A Taxonomy of Business Process Modeling and Information Systems Modeling Techniques

Article *in* International Journal of Flexible Manufacturing Systems · April 2001

DOI: 10.1023/A:1011139719773 · Source: CiteSeer

George Giaglis
University of Nicosia

A TAXONOMY OF BUSINESS PROCESS MODELLING AND INFORMATION SYSTEMS MODELLING TECHNIQUES

George M. Giaglis
Department of Information Systems and Computing
Brunel University, Uxbridge UB8 3PH, Middlesex, UK
Tel: +44 1895 203363, Fax: +44 1895 251686, E-mail: George.Giaglis@brunel.ac.uk

Abstract

Modelling has always been at the core of both organisational 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 towards 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 Modelling (BPM) and Information Systems Modelling (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/ISM techniques, can assist decision-makers in comparatively evaluating and selecting suitable modelling techniques depending on the characteristics and requirements of individual projects.

1. Introduction: IS-Enabled Business Process Change

According to Davenport and Short (1990), although business process design and Information Technology are natural partners, their relationships have never been fully exploited in practice. The authors define this relationship as a recursive pattern. One the one hand, it is naturally expected that the choice of a particular way of conducting business in an organisation 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 organisations and hence influence the design of specific business process layouts.

Such recursive relationships imply that organisations should align the design of Information Systems (IS) with the design of the corresponding business processes if maximum benefits from their synergy are to be achieved (Meel et al 1994, Grover et al 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 have rarely been the case in practice. Business analysts and IS professionals have traditionally had distinct roles within organisations, each equipped with their own tools, techniques, skills, and even terminology (Earl 1994). There seems to be very limited support for predicting the consequences that changes in one organisational facet (business processes or Information Systems) will have on the other (MacArthur et al 1994).

This distinction is reinforced when the issue of *modelling* business processes and Information Systems is addressed. Most extant 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 process 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 modellers in choosing appropriate modelling techniques depending on the requirements of a particular problem. In section 2 we introduce the concepts of business process modelling and IS modelling in the context of organisational 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 and by proposing avenues for further research into the subject.

2. Organisational Change and IS Development as Design Problems

It can be argued that process-based thinking in the context of organisational change, is primarily 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 organisational 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 organisation: its processes, its people, its strategy, its environment, its culture, and its Information Systems, to name but a few. A change in one of these aspects may have unknown or unexpected consequences on the others.

Based on these theoretical foundations, we can deduce that techniques that allow for modelling business process components, experimenting with alternative configurations and process layouts, and comparing between diverse proposals for change, would be highly suitable for organisational 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 modelling. The importance of the modelling process for organisational change has been heavily emphasised in the literature (for example in Curtis et al 1992, Hansen 1994, Tsalgatidou and Junginger 1995, Blyth 1995). The term *Business Process Modelling* (BPM) has been used to incorporate all activities relating to the transformation of knowledge about business systems into models that describe the processes performed by organisations (Scholz-Reiter and Stickel 1996). The term *Information Systems Modelling (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 ‘*modelling techniques*’ fits within a hierarchical decomposition of modelling elements (the same line of thought has been followed by Kettinger et al 1997). According to this decomposition, modelling in general can be thought of as being supported by one or more methodologies. Methodologies are taken to refer to modelling paradigms (for example, data-focused, object-oriented, and so on), and are outside the scope of this paper. Modelling 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 analysing modelled systems. Specific techniques, as well as their underlying methodologies, can be supported (and in most cases are supported) by software modelling *tools*, such as CASE tools, Workflow Management Systems, process modelling software, and others. Like methodologies, the study of modelling tools falls outside the scope of this paper.

=====================

Insert Figure 1 here

=====================

Due to the complex and dynamic nature of organisations, it has been argued that carefully developed models are necessary for understanding their behaviour in order to be able 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 modelling 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 extant BPM and ISM techniques have been developed without a reference to such integration, a fundamental research question would involve studying existing approaches to modelling with a view of developing a novel taxonomy for their positioning, comparison, and evaluation. To this end, the following section discusses the development of an evaluation framework for studying BPM/ISM techniques. Drawing on this framework, a number of selected modelling techniques are reviewed and classified, thus providing the foundation upon which a taxonomy is proposed in the concluding section 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, investment evaluation, and so on. The goals and objectives of a particular study will necessarily impact 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 modelling techniques in each case (Curtis et al 1992).

=====================

Insert Table 1 here

=====================

To be able 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 comprise the process, who is performing these activities, when and where are these activities performed, how and why are they executed, and what data elements they manipulate. Modelling techniques differ in the extent to which their constructs highlight the information that answers these questions. To provide this information, a modelling technique should be capable of representing one or more of the following ‘process perspectives’ (Curtis et al 1992):

a) *Functional perspective*: Represents *what* process elements (activities) are being performed.
b) *Behavioural 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.
c) *Organisational perspective*: Represents *where* and *by whom* activities are performed, the physical communication mechanisms used for transfer of entities, and the physical media and locations used for storing entities.
d) *Informational perspective*: Represents the informational entities (*data*) produced or manipulated by a process and their relationships.

The combination of modelling goals and objectives with the perspectives of modelling can provide the basis of an evaluation framework for studying, analysing, and comparing extant and new BPM and ISM techniques. This framework is illustrated in Figure 2. The framework suggests three evaluation variables to classify and evaluate modelling techniques: *Breadth* (the modelling goals typically addressed by the technique), *Depth* (the modelling perspectives that are 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 modelling goals and 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 *behavioural* aspects of modelling. It is worth repeating that the emphasis is on modelling goals and perspectives *typically* associated with projects, rather than on laying out strict guidelines for the selection of modelling techniques.

=====================

Insert Figure 2 here

=====================

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

a) The *horizontal flow* of projects within a modelling perspective is consistent with extant theoretical approaches to systems analysis and design. For example, in the *informational* perspective (top row in the framework) one can easily identify a sequence of steps that resembles closely the Systems Development Life Cycle paradigm (Avison 1997): Documentation, Analysis and Design, Development, and Operation/Maintenance.

b) The *vertical integration* of projects within a given modelling goal points towards the need for combining business and IS modelling in the context of projects that spread across the boundaries of individual modelling perspectives. For example, in a modelling project aiming at improving understanding of an existing business system (first column in the framework), one might need to employ all modelling perspectives to grasp the wider system picture: Functional modelling to document the detail of individual tasks, Behavioural modelling to identify how individual tasks interact with each other to produce the whole process, Organisational modelling to examine user roles within the process, and Informational modelling 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 are in reality much more blurred than this theoretical classification might imply. For example, ‘workflow execution’ and ‘automated task execution’ may in most cases be inseparable activities in real-life situations. However, the framework classification allows for isolating the different goals and perspectives of an overall project’s steps. Hence, it can provide a solid foundation upon which BPM and ISM techniques can be more easily positioned and integrated. In other words, although the above framework possesses enough explanatory and analytical power on its own, its real value can be harnessed if it is expanded to show how extant 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 will be reviewed. The overview presented in the following sections is not intended to be exhaustive, but rather aims at assisting towards the development of a generic taxonomy of modelling techniques to which other techniques can be easily added at a later stage. The techniques reviewed in this paper are summarised in Table 2.

=====================

Insert Table 2 here

=====================

4. Business Process Modelling Techniques

4.1. Flowcharting

Flowcharting is amongst the first graphical modelling techniques, dating back to the 1960s (Schriber 1969). The advantages of flowcharts centre 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 input, output and stored, and to highlight key processing and decision points (Jones 1986).

Flowcharting was initially intended to provide computer program logic representation, but, due to its generic nature, it has been used in many other application areas as well, including business process modelling. Despite its advantages (namely familiarity and ease of use), flowcharting is no longer a dominant modelling technique because it can provide only basic facilities in representing processes. Therefore, flowcharts are nowadays typically 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 modelling techniques was developed as a set of notational formalisms for representing and modelling 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 Modelling*), IDEF1x (*Data Modelling*), and IDEF3 (*Process Description Capture*). In this section we will describe IDEF0 and IDEF3 since they relate primarily to business process modelling. IDEF1x will be considered later along with other techniques related to Information Systems modelling.

The IDEF0 method is designed to model the decisions, actions, and activities of an organisation or other system and, as such, it is targeted mostly towards the functional modelling 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, called the ICOM (Input-Control-Output-Mechanism, see Figure 3). IDEF0 supports process modelling by progressively decomposing higher-level ICOMs into more detailed models that depict the hierarchical decomposition of activities.

======================

Insert Figure 3 here

======================

Despite its advantages, IDEF0 presents 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 between activities. As such, IDEF0 models cannot represent the *behavioural* or *informational* modelling perspectives.

To overcome some of the limitations of IDEF0 models, IDEF3 has been developed. IDEF3 describes processes as ordered sequences of events or activities. As such, IDEF3 is a scenario-driven process flow modelling 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 for expressing the domain experts' knowledge about *how* a particular system or organisation works (as opposed to IDEF0, which is mainly concerned with *what* activities the organisation performs).

IDEF3 makes use of 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.

======================

Insert Figure 4 Figure 5 here

======================

4.3. Petri Nets

Strictly speaking, Petri Nets are not a business process modelling technique, since they have originated from and have been traditionally used for systems modelling. However, amongst the systems modelling techniques, Petri Nets is perhaps the one that has received the most attention as a potential candidate for business process modelling as well (Reising et al 1992). Basic Petri Nets are mathematical/graphical representations of systems, aiming at assisting analysis of the structure and dynamic behaviour of modelled 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.

=====================

Insert Figure 6 here

=====================

It has been recognised that basic Petri Nets are not succinct and manageable enough to be useful in modelling 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 'colour', 'time', and 'hierarchy') have been proposed. These extensions are collectively referred to as 'high-level Petri Nets' (van der Aalst and van Hee 1996) and include, for example, Generalised Stochastic Petri Nets (GSPN) (Marsan et al 1995), Coloured Petri Nets (CPN) (Jensen 1996), and others.

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), 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. Simulation can have many forms (for example, discrete-event simulation, continuous simulation, system dynamics, Monte-Carlo simulation, qualitative simulation, etc.). In relation to BPM and ISM, *discrete-event simulation* and *system dynamics* seem to have received most attention, and will be reviewed here.

Discrete-event Simulation

Shannon (1975) has 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 behaviour 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 modelling will usually originate 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 on grounds of cost, time or some human restriction.

The very definition of simulation reveals its theoretical potential as a tool for BPM. Indeed, simulation modelling of an organisation'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 organisational performance impact.

System Dynamics

System Dynamics (SD) was originally 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. Diagrammatic representations of 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 allow mental models about system structure and strategies to be made explicit. The word 'structure' is taken to imply the information feedback structure of the system, and hence system dynamics models are often 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 behaviour. 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 by the links in a system dynamics model, it is possible to simulate the model and gain quantitative information on model dynamics.

=====================

Insert Figure 7 here

=====================

Despite its advantages, the application of system dynamics as a BPM/ISM technique may present a number of limitations. Firstly, it places a great degree of emphasis on feedback and control processes, which may be of limited importance in many practical situations of business/IS modelling. Secondly, modelling is essentially deterministic and hence unable to cope with the stochastic elements that are so frequent in real-world business processes. Finally, according to Wolstenholme et al (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 have started to appear as building blocks in business process modelling applications (Hedberg 1996). These techniques are mainly targeted to addressing the issue of linking business processes to organisational rules and business objectives in a formal manner (Yu et al 1996). Amongst the AI techniques that have been proposed, *Knowledge Based Systems (KBS)* and *qualitative simulation* seem to have attracted the most attention by researchers and will be reviewed here.

Knowledge-based Systems (KBS)

Ba et al (1997) present a knowledge-based enterprise modelling framework to support organisational decision-making in the context of strategic change. This framework bases its reasoning about a particular organisation upon a ‘library of knowledge’ representing significant organisational 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 modelling at the conceptual level. They claim that their approach could form the foundation of a framework for the development of computer-aided modelling 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 for creating an enterprise knowledge base.

Qualitative Simulation

Nissen (1994, 1996) follows a similar approach and employs the AI technology of *qualitative simulation* for developing models of organisational processes for the purpose of informing the process of analysis and redesign. Qualitative simulation is a technology of the common-sense reasoning branch of AI and exploits the use of knowledge to support ‘intelligent’ reasoning about modelled phenomena. Qualitative simulation enables entities and relationships to be modelled and codified even with only minimal understanding or information regarding them. The output of qualitative simulation is an ‘envisionment’, or, in other words, a description of all possible behaviours for the modelled process.

Despite its potential advantages, qualitative simulation also presents a number of severe limitations. Its inherently qualitative nature makes it more suitable for modelling general classes of phenomena, as opposed to specific instances. Nissen (1996) recognises that qualitative and quantitative simulations should complement each other if a comprehensive picture of the organisational processes is to be drawn. The author also recognises 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 endeavour in practice.

4.6. Role Activity Diagramming

Role Activity Diagrams (RADs) are diagrammatic notations that concentrate on modelling 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.

=====================

Insert Figure 8 here

=====================

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

5. Information Systems Modelling Techniques

5.1. Data Flow Diagramming

Data Flow Diagramming (DFD) is a technique for graphically depicting the flow of data amongst 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 modelling purposes and have become the 'standard' notation for traditional systems analysis and design (Yourdon 1989). However, they present a number of limitations. Firstly, they focus exclusively (or at least primarily) on data and they do not provide modelling constructs on which to base representation of workflows, people, events, and other business process elements. Secondly, they do not provide any information on decisions and event sequences (temporal or precedence relationships). Finally, DFDs have no beginning or end points, or execution paths. In other words, they are static representations of a system and the system's functions that involve data manipulation, and therefore they do not lend themselves easily to analysis or decision-making. To facilitate such analysis, data flow diagramming is sometimes 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 modelling technique. ER diagrams are network models that describe the stored data layout of a system (Yourdon 1989). ER diagrams focus on modelling the data present in a system and their relationships in a manner that is entirely *independent* of the processing that may take place on that data. Such separation of data and operations may be desirable in cases where the data and their relationships are complex enough to necessitate such an approach. For the system analyst, ER diagrams have another advantage: they highlight relationships between data stores in the DFD that would otherwise be visible only in the (textual) process specification.

For the purposes of business process modelling, ER diagrams share similar limitations with DFDs. More specifically, they focus too much on data and their relationships and hence they do not provide constructs for modelling other process elements. Even more importantly, they do not even provide any information about the functions depicted that create or use these data (as DFDs do). Finally, they are entirely static representations, not providing any 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 being used by standard ST diagrams is very simple, consisting only of rectangular boxes that represent states and arrows that represent changes of state (transitions).

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

5.4. IDEF Techniques (IDEF1x)

IDEF1x was designed as a technique for modelling and analysis of data structures for the establishment of Information Systems requirements (Mayer et al 1995). IDEF1x differs from traditional data modelling techniques in that it does not restrict modelling in the data elements that are being manipulated by computers, but extends its application to modelling manual-handled data elements as well. IDEF1x utilises simple graphical conventions (see Figure 9) to express sets of rules and relationships between entity classes in a fashion similar to Entity-Relationship diagrams.

=====================

Insert Figure 9 here

=====================

The power of IDEF1x 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 can complement each other effectively and, when combined, can provide a holistic perspective of a modelled 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 Modelling Language (UML)

Introduced in 1997 and supported by major industry-leading companies, the Unified Modelling Language (UML) has rapidly been accepted throughout the object-technology community as the standard graphical language for specifying, constructing, visualising, and documenting software-intensive systems (Booch et al 1999). UML utilises a wide array of diagrammatic notations, including:

a) *Use case* diagrams, which capture system functionality as seen by the users (see Figure 10).
b) *Class* diagrams, which capture the vocabulary of the system.
c) *Behaviour* diagrams (for example *statechart*, *activity* and *interaction* diagrams).
d) *Implementation* diagrams (for example, *component* and *deployment* diagrams).

=====================

Insert Figure 10 here

=====================

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 typically aligned with a particular analysis and design method. This wide variety can be a source of complexity and problems of non-compatibility between 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 modelling. According to its developers, UML '*will reduce the degree of confusion within the industry surrounding modelling 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 mostly targeted to systems modelling situations, although an 'extension for business modelling' has also been developed. Furthermore, some may argue that the language is heavily based on the object-oriented paradigm and hence may not be applicable in situations where the modellers want to follow a more 'traditional' modelling approach.

6. Conclusions: A Taxonomy of Modelling Techniques

The above review of techniques used in modelling business processes and Information Systems can lead to some interesting observations. Firstly, the various techniques differ significantly in the extent to which they provide the ability to model different business and system perspectives. Some techniques focus primarily on functions, some others on roles, and yet some others on data. Ideally, what might be needed is the development of a single, 'holistic' technique that could effectively represent all modelling perspectives in a rigorous and concise fashion, and hence be applicable in all modelling situations.

However, the multiplicity of possible modelling goals and objectives possibly renders the development of such a modelling technique impossible, or at least impractical. Such a technique, if existed, would probably generate complex models, thus 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 above chooses to concentrate on a subset of modelling perspectives and therefore provides support for specific modelling goals and objectives.

To assist in technique evaluation and selection depending on the characteristics of individual projects, in this section we present an attempt to combine the characteristics of the modelling techniques reviewed earlier, with the evaluation framework of Figure 2, in order to develop a taxonomy of BPM/ISM techniques. As a starting point, Table 3 illustrates the degrees to which the techniques reviewed above provide support for representing the process modelling perspectives of the evaluation framework (*Depth* of modelling).

=====================

Insert Table 3 here

=====================

Based on the above 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 modelling depth and breadth are by definition 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 modelling exercise. For example, in a typical 'business process documentation' project (or in any similar endeavour aiming at improving human understanding and focusing on the behavioural aspects of modelling), the following modelling techniques seem more appropriate to use (with reference to Figure 11): simulation, system dynamics, role activity diagramming, and (to a lesser degree, indicated by the parentheses) IDEF3. Of course, nothing prevents modellers from using a different technique. The taxonomy merely suggests modelling techniques that are better fitted (due to the constructs they provide) than others to the characteristics of the problem under investigation.

=====================

Insert Figure 11 here

=====================

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 towards:

a) Enhancing the evaluation framework by adding new project types to the '*Fit*' dimension.
b) Reviewing other modelling techniques and adding them to the taxonomy.
c) 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 organisational modelling projects).
d) Further enhancing the framework and the taxonomy by means of addressing the issue of *integration* between project steps and modelling techniques, an issue of paramount

importance in the face of the arguments discussed in the earlier sections of this paper. Figure 12 illustrates a potential arrangement of software modelling tools (and therefore of the techniques they support) into an ‘organisational design workbench’ (Paul et al 1999).

=====================

Insert Figure 12 here

=====================

References

van der Aalst, W.M.P and van Hee, K.M. (1996) Business Process Redesign: A Petri-net-based Approach, *Computers in Industry, 29*, pp. 15-26.

Avison, D.E. (1997) *The Information Systems Development Life Cycle: A First Course in Information Systems*, McGraw-Hill, London.

Ba, S., Lang, K.R. and Whinston, A.B. (1997) Enterprise Decision Support Using Intranet Technology*, Decision Support Systems, 20*, pp. 99-134.

Bhaskar, R., Lee, H.S., Levas, A., Petrakian, R., Tsai, F. and Tulskie, B. (1994) Analysing and Re-engineering Business Processes Using Simulation. In Tew, J.D., Manivannan, S., Sadowski, D.A. and Seila, A.F. (Eds.), *Proceedings of the 1994 Winter Simulation Conference*, Lake Buena Vista, Florida, December, pp. 1206-1213.

Blyth, A. (1995) Modelling the Business Process to Derive Organisational Requirements for Information Technology, *SIGOIS Bulletin, 16, 1*, pp. 25-33.

Booch, G., Rumbaugh, J. and Jacobson, I. (1999) *Unified Modelling Language User Guide*, Addison-Wesley, Reading, MA.

Compatangelo, E. and Rumolo, G. (1997) Automated Reasoning about Enterprise Concepts, *SIGGROUP Bulletin, 18, 2*, pp. 56-58.

Curtis, W., Kellner, M.I. and Over, J. (1992) Process Modelling, *Communications of the ACM, 35, 9*, pp. 75-90.

Davenport, T.H. and Short, J.E. (1990) The New Industrial Engineering: Information Technology and Business Process Redesign, *Sloan Management Review, 31, 4* (Summer), pp. 11-27.

Davenport, T.H. and Stoddard, D.B. (1994) Reengineering: Business Change of Mythic Proportions?, *MIS Quarterly, 18, 2*, pp. 121-127.

Doran, J. and Gilbert, N. (1994) Simulating Societies: An Introduction. In Gilbert, N. & Doran, J. (Eds.), *Simulating Societies: The Computer Simulation of Social Phenomena*, UCL Press, London.

Earl, M.J. (1994) The New and the Old of Business Process Redesign, *Journal of Strategic Information Systems, 3, 1*, pp. 5-22.

Forrester, J.W. (1961) *Industrial Dynamics*, MIT Press, Cambridge, MA.

Gladwin, B. and Tumay, K. (1994) Modelling Business Processes with Simulation Tools. In Tew, J.D., Manivannan, S., Sadowski, D.A. and Seila, A.F. (Eds.), *Proceedings of the 1994 Winter Simulation Conference*, Lake Buena Vista, Florida, December, pp. 114-121.

Grover, V., Fielder, K.D. and Teng, J.T.C. (1994) Exploring the Success of Information Technology Enabled Business Process Reengineering, *IEEE Transactions on Engineering Management, 41, 3*, pp. 276-284.

Hansen, G.A. (1994) *Automating Business Process Reengineering: Breaking the TQM Barrier*, Prentice-Hall, Englewood Cliffs, New Jersey.

Hedberg, S.R. (1996) AI Tools for Business Process Modelling, *IEEE Expert*, pp. 13-15.

HPS (1997) *iThink Analyst Technical Documentation*, High Performance Systems Inc., Hanover.

Huber, G.P. & McDaniel, R.R. (1986) The Decision Making Paradigm of Organisation Design, *Management Science, 32, 5*, pp. 576-589.

Huckvale, T. and Ould, M. (1995) Process Modelling – Who, What and How: Role Activity Diagramming. In Grover, V. and Kettinger, W.J. (Eds.), *Business Process Change: Concepts, Methods and Technologies*, Idea Group Publishing, Harrisburg, PA, pp. 330-349.

Jensen, K. (1996) *Coloured Petri Nets: Basic Concepts, Analysis Methods and Practical Use*, Springer Verlag, Berlin.

Jones, J.L. (1986) *Structured Programming Logic: A Flowcharting Approach*, Prentice Hall, New Jersey.

Kettinger, W.J., Teng, J.T.C. and Guha, S. (1997) Business Process Change: A Study of Methodologies, Techniques, and Tools, *MIS Quarterly, 21, 1*, pp. 55-80.

Leymann, F. and Altenhuber, W. (1994) Managing Business Processes as an Information Resource, *IBM Systems Journal, 33, 2*, pp. 326-348.

Liles, D.H. and Presley, A.R. (1996) Enterprise Modelling Within an Enterprise Engineering Framework. In Charnes, J.M., Morrice, D.J., Brunner, D.T. and Swain, J.J. (Eds.), *Proceedings of the 1996 Winter Simulation Conference*, San Diego, California, December, pp. 993-999.

MacArthur, P.J., Crosslin, R.L, Warren, J.R. (1994) A Strategy for Evaluating Alternative Information System Designs for Business Process Reengineering, *International Journal of Information Management, 14, 4*, pp. 237-251.

Marsan, M.A., Balbo, G., Conte, G., Donatelli, S. and Franceschinis, G. (1995) *Modelling with Generalised Stochastic Petri Nets*, Wiley, Chichester.

Mayer, R.J., Benjamin, P.C., Caraway, B.E. and Painter, M.K. (1995) A Framework and a Suite of Methods for Business Process Reengineering. In Grover, V. and Kettinger, W.J. (Eds.), *Business Process Change: Concepts, Methods and Technologies*, Idea Group Publishing, Harrisburg, PA, pp. 245-290.

Meel, J.W. van, Bots, P.W.G. and Sol, H.G. (1994) Towards a Research Framework for Business Engineering, *IFIP Transactions A: Computer Science and Technology, 54*, pp. 581-592.

Moore, T.C. & Whinston, A.B. (1986) A Model of Decision Making with Sequential Information Acquisition, *Decision Support Systems, 2, 4*, pp. 289-308.

Nissen, M.E. (1994) Qualitative Simulation of Organisational Microprocesses. In Nunamaker, J.F. and Sprague, R.H. (Eds.), *Proceedings of the 27th Annual Hawaii International Conference on System Sciences, vol. IV*, IEEE Press, Los Alamitos, CA, pp. 635-644.

Nissen, M.E. (1996) Designing Qualitative Simulation Systems for Business, *Simulation and Gaming, 27, 4*, pp. 462-483.

Orman, L.V. (1995) A Model Management Approach to Business Process Reengineering. In the *Proceedings of the American Conference on Information Systems*, August, Pittsburgh, PA.

Paul, R.J. and Doukidis, G.I. (1987) Artificial Intelligence Aids in Discrete-Event Digital Simulation Modelling, *IEE Proceedings, 134, D, 4*, pp. 278-286.

Paul, R.J., Giaglis, G.M. and Hlupic, V. (1999) Simulation of Business Processes, *American Behavioral Scientist, 42, 10*, pp. 1551-1576.

Peterson, J.L. (1981) *Petri Net Theory and the Modelling of Systems*, Prentice-Hall, Englewood Cliffs, NJ.

Reising, W., Muchnick, S.S. and Schnupp, P. (Eds.) (1992) *A Primer in Petri Net Design*, Springer Verlag, Berlin.

Scholz-Reiter, B. and Stickel, E. (Eds.) (1996) *Business Process Modelling*. Springer-Verlag, Berlin.

Schriber, T.J. (1969) *Fundamentals of Flowcharting*, Wiley, New York.

Shannon, R.E. (1975) *Systems Simulation: the art and the science*, Prentice-Hall New Jersey.

Sol, H.G. and Crosslin, R.L. (Eds.) (1992) *Dynamic Modelling of Information Systems, II*, North-Holland, Amsterdam.

Streng, R.J. (1994) BPR Needs BIR and BTR: The PIT-framework for Business Re-engineering. In the *Proceedings of the 2nd SISNET Conference*, Barcelona, Spain, September.

Teufel, S. and Teufel, B. (1995) Bridging Information Technology and Business: Some Modelling Aspects, *SIGOIS Bulletin, 16, 1*, pp. 13-17.

Tsalgatidou, A. and Junginger, S. (1995) Modelling in the Re-engineering Process, *SIGOIS Bulletin, 16, 1*, pp. 17-24.

Tushman, M.L. & Nadler, D.A. (1978) Information Processing as an Integrating Concept in Organisation Design, *Academy of Management Review, 3, 3*, pp. 613-624.

UML (1997) *UML Proposal to the Object Management Group*, Available online at: http://www.rational.com/uml.

Warren, J.R., Stott, J.W. and Norcio, A.F. (1992) Stochastic Simulation of Information Systems Designs from Data Flow Diagrams, *Journal of Systems and Software, 18, 2*, pp. 191-199.

Wolstenholme, E.F., Henderson, S. and Gavine, A. (1993) *The Evaluation of Management Information Systems: A Dynamic and Holistic Approach*, John Wiley & Sons, Chichester.

Yourdon, E. (1989) *Modern Structured Analysis*, Prentice Hall International, Englewood Cliffs, NJ.

Yu, E.S.K., Mylopoulos, J. and Lesperance, Y. (1996) AI Models for Business Process Reengineering, *IEEE Expert*, pp. 16-23.

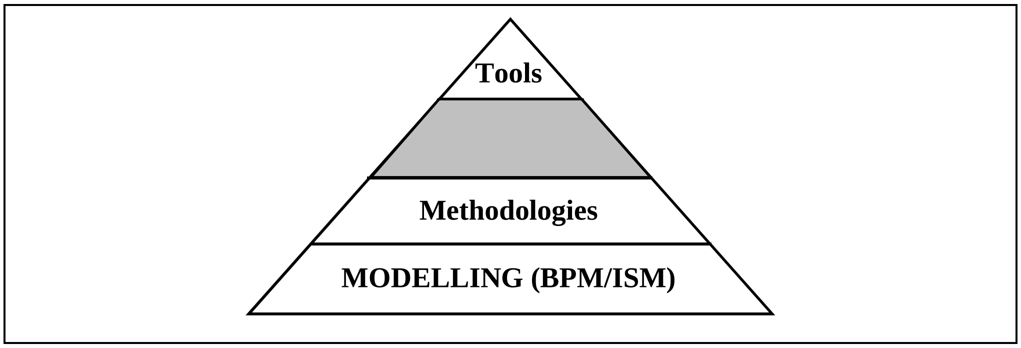

Figure 1. Modelling Methodologies, Techniques, and Tools

Modelling Goals and Objectives	Requirements for Modelling Techniques
Support Human Understanding and Communicating	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 Co-ordination
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

Table 1. BPM/ISM Goals and Requirements (adapted from Curtis et al 1992)

FIT

DEPTH / BREADTH	Understanding & Communication	Process Improvement	Process Management	Process Development	Process Execution
Informational Perspective (Data)	SYSTEMS DOCUMENTATION	SYSTEMS ANALYSIS & DESIGN	SYSTEMS PROJECT MANAGEMENT	SOFTWARE REENGINEERING / SYSTEMS DEVELOPMENT	SYSTEMS OPERATION / MAINTENANCE
Organisational Perspective (Where, Who)	ORGANISATIONAL STRUCTURE REPRESENTATION	ROLE REDESIGN	HUMAN RESOURCE MANAGEMENT	WORKPLACE DESIGN	-----
Behavioural Perspective (When, How)	BUSINESS PROCESS DOCUMENTATION	BUSINESS PROCESS REENGINEERING	BPR PROJECT MANAGEMENT	WORKFLOW DESIGN	WORKFLOW EXECUTION
Functional Perspective (What)	TASK DOCUMENTATION	TASK REDESIGN	CPI/TQM PROJECT MANAGEMENT	QUALITY ASSURANCE / CONTROL	AUTOMATED TASK EXECUTION

Figure 2. An Evaluation Framework for BPM/ISM Techniques

Business Process Modelling Techniques	*IS Modelling 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	

Table 2. BPM/ISM Techniques Reviewed

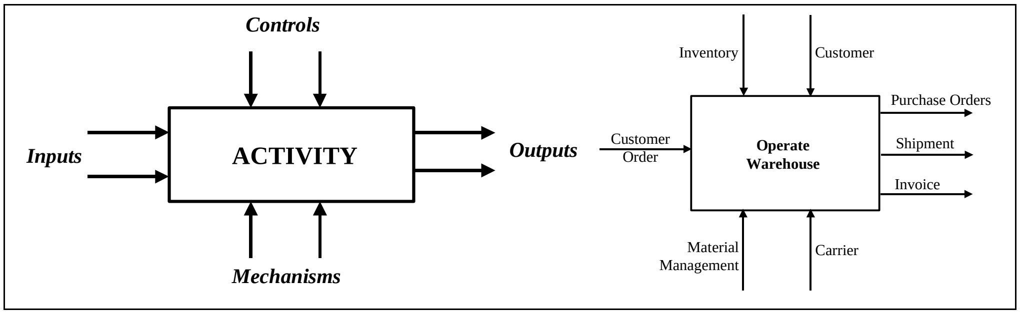

Figure 3. IDEF0 Notation (ICOM) and Example Diagram

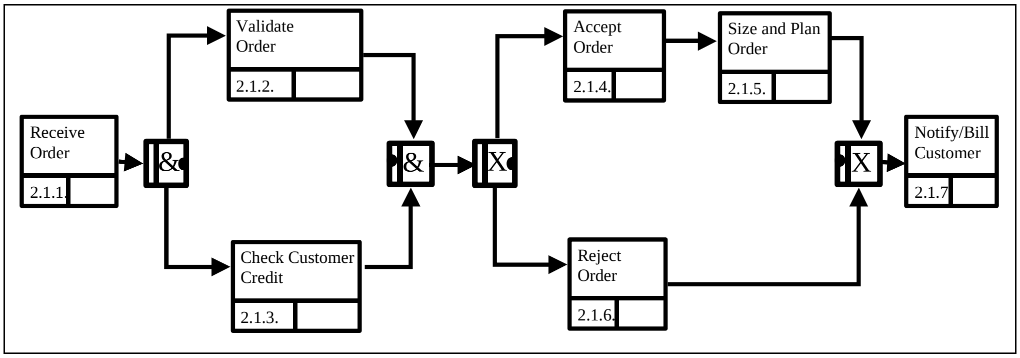

Figure 4. IDEF3 Example (Process Flow Diagram)

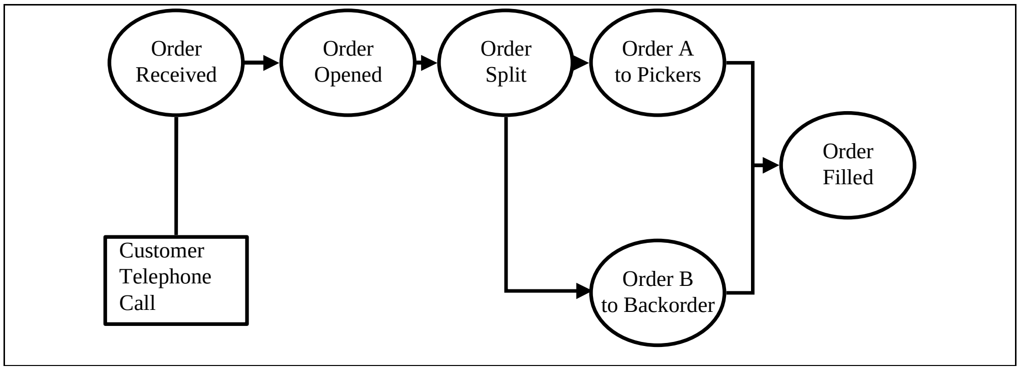

Figure 5. IDEF3 Example (Object State Transition Diagram)

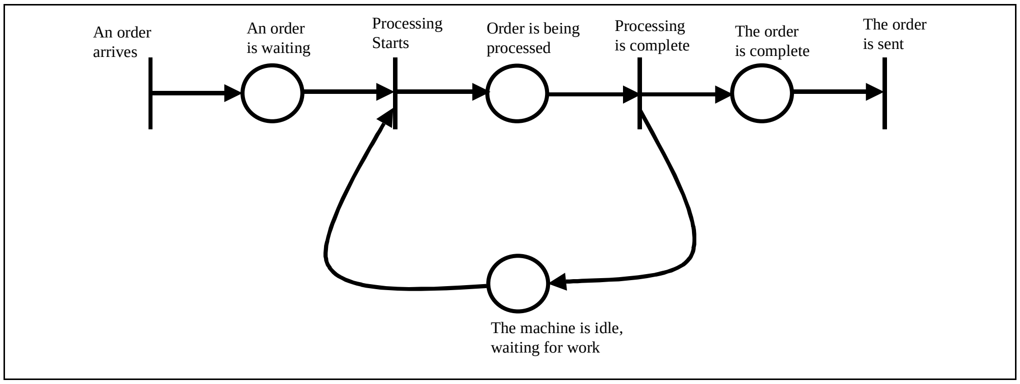

Figure 6. Petri Net Example (Peterson 1981)

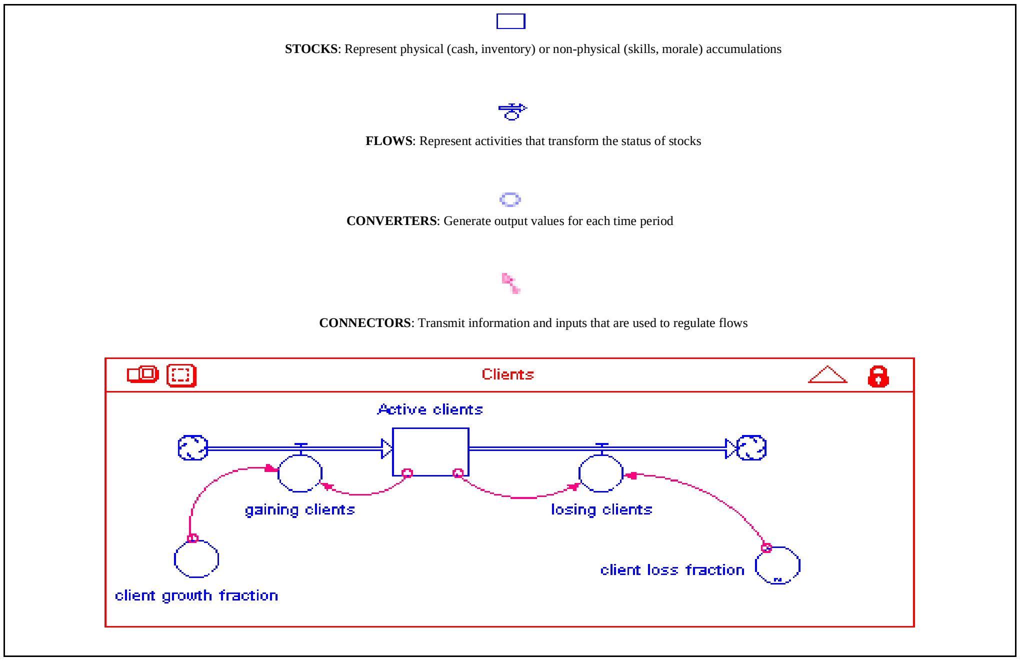

Figure 7. System Dynamics Notation and Example (Pipe Diagram)

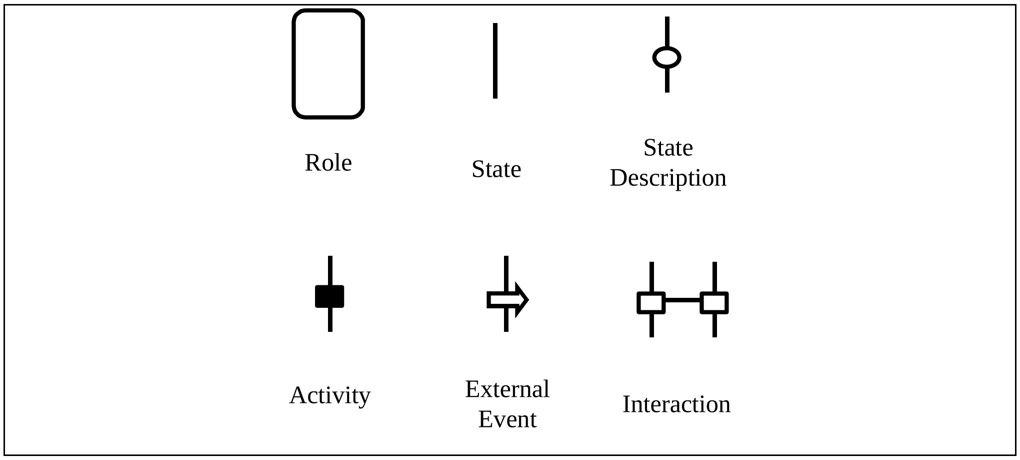

Figure 8. RAD Notation

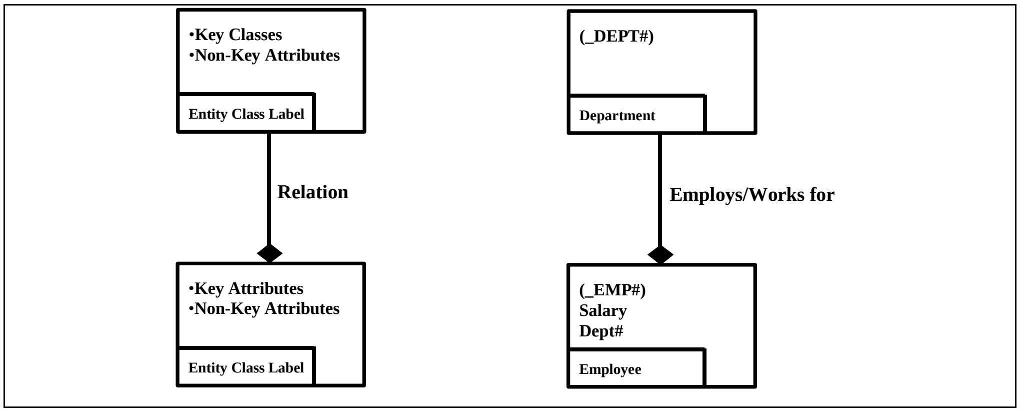

Figure 9. IDEF1x Notation and Example

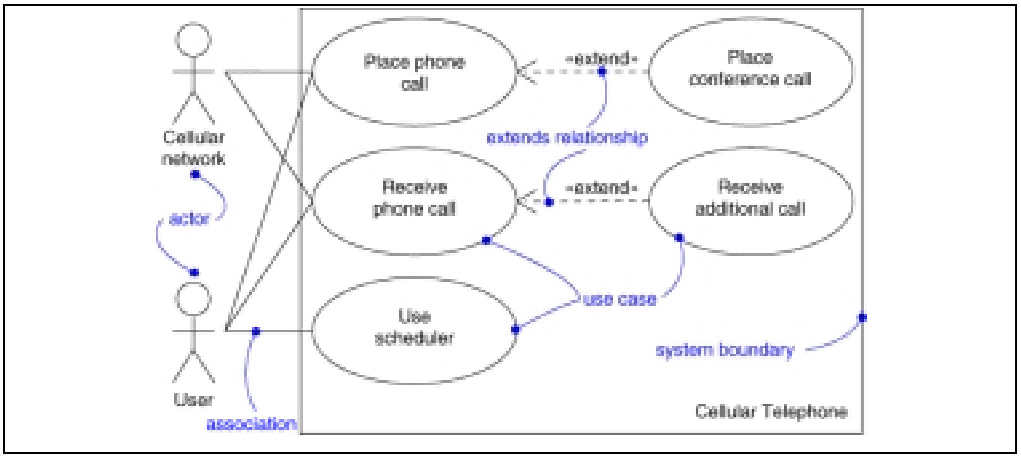

Figure 10. Use Case Diagram (Example)

BPM/ISM Techniques	Modelling Perspectives (Depth)			
	Functional	Behavioural	Organisational	Informational
Flowcharting	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 Diagramming	No	Limited	Yes	No
Data Flow Diagramming	Yes	No	Limited	Yes
Entity Relationship Diagramming	No	No	No	Yes
State-Transition Diagramming	No	Limited	No	Limited
IDEF1x	No	No	No	Yes
UML`	Yes	Limited	Limited	Yes

Table 3. Depth of BPM/ISM Techniques (Modelling Perspectives)

DEPTH / BREADTH	Understanding & Communicating	Process Improvement	Process Management	Process Development	Process Execution
Informational (Data)	(Flowcharting) (IDEF3) DFD Entity Relationship State-Transition IDEF1x UML	(Simulation) DFD Entity Relationship State-Transition IDEF1x UML	Simulation DFD Entity Relationship State-Transition IDEF1x UML	Simulation DFD Entity Relationship State-Transition IDEF1x UML	Simulation DFD Entity Relationship State-Transition IDEF1x UML
Organisational (Where, Who)	(IDEF0) (Simulation) System Dynamics RAD	(IDEF0) Simulation System Dynamics RAD	(IDEF0) Simulation System Dynamics RAD	Simulation (UML) (RAD)	-----
Behavioural (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)	Flowcharting IDEF0 (IDEF3) Simulation (System Dynamics) DFD (UML)	Flowcharting IDEF0 (IDEF3) Simulation System Dynamics DFD (UML)	Flowcharting IDEF0 (IDEF3) Simulation	IDEF0 Petri Nets Simulation DFD UML	Petri Nets Simulation DFD UML

Figure 11. A Taxonomy of BPM/ISM Techniques

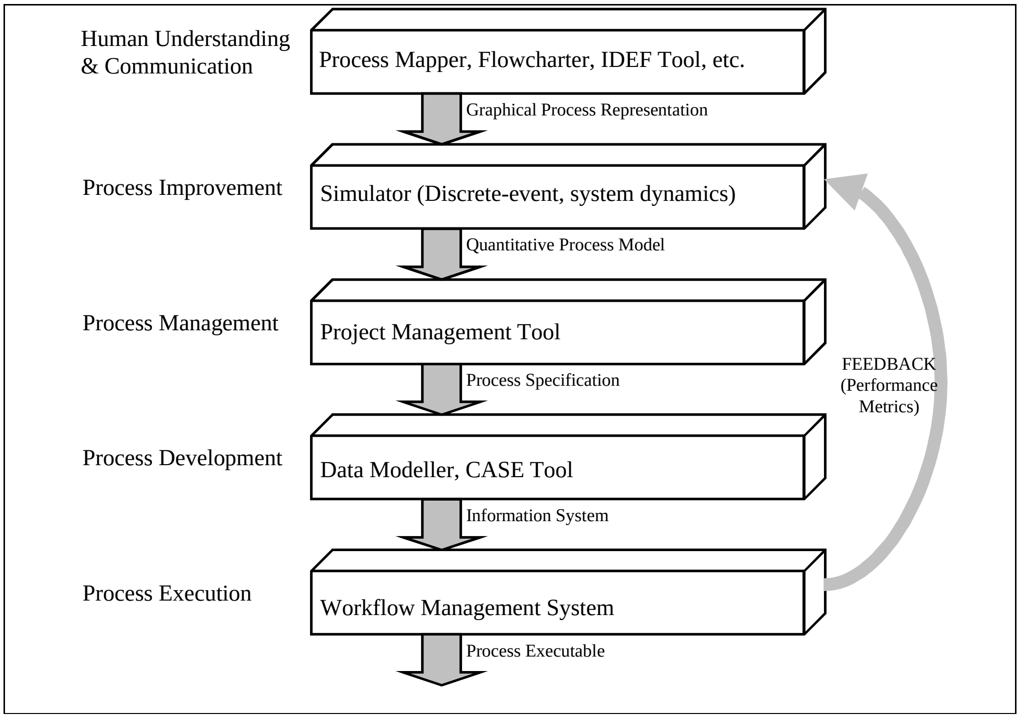

Figure 12. Organisational Design Workbench Architecture