

Nissen (1994a) argues that many important aspects of business processes are inherently qualitative and not well understood; therefore, qualitative simulation can provide useful capabilities for the support of BPR. Qualitative simulation enables an effective abstraction of complex problems and the development of an ontology addressing key entities and relationships about a phenomenon based only on a few, dominant features. Thus, entities and relationships can be modeled and codified, even with only minimal understanding or information regarding them. The output of qualitative simulation is an "envisionment," that is, a description of all possible behaviors for the modeled process.

On the other hand, Nissen (1994a) recognizes that qualitative and quantitative simulations should complement each other if a comprehensive picture of the organizational processes is to be drawn. Qualitative simulation is a divergent activity, which can be useful in supporting "early-stage" problem solving. Quantitative simulation can be more effective in the later stages of decision making. 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." (p. 641). Moreover, the simulation generates a very large state space, even for simple processes, "which presents problems for the interpretation of more complex envisionments."

Moving away from knowledge-based representations, but remaining in the sphere of qualitative modeling techniques, Clemons (1995) advocates the use of scenario analysis to manage the strategic risks associated with BPR. Scenario analysis acknowledges the fact that the future is uncertain and future discontinuities may mean that companies cannot base their future strategies on the existing situation. Instead, a range of potential "futures" should be identified and appropriate actions should be planned so that the company knows what operations to implement or avoid within each possible future. However, scenario analysis is more of a conceptual approach to business analysis than a representational modeling technique. As such, it does not provide any formalism or language for specifying process models.

Liles and Presley (1996) have used the IDEF family of modeling methods to model business processes in the context of a five-view reference architecture for enterprise engineering. IDEF is a collection of process- and data-modeling methods designed to support modeling activities in the context of enterprise integration. Liles and Presley model different organizational views using different IDEF methods (for example, IDEF0 for *activity* view, IDEF3 for *business process* view, and IDEF5 for *business rule* view). Thus, a collection of process models is created to depict different organizational perspectives. When

combined, these models would provide a comprehensive picture of the organization containing all information necessary for the representation of a business process.

The approach exhibits an obvious advantage of modularity. Different, but interrelated, modeling techniques are employed to model different organizational perspectives. Modelers and decision makers may choose to employ only a limited number of techniques in the context of particular applications or develop a holistic, multiperspective model that captures all organizational views. In any case, individual models retain their independence and validity for their intended uses, and information may be exchanged between models in a consistent manner. On the other hand, the approach suffers from an inability to embrace the necessary amount of quantitative information as well as capture the dynamic nature of processes. Static IDEF models cannot satisfy the requirements for measurement and comparison between alternative process designs. Moreover, the approach provides limited support for the integration between process models and process execution environments.

Similar arguments hold true for petri net-based process modeling. Tsalgati-dou, Louridas, Fesakis, and Schizas (1997) follow this approach and propose the use of multilevel modified petri nets (MPN) as an appropriate representational formalism for the development of business process models. They define a structure for MPNs, discuss their appropriateness, and demonstrate their feasibility and usefulness in a real-life case study. They advocate that MPNs enable modeling of activities, resources, control, data flow, and the organizational structure (multiperspective modeling). The derived MPN models are evaluated (statically and dynamically) and simulated to facilitate experimentation and decision making in a business setting. The authors identify the following advantages of their approach: (a) model decomposition that allows for handling real-world complexity and facilitates better validation of and experimentation with models and (b) the ability to simulate and animate models, which facilitates validation, experimentation, communication, and decision making. They identify formality as the major disadvantage of their approach (developers and users need to be accustomed to the MPN formalism).

On the more detailed level of process execution, Jablonski (1995) discusses the interrelationship between BPM and work-flow management (WFM) and presents a methodology for integrating business process models and work flows. The methodology is based on the notion of meta models that are used to provide a generic mechanism for translating between business process models and work-flow specifications. The mapping of business processes to work flows would be a necessary step toward a holistic approach to business process management in organizations. Along the same lines, Karagiannis (1995) follows a holistic approach to the management of processes within an organization and introduces the concept of business process management systems (BPMS). A BPMS application is an extension of the idea of workflow management systems (WMS) and integrates process definition, modeling, administration, and

evaluation under a single environment. The author recognizes the role of modeling and analysis of business processes as critical to a BPMS and discusses how BPS models fit within a BPMS environment.

### DISCRETE-EVENT SIMULATION MODELING OF BUSINESS PROCESSES

For the rest of the article, we will concentrate on the process-modeling technique of discrete-event simulation. Simulation appears to offer significant capabilities for modeling processes, integrating models with other modeling techniques, and supporting business improvement efforts. Simulation modeling has many forms (we have already mentioned system dynamics and qualitative simulation). For the rest of the article, the term *simulation* will be used to refer to the most widely used form of the technique, namely, *discrete-event simulation modeling*.

The basic idea behind simulation is simple (Doran & Gilbert 1994): We wish to acquire knowledge and reach some informed decisions regarding a real-world system (the business). But the system is not easy to study directly. We therefore proceed indirectly by creating and studying another entity (the simulation model), which is sufficiently similar to the real-world system that we are confident that some of what we learn about the model will also be true of the system.

Computer-based discrete-event simulation relates to a symbolic representation of processes in ways that can be made persistent, replayed, dynamically analyzed, and reconfigured into alternative scenarios. Simulation models can dynamically model different samples of parameter values such as arrival rates or service intervals, which can assist in discovering process bottlenecks and suitable alternatives. These models can provide a graphical display of process models that can be interactively edited and animated to show process dynamics.

#### BPS

Being a research area that has only recently emerged, work on BPS is rather limited. MacArthur, Crosslin, and Warren (1994), in one of the first articles specifically concerned with discrete-event simulation of business processes, investigate the suitability of simulation BPR projects. The authors present modeling requirements as well as a methodology for using simulation in BPR. The major driver behind this approach is the recognition that a key component of practical implementation of BPR is measurement. There is a need for justification of the costs of changes as well as for objective comparisons of the merits of design alternatives. Simulation can effectively accommodate these requirements.

The authors discuss requirements for the successful deployment of simulation in BPR and identify a number of requirements similar in nature to the BPM requirements discussed earlier:

- A holistic approach to modeling is needed to incorporate multiple organizational perspectives.
- Models should allow for hierarchical decomposition of processes and design modularity in the development of simulation models.
- There is a need for integrating component simulation results obtained from alternative process design considerations.

At the moment, only a few simulation tools are available that fully support hierarchical decomposition and design modularity. The authors point to the lack of off-the-shelf, turnkey modeling solutions to achieve appropriate performance measurement in the assessment of alternative designs for BPR. On the other hand, the use of general-purpose simulation languages requires a great deal of skill and effort.

Data collection and information management are identified as the most arduous tasks in BPR simulation because of the formidable wealth of information that must be gathered across the organization (and sometimes beyond it) to capture the structure and dynamics of the business.

Despite these difficulties (that should be addressed in future research), simulation can produce a quick return on investment through improved decision quality and, through the use of a simulation tool, can be more economical than computer programming, extensive spreadsheet analysis, opinion modeling, or trial-and-error experimentation. Furthermore, simulation can have intangible benefits of educating participants in the decision process by encouraging (a) a deeper understanding of the modeled process and (b) articulation of the goals and objectives of the analysis efforts. In the longer term, the use of simulation encourages a culture of measurement in the organization that can provide the basis for continuous process improvement (CPI).

Giaglis and Paul (1996) have also reviewed the suitability of simulation for BPR and have identified a number of modeling requirements specific to simulation-assisted BPR modeling. These requirements fall into two main categories (technical and political requirements). When combined, these requirements can capture the dual nature of sociotechnical business systems. The requirements are as follows:

### **Technical Requirements**

- Processes need to be formally modeled and documented.
- Models should be easily updateable to follow changes in actual processes.
- Models should be reusable and reconfigurable.
- Modeling should take into account the stochastic nature of business processes, especially the way in which they are triggered by external factors.
- There is a need to quantitatively evaluate the value of proposed alternatives.
- The evaluation is highly dependent on the objectives of the particular study.

## Political Requirements

- Modeling and decision making should take into account “political” factors, such as legislation restrictions, user acceptance of changes, and so forth.
- Modeling should be flexible to allow for different interpretation of analysis results according to specified objectives.
- There is a need to communicate alternatives to the senior management as well as to end users.
- A holistic approach is necessary to identify implicit interdependencies among processes. On the other hand, parts of the organization should be able to use partial models to assess their own performance.
- Modeling tools should be easy to use to allow users of the processes to be involved in the modeling process.

## EXAMPLES OF BPS APPLICATION

Simulation models have been used in various practical BPM applications. An example is MOSES (Pruett & Vasudev, 1990), which simulates organization functions, categorized as marketing, production, inventory, and accounting. The system models these functions, simulates the basic relationships with each other, and shows the immediate effect of a multitude of decisions made with respect to those functions. MOSES provides the opportunity for the manager in charge of one function (for example, inventory) to see the impact his policies might have on the organization’s other major functions (for example, production).

Nissen (1994b) follows the same principle and presents a small-scale simulation of business processes for selecting among alternative IT investments. This approach emphasizes the modeling of, and experimentation with, alternative organizational processes for the purposes of redesign and reengineering. Prospective ISs are then designed to suit the chosen process schema.

Lee and Elcan (1996) present a specific, real-life application of simulation for process reengineering in the telecommunications industry (service processes in U.S. West Communications). Simulation models are developed to help managers gain insight, identify opportunities for change, predict the quantitative impact of reengineering efforts, and establish tangible management goals. In a similar application, Bruno, Briccarello, and Gavazzi (1995) present the development of an object-oriented simulation model that was applied to a real-life telecommunications project in Telecom, Italy. The authors propose the transformation of data-flow diagrams into object-oriented simulation models, in which data-flow diagram activities (“bubbles”) are modeled as objects that exchange messages with each other. Hunt, Hansen, Madigan, and Phelps (1997) also outline the potential uses of simulation modeling in BPR. The authors present (albeit very briefly) three examples of successfully applying simulation in BPR projects in vehicle maintenance facilities evaluation, proof of concept

phase in the product development process, and reengineering of strategic operations in the offshore oil industry.

Giaglis, Paul, and Doukidis (1999) present a practical application of BPS in an interorganizational process design setting, in which more than one organization initiated a joint effort to change their relationships and communication schemes within the pharmaceuticals industry. The authors discuss the unique characteristics and requirements associated with interorganizational simulation modeling and argue for the need to develop special-purpose simulation environments that will address BPS requirements.

Remaining on the subject of multiorganizational modeling, Yarden (1997) discusses a simple simulation meta-model structure for modeling electronic commerce payment transactions over the Internet. Despite the innovative nature of the application, the article does not give many details on the simulation techniques and structures used, and there is no discussion of issues raised.

Simulation models have been used (Giaglis, 1996; Mylonopoulos, Doukidis, & Giaglis, 1995a, 1995b) to assess the expected benefits of interorganizational changes made possible by the use of IT. The authors have developed a model that simulates trading between a number of companies along a value chain, and they used it as a vehicle for assessing efficiency gains introduced by the use of electronic data interchange applications in three different industry sectors (namely, textile/clothing, pharmaceuticals, and supermarkets). They argue that similar simulation systems can be developed for evaluating the expected impacts of organizational changes in general by the introduction of reusable and reconfigurable simulation modules that can be incorporated in simulation libraries.

Ninios, Vlahos, and Bunn (1995) report on a similar setting and present the development of an object-oriented modeling environment to facilitate the use of industry simulation models. The authors report on the development of this environment and comment on the suitability of object orientation and discrete-event system specification (DEVS) for simulating industries. Furthermore, they compare their approach to traditional system dynamics modeling and highlight the differences between discrete-event and continuous simulation approaches. The authors conclude that object-oriented discrete-event simulations can efficiently model the operations of industry structures in a more natural way than system dynamics. Furthermore, the DEVS formalism allows for handling discrete events that change the state of the model. To substantiate their claims, the authors present a case study of modeling the U.K. electricity industry using both system dynamics and the OO/DEVS approach. They conclude that although system dynamics can support strategic thinking in a specific market, the OO/DEVS modeling approach enhances the potential for reusability, can be used by various individuals at different levels of detail, and can model various relationships amongst entities (e.g., generalizations, aggregations, and associations).

In the social sciences area, the emergence of the new field of computational and mathematical organizational theory (CMOT) (Carley, 1995) signals the

growing interest of social scientists in the potential of simulation to assist organizational theory building. For example, Hyatt, Contractor, and Jones (1996) discuss *Blanche*, an object-oriented simulation environment designed and built to specifically support simulation of organizational networks. The authors describe how the tool can support the process of theory construction and present an empirical example to test the theoretical predictions of a network-based social influence model for the adoption of new communication technologies. The authors also point to the need for model-building and simulation tools that are easily accessible and understood by organizational researchers who are not necessarily proficient in simulation.

The above examples show that simulation modeling has already been identified as a suitable tool for BPM and has been used successfully in individual applications. Despite the existence of these cases, a comprehensive methodology that uses simulation modeling to evaluate alternative redesign scenarios and capture business process performance has not yet been developed (MacArthur et al., 1994).

#### INTEGRATED BUSINESS PROCESS AND ITS SIMULATION

The role of IT as an agent for organizational change has been heavily emphasized in the literature. ISs have usually become the major vehicles on which business change relies. Indeed, the idea of aligning the design of organizational processes with the associated IT infrastructure has been one of the major driving forces for the development of change management paradigms like BPR (Davenport, 1993; Hammer & Champy, 1993).

Over the past decades, organizations have become increasingly dependent on IT. However, despite enormous capital investments in this kind of technology, organizations have not always been able to enjoy commensurate productivity improvements (Roach, 1991). This has become known as the IT productivity paradox (Brynjolfsson, 1993). Many reasons have been offered to explain why IT has not always been able to deliver the benefits it promises in theory. Some researchers argue that IT has been used mainly to automate existing processes rather than as an opportunity for change. In other words, business processes are seldom structured with the possibilities of new technologies in mind, and therefore, optimal design strategies cannot be envisaged.

Because ISs in an organizational context are used to support some kind of business activity, it has been proposed that the design of ISs should be aligned with the design of the corresponding organizational processes. Figure 2 illustrates the concept of concurrent simulation of business processes and ISs.

Blyth (1995) presents the Organizational Requirements Definition for Information Technology (ORDIT) approach for modeling business processes to specify requirements for the implementation of ISs. The approach is based on sociotechnical design and recognizes that business systems contain a social element alongside a technical one. The aim of ORDIT is to enable system designers

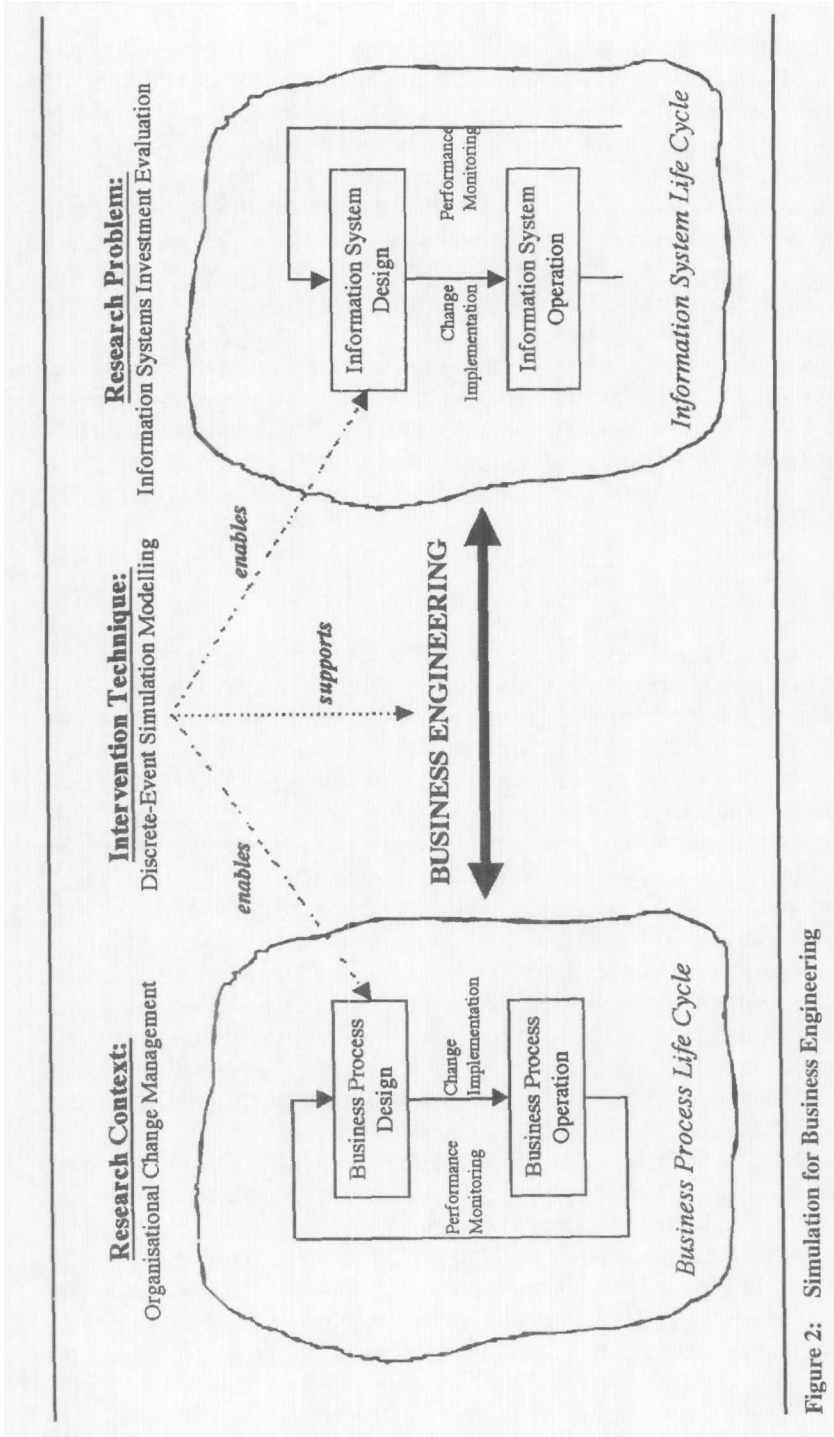


Figure 2: Simulation for Business Engineering

to reason about organizational goals, policies and structures, and the work roles of intended end users in a way that will facilitate the identification and expression of organizational requirements for IT. Therefore, the approach focuses on modeling responsibilities and relationships rather than business processes.

Teufel and Teufel (1995) also discuss the issue of aligning business strategy and IT in organizations and present a generic modeling framework (called strategic alignment model [SAM]) as a strategic management instrument for describing the dependencies between business and IT. The SAM acknowledges four aspects that must be aligned to facilitate business success: (a) business strategy, (b) IT strategy, (c) organizational infrastructure and processes, and (d) IT infrastructure and processes. The authors acknowledge the integral role of BPM within business and IT alignment.

In strictly simulation terms, Warren (1996) takes the issue of BPS one step further and introduces the term *simulation of information systems* (SIS) to refer to the integrated modeling of business processes and ISs in organizational improvement efforts. This is a youthful field, and the author points to the problem of a nonstandardized terminology because of this (much in line with the earlier discussion on process ontologies). Warren identifies three major reasons for the emergence of the field:

1. The phenomenon of BPR, which created a "market" for organizational-modeling techniques,
2. The fact that simulation is already mature in modeling the computer-based portion of an IS (i.e., networks, algorithms, and architectures) but not the people and the procedures, and
3. The commonness of IT as an element in organizational change.

Meel and Sol (1996) provide a thorough introduction to the use of simulation for the integrated modeling and analysis of business processes and ISs (the term *business engineering* [BE] is used to refer to this). The authors argue that, despite numerous success stories, BE has so far achieved little theoretical and methodological support. They use discrete-event simulation (referring to it as dynamic modeling) as the intervention technique and produce a design theory (based on sociotechnical design), a design approach, and a design tool (a prototype simulation environment for experimentation). They conclude that BE is a new and promising interdisciplinary research domain that lacks methodological support that would ensure a minimum level of rigor; facilitate structuring, planning, and monitoring; and assist in codifying experience and ideas.

Painter, Fernados, Padmanaban, and Mayer (1996) take the matter even further and present a methodology for integrating simulation models of business processes, IT applications, and computer networks. The authors argue that BPR and information infrastructure (II) modernization, although mutually supportive and complementary in nature, are rarely conducted together. Making changes to the logic and structure of a business process may introduce new

requirements on the supporting infrastructure. Likewise, making changes to the network or computer applications domain can have a dramatic impact on business performance and/or may provide additional opportunities for or constraints on process redesign. Hence, there is a need to merge these two domains (process simulation and network simulation).

The authors use three model types: business process models, application models, and network models. They advocate an approach in which integrated business models of these three types would effectively assist change impact assessment at any stage (process, application, or infrastructure). The IDEF3 method is used for model depiction at all levels. Extensive use of the decomposition mechanism is employed to accommodate the different levels (viewpoints) for assessing change impact. A rather complex methodology is presented (called BPR-II) with highly technical and detailed steps for model specification, development, implementation, experimentation, and analysis. The authors also present a prototype implementation of their approach comprising KBSIs PROSIM (an IDEF3 modeling tool), WITNESS (for process simulations), and COMNET III (for network simulations). Moreover, they have developed a tool of their own that guides the user through the whole exercise and the steps of the methodology.

#### INTEGRATING SIMULATION IN ORGANIZATIONAL DESIGN

Gladwin and Tumay (1994) have studied BPS and highlighted some of the unique characteristics of "service business processes" (as opposed to manufacturing processes that have traditionally been in the forefront of simulation applications):

- Entities and resources are often people. This may result in complex queuing behavior, which in turn may require complex programming logic in a simulation model.
- Arrivals are usually random and cyclic.
- Processing times and requirements are highly variable.
- Business processes do not normally exhibit steady-state behavior, making their analysis more problematic than other systems.

The aforementioned characteristics have certain simulation implications:

- Because business systems do not usually reach a steady state, it is extremely important to define "correct" ways of experimentation and output analysis. For example, simulation length and number of replications become very important variables when analyzing a model. Models should be studied in transient behavior, and the values of performance measures should be evaluated for each *time window* and not for the entire simulation run. For example, resource utilization analysis for the whole length of run is meaningless, because there may be different arrival patterns and/or shift arrangements in each time window.
- It is also important to define the appropriate statistics to use for performance measurement. Because of the variability and the "burst" mode in queues, one should

probably evaluate the maximum number of customers in a queue rather than the average when designing a service facility.

Furthermore, the authors identify some of the obstacles that have prevented simulation from becoming a mainstream BPM tool:

- There are few connection or interface capabilities between simulation software and other BPM tools, such as flowcharting and CASE tools.
- A certain amount of expertise is required to build models with most simulation languages.

To provide a solution for the first problem, Harrel and Field (1996) discuss how process-mapping (flowcharting) tools can be integrated with simulation software. According to the authors,

one of the reasons for the lag in application of simulation technology is that it has not been effectively integrated with more general purpose process mapping tools. Consequently, even though much of the process definition used in a simulation model is contained in a process map, a decision maker must start over from scratch in building a simulation model (p. 1292).

Advances in software technology to support product interoperability has opened the door for integrating technologies such as process mapping and simulation that previously functioned only as stand-alone applications.

The concept of integrating process mapping and simulation is not new (see also Bruno et al., 1995; Gladwin & Tumay, 1994). Several attempts have been made, albeit with not very successful results. This is due largely to incompatibilities in both purpose and paradigm. Because insufficient data are provided in a process map for running a simulation, additional information has to be manually added on the simulation side.

Harrel and Field (1996) distinguish between two categories of process mapping environments: *structured* (those that restrict mapping into specific representational formalisms) and *unstructured* (those that do not enforce the use of particular formalisms). The major problem (from a simulation point of view) for integrating structured process mapping and simulation environments is that the representational approaches supported by the former may provide less or different information for analysis. To use such a tool directly with simulation, some modifications to the methodology may be necessary. Harrel and Field present a case of integration between Design/IDEF (an IDEF-based process mapping tool) and ProModel (a simulation environment). Additions included entity attributes, input buffers, ways to model different entities, and addition of data fields to capture dynamic information. This required modification to the code of the process-mapping tool. On the other hand, unstructured process-mapping tools are more suitable for integration with simulation because they can be more easily adapted to a simulation paradigm. This was the case with integrating ABC

Flowcharter (a flowcharting tool that does not rely on any particular representational formalism) and ProModel. A modeling paradigm was developed, and an object linking and embedding (OLE) application was written that communicated with ABC Flowcharter to display simulation-related property sheets that are displayed as the process map is developed.

On a more conceptual level of integration, Srinivasan and Jayaraman (1997) present an approach for integrating the Enterprise Modeling Framework (EMF) with simulation modeling of organizations. EMF consists of a methodology that distinguishes between three major facets of an enterprise: function, information, and dynamics. The authors argue that the EMF activity (function) and entity (information) models contain all the information needed for developing discrete-event simulation models of an enterprise. A model generator has been developed (called EMF-SIMAN) that automatically generates SIMAN simulation code from EMF models. The authors present an example of applying their approach and conclude that it offers two important benefits: reducing the workload on the developers of business simulation models and ensuring consistency and integrity between EMF and simulation models.

#### **BPS SOFTWARE**

Bradley, Browne, Jackson, and Vagdev (1995) provide an overview of four BPR software tools that include modeling and simulation capabilities. The tools are DECmodel, ProcessWise, Business Design Facility (BDF), and Enterprise Modeling System (EMS) or FirstSTEP. An example business process is described and modeled using the four packages to allow for comparisons of their capabilities and characteristics. The authors also propose a methodology for the evaluation of different BPR software tools.

Mertins and Jochem (1997) discuss the Method for Object-Oriented Business Process Optimization (MO<sup>2</sup>GO) developed at the Fraunhofer Institute for Production Systems and Design Technology. The method employs object-orientation principles to describe object information and functions as views of enterprise models. The core enterprise model consists of two complementary views: the business process model and the information model. The former emphasizes the tasks and business processes that are executed on the objects, whereas the latter emphasizes the structures and features that describe objects. The method uses only three primary object classes that can be used to define any enterprise model: product, resource, and order. The method is primarily targeted at manufacturing enterprises, although its concepts can form the basis for similar work in service organizations. The authors also present the development of a commercially available software tool based on the principles of their method. The tool can be used for the development of business process models and allows users to view different perspectives of the same enterprise model. It also supports consistency checking on the model, as well as graphical and textual documentation of models (including standardized ISO 9000 documents).

**TABLE 3: Positioning of Business Process Modelling (BPM) Techniques**

| <i>BPM Objectives and Goals</i>                  | <i>BPM Techniques</i>  |
|--|--|
| Facilitate human understanding and communication | Flowcharting<br>Scenario Analysis<br>IDEF0, IDEF3, IDEF5<br>Qualitative simulation<br>Knowledge-based techniques<br>System dynamics<br>Discrete-event simulation |
| Support process improvement                      | System dynamics<br>Petri nets<br>Discrete-event simulation   |
| Support process management                       | Petri nets<br>Plan-based models  |
| Automated guidance in performing process         | IDEF1x<br>Programming models<br>Computer-aided software engineering<br>(CASE) tools  |
| Automated execution support                      | Workflow management systems<br>Functional models   |

### CONCLUSIONS: THE ROAD AHEAD

Table 3 illustrates how the various process-modeling techniques reviewed in this article can be positioned within the overall framework of BPM goals and objectives. The table is intended to highlight techniques typically suitable for different goals rather than provide prescriptive advice on choice of techniques for individual projects. It is worth reiterating that no single technique or approach can capture the whole spectrum of requirements posed by different people and applications. The choice of a modeling technique for a particular project should be based on matching the virtues and limitations of various techniques with the objectives of the project.

We have argued that the analysis and design of organizational processes in the context of process improvement can be greatly assisted by the use of discrete-event BPS. Simulation can provide a valuable mechanism for addressing the problem of quantitative and qualitative evaluation of prospective designs of business processes. Furthermore, it can facilitate experimentation with and study of multiple perspectives of organizations, thus contributing toward a holistic view of enterprises and, ideally, toward increasing the quality of change decisions.

However, the road to successfully applying simulation in business process design is not trouble free. Organizations and organizational processes are sufficiently complex systems that their analysis presents a number of difficulties and particular issues that should be addressed. Problems related to data collection, experimental design, and multiperspective levels of analysis are only some of the issues that have been identified in this article.

BPS is still at an embryonic level of study, despite the widespread use of simulation as a modeling technique in various other application areas. There is ample space for further research that will identify further issues and propose remedies for problems relating to the application of simulation in organizational design. Future research can be directed to a number of areas that can be classified under the two broad categories discussed below.

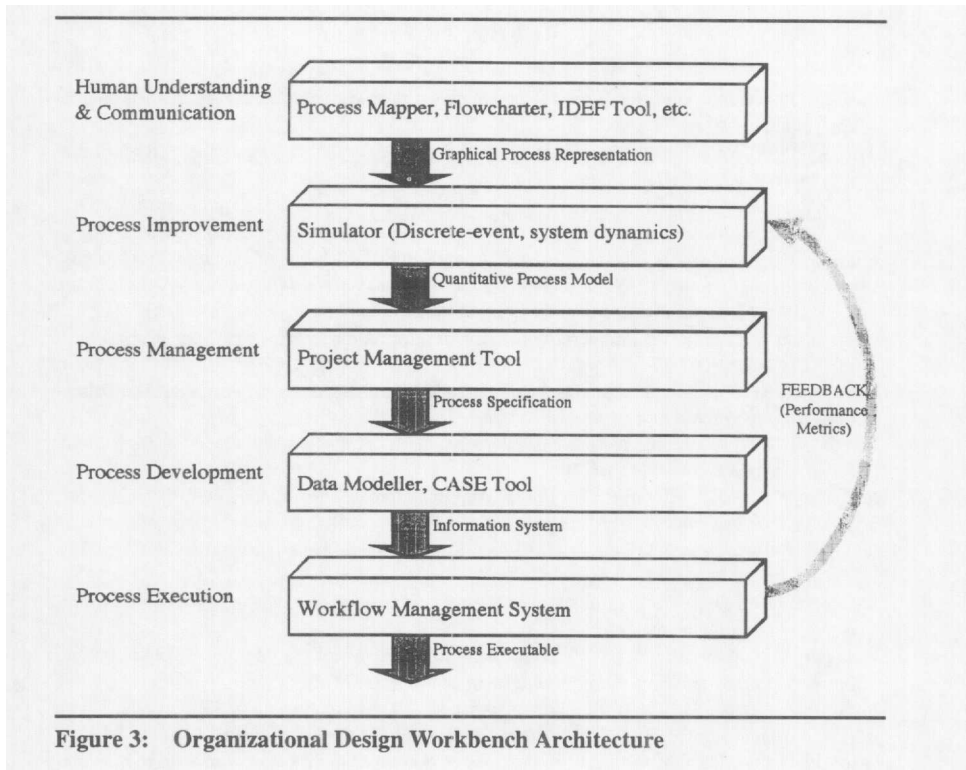
#### **SIMULATION-RELATED RESEARCH**

This area of research is primarily concerned with developing simulation theories, methods, and software tools that will directly address the problem of process-based organizational design. One aim should be to develop a comprehensive theory of BPS that will generalize the distinct problems and modeling requirements of this application area. This theory could drive the development of special-purpose simulation software packages that will assist organizations in employing simulation in organizational studies. Particular research questions to be asked concern the ability of simulation models to allow for multiperspective organizational modeling, the ability to share information with other modeling tools and paradigms, and mechanisms to support group work in model development (Lee, Dean, & Vogel, 1997).

Other related areas of research are concerned with the application of simulation for ISs modeling or with the special requirements of modeling human behavior as part of the business environment. These areas relate primarily to the need identified above for aligning multiple perspectives of analysis in BPS studies (polymorphism).

#### **BUSINESS-PROCESS-ANALYSIS RELATED RESEARCH**

Perhaps the single most important advance that could contribute to a better understanding of BPM-related issues and promote the use of modeling within organizations would be the development of a specific process ontology, as discussed earlier. A thorough analysis of the distinct characteristics of business processes is required to comprehend fully the fundamental nature of processes. This area of research could provide valuable input to the design of BPM approaches. Even more important, it could form the foundation on which to base an integration and exchange of information between different modeling tools.



**Figure 3: Organizational Design Workbench Architecture**

The convergence of these research directions could lead to the development of integrated computer-supported environments to support the process of organizational design in a holistic fashion. We envisage the development of "organizational design workbenches." Figure 3 illustrates the generic architecture of such tools. Workbenches will combine a number of computer-supported tools to assist the various phases of organizational design. Such tools may include the following:

- Process mapping tools, such as flowcharting environments, to support human understanding and communication of models;
- Business process simulators to capture the quantitative and dynamic nature of processes and drive organizational improvement efforts at the levels of business processes modeling, IS modeling, and data modeling;
- Project management tools to support management of organizational development efforts;
- Data modeling tools and CASE environments to provide the basis of application development environments; and
- WMS to support automated execution of processes and automated performance measurement to provide feedback to organizational improvement efforts.

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