INT. J. PROD. RES., 2002, VOL. 40, NO. 11, 2521–2546

Modelling and analysis of business process reengineering

A. GUNASEKARAN†* and B. KOBU†

Business process design and business process reengineering (BPR) depend crucially on linking production procedures and organizational services to business goals and objectives. There is currently very little formula support for this kind of reasoning as analytical tasks are usually carried out informally and individual design decisions are hard to relate to business objectives. If BPR is carried out without understanding the way it is done, then the most likely outcome would be continuing less-than-satisfactory current practice and automating outdated processes. This kind of practice misses opportunities for innovation and rationalization. The modelling and analysis of business processes along with business strategies and organizational structures are essential to study the implications of BPR. In this paper, an attempt has been made to study the modelling, analysis and tools/techniques used for modelling of BPR with the help of a survey on the recently (1993–2000) employed methods and tools used for BPR modelling and analysis. A framework for modelling and analysis, and guidelines for the selection of tools/techniques of business process reengineering are presented.

Acronyms

ABA	Activity Based Analysis
ABM	Activity Based Management
AHP	Analytical Hierarchical Process
AI	Artificial Intelligence
ARENA	Name of a Commercial Simulation Software System
ATM	Asynchronous Transfer Mode
BPR	Business Process Reengineering
CAD/CAM	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CASE	Computer-Aided Systems Engineering
CBR	Case Based Reengineering
CD-ROM	Compact Disc – Read Only Memory
CE	Concurrent Engineering
CIM	Computer Integrated Manufacturing
ConGolog	A process specification language
DEA	Data Envelopment Analysis
DM	Database Management
DSS	Decision Support Systems

Revision received November 2001.
† Department of Management, Charlton College of Business, University of Massachusetts Dartmouth, North Dartmouth, MA 02747, USA.
* To whom correspondence should be addressed. e-mail: agunasekaran@umassd.edu

International Journal of Production Research ISSN 0020–7543 print/ISSN 1366–588X online © 2002 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/00207540210132733

E-commerce	Electronic Commerce
EC	Electronic Commerce
ECS	Embedded Computer Systems
ES	Expert Systems
EDI	Electronic Data Interchange
EFQM	European Forum for Quality Management
EFT	Electronic Fund Transfer
ERP	Enterprise Resource Planning
GMI	General Motors Institute
HR	Human Resources
HPM	Hierarchical Process Modelling
IBRS	Intelligent Bank Reengineering System
IBPRS	Intelligent Business Process Reengineering System
IDEF0	Integration Definition Modelling
IS	Information Systems
ISDN	International Switching Digital Networks
IT	Information Technology
LP	Lean Production
MEI	Minimum Essential Information
MRP	Material Requirements Planning
MRPII	Manufacturing Resource Planning
OTPM	Object Transformation Process Model
OTS	Order-To-Ship
PERT/CPM	Program Evaluation Review Technique/Critical Path Method
PFA	Process Flow Analysis
PM	Process Mapping
QFD	Quality Function Deployment
RCM	Reliability Centre Maintenance
SCM	Supply Chain Management
SFT	Sales Force Transformation
TASC	Information Management and Systems Engineering Solutions Firm
TELOS	Knowledge based representation language
TBC	Time Based Competition
TPM	Total Productive Maintenance
TQM	Total Quality Management
TOC	Theory of Constraints
WWW	World Wide Web

1. Introduction

Business Process Reengineering (BPR) concerns the fundamental rethinking and radical redesign of a business process to obtain dramatic and sustained improvements in quality, cost, service, lead time, flexibility and innovation. BPR focuses on the whole process—starting from product conceptual stage to final product design. It provides the opportunity to reengineer the process or to reduce radically the number of activities it takes to carry out a process with the help of advanced Information Technology (IT), (Hammer 1990, Hammer and Champy 1993, Peppard and Rowland 1995). New developments in IT, such as multimedia, image processing and expert systems, can be used to reduce the number of non-value added activities. Organizational restructuring including job redesign can be used to improve the delivery of goods and services.

A group of related tasks that together create value for a customer is called a *business process*. Common corporate goals include: (a) customer satisfaction, (b) return on investment, and (c) market share (Hales and Savoie 1994, Hewitt 1995). These goals require process inter-dependencies and system dependencies that are established through the integration of various business processes. Another definition of a business process is the type of commodity that flows through the system. For example, a product development and its transformation into a final product can be viewed as a process. Davenport and Short (1990) define 'process' as a set of logically related tasks performed to achieve a defined business outcome and suggest that processes can be divided into those that are operationally oriented (those related to the product and customer) and management oriented (those that deal with obtaining and coordinating resources). Love *et al.* (1998) consider the technical and social dimension of a process and identify four enablers: quality management, technology, information and people.

Radical process change is the first major step in BPR. Therefore, a process improvement team should be established with the objectives of analysing the whole process, identifying non-value-added activities such as storage and inspection, and eliminating them. The delivery process emphasizes cross-functional performance rather than encouraging departmental optimization and consequently system-wide sub-optimization. Sage (1995) defines three levels of BPR: product, process and system.

Business process and enterprise activity modelling play a central role in enterprise representation in the context of Computer-Integrated Manufacturing (CIM) and integration. Business processes determine enterprise behaviour while the activities characterize functionality. Vernadat (1996) discussed a formalism to specify business processes and enterprise activities. The formalism makes use of behavioural rules derived from process algebra for structured processes and temporal logic for semi-structured processes. The paradigm assumes that human or non-human agents (functional entities), performing elementary actions (functional operations) execute processes and their activities.

The role of IT in reengineering can be viewed from two perspectives: (i) the role of the IT function (e.g. Internet, E-Commerce, Multimedia, EDI, CAD/CAM, and ISDN), and (ii) the role of the technologies themselves (e.g. CD-ROM, ATM, and fibre optics). IT has played a vital role in the success of the overall reengineering initiative. Information management throughout the company should be encouraged to develop skills in computer-aided systems engineering (Davenport and Short 1990, Hewitt 1995, Gunasekaran and Nath 1997). Soliman and Youssef (1998) claim that the success of BPR relies on the use of IT and they also identify the characteristics of successful BPR. In a more recent Australian survey, 75% of 535 firms identified IT as the most important enabler in BPR (O'Neill and Sohal 1998). There are many articles available in the literature on IT in BPR (Hansen 1997, Davies 1994, Bradley *et al.* 1995, Swami 1995, Giaglis and Paul 1996, Love *et al.* 1998). However, most of the studies deal with conceptual frameworks and strategies and do not deal with modelling and analysis of business processes, with the objective of improving the performance of reengineering efforts.

Modelling of BPR is intended to represent the information and the information flows in an organization with the idea of abstraction, through the use of tools such as conceptual framework, mathematical models and simulation. The purpose of modelling BPR is to understand the problems and to recognize the constraints with the information and material flows and to seek optimal solutions for improving the overall performance of the system. Im *et al.* (1999) developed a model to explain the relationship between BPR tools and the determinant of success. Analysis of 83 BPR practitioners' responses from different industries indicated that (a) BPR tools' competencies are linked to their effectiveness rather than their efficiency, and (b) BPR tools' competencies are strongly related to the success of BPR project.

The main objectives of the paper are to: (a) understand the various definitions of BPR; (b) study the roles of modelling and analysis as enablers of BPR; (c) review the literature available on BPR; (d) classify the tools and techniques based on the nature of the applications and characteristics of the tools/techniques of BPR; (e) develop a framework for identifying and selecting the most appropriate tools/techniques for reengineering business processes; and (f) suggest some future research directions to improve the modelling and analysis of BPR in the wake of advanced IT.

Realizing the importance of modelling and analysis of BPR, an attempt has been made in this paper to understand first the role of modelling of BPR and then to study the various tools used for modelling and analysis of reengineering efforts. Finally, a framework has been presented for modelling and analysis of a BPR.

2. Business process reengineering

The keywords for BPR are 'fundamental', 'radical', 'dramatic', 'change' and 'process'. A business process has to undergo fundamental changes to improve productivity and quality. Radical changes, as opposed to incremental changes, are made to create dramatic improvements. Reengineering is not about fine-tuning or marginal changes. It is for ambitious companies that are willing to make substantial changes to achieve significant performance improvements.

Chan and Peel (1998) conducted a survey of 37 companies in 17 different industries to investigate the causes and the impact of BPR. They concluded that the primary reasons for BPR are increasing efficiency (internal) and improving customer service (external). Francis and McIntosh (1997) identified causes for the emergence of BPR such as consumers, competition (global), technological development, and IT. Most companies are function- or department-oriented, and not process-oriented. Often, many people are involved in order fulfilment, but no one tracks a product and reports the status of an order directly. Reengineering makes one individual responsible for the complete business process (Self 1995). In another study, the success of BPR is related to the creativity of the people in the organization (Paper 1997). Some of the factors that will prevent reengineering and hence innovation and growth are: (i) correcting the process instead of changing it; (ii) loss of nerve; (iii) the barons; (iv) change of company champion; (v) settling for minor results; (vi) culture, attitudes and skill base; (vii) skimping on resources; and (viii) pulling back when people resist change.

BPR is a structured approach to analysing and continually improving fundamental activities such as manufacturing, marketing, communications and other major elements of a company's operation (Elzinga *et al.* 1995). Wright and Yu (1998) defined the factors to be considered before actual BPR starts and developed a model for identifying the tools for BPR. Childe *et al.* (1994) have presented frameworks for BPR that focus upon the sequence of activities that form business processes. They attempted to develop a framework for understanding BPR and to explain the relationship between BPR and TQM, TBC and IT. BPR should enable firms to model and analyse the processes that support products and services, highlight opportunities for both radical and incremental business improvements through the identification and removal of waste and inefficiency, and implement improvements through a combination of IT and good working practices.

A conceptual model explaining the major components of BPR is shown in figure 1. This model demonstrates the link between organizational restructuring and behavioural changes with the help of Information Technology for reengineering business processes, and hence effective process delivery systems, with the objective of improving customer satisfaction.

BPR requires organizational restructuring (include the facility location, capacity, types of products, technology, people) and changes in employees' behaviour (training, education, job enrichment, job enlargement, and employee empowerment) with a view to accommodating and facilitating radical changes for achieving dramatic improvements in business performance. IT, such as the Internet, E-Commerce, CAD/CAM, CIM, MRP, Multimedia, ERP and WWW, EDI and EFT, would help to restructure an organization and promote changes with acceptance from

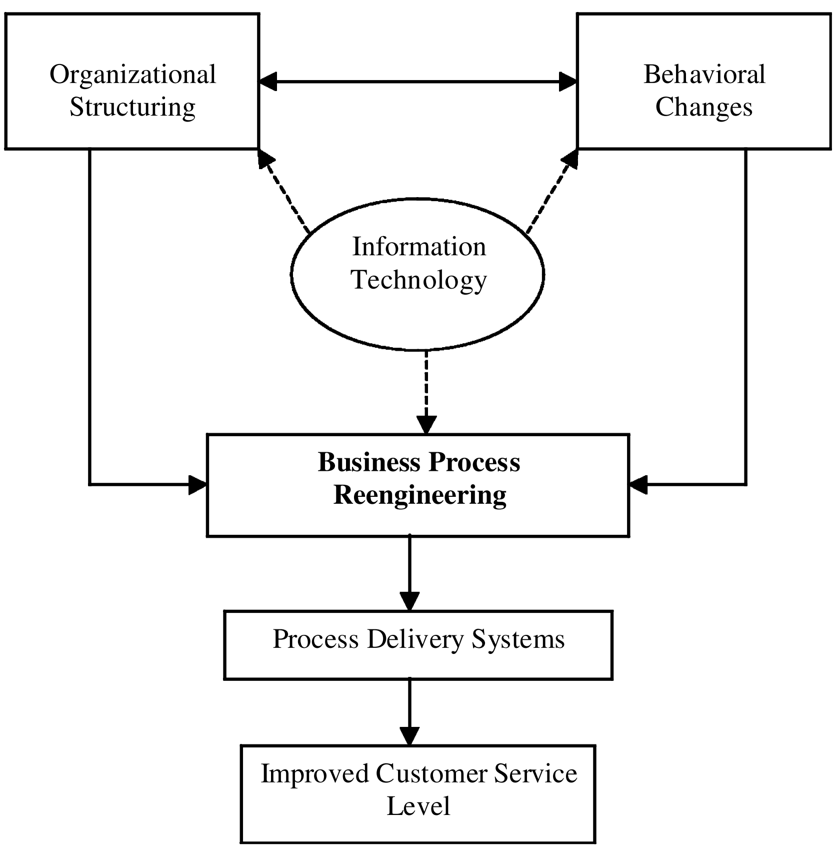

Figure 1. A conceptual model for BPR.

employees on any radical changes in the company. The reengineering of a business process will result in improved process delivery systems and hence an improved customer service level.

Organizational restructuring by standardization and simplification eliminates barriers for a smooth flow of information and materials along the supply chains. The smooth flow of information can be facilitated by the use of various ITs to improve the integration of various functional areas. The basic aim of BPR is to deliver quality goods at competitive prices in a timely fashion. Therefore, a manufacturing system as well as a business organization should be modified emphasizing *coordination* of the basic business processes in the chain, from suppliers to customers, as opposed to the existing complex structures of the functional hierarchies. The behavioural changes should precede the reengineering. Therefore, issues such as training and education, employee empowerment, teamwork and incentive schemes should be given priority in BPR.

In order to reengineer a business process, both internal and external process capabilities, such as product development, production, distribution, suppliers and markets, and inter-organizational relationships, especially in a global manufacturing environment, need to be integrated. Reengineering helps to achieve lean production through the integration of production activities into self-contained units along the production flow. IT is an important element in such integration. Wyatt and Kletke (1997) presented a descriptive model to illustrate the impact of telecommunication technology on BPR. The techniques, such as time-based analysis, systems reengineering tools and IT can be applied to supply chain management as well as to the customer administration cycle (order taking to cash collection), product design cycle (concept definition to product availability), human resource development cycle (skills need identification to training completion), and virtually every other process within an organization, The appropriate handling of the *human motivational reactions* to change is unquestionably as important in the successful introduction of radically new methods as are the technical aspects of process design (Gunasekaran and Nath 1997). Al-Essa *et al*. (1996) discuss the critical roles of IT in development and operations stages in BPR. Mahapatra and Lai (1996) explored the similarities between IT-enabled BPR and the competitive use of IT, and argued that BPR extends the competitive use of IT to all levels in an organization.

Collins and Reynolds (1995) presented the experience of Microsoft Ireland's reengineering programme and explained how to solve inventory problems effectively. The company has solved the inventory problems in supply-chain by using online stock control with advanced IT. Kenlaw (1995) explained how IBM's Sales Force Transformation (SFT) unit provides provisional services to Fortune 2000 customers seeking to *automate* sales and marketing functions. Increasingly, sales managers are looking for an integrated system that links front-end departments to manufacturing resource planning and enterprise resource planning systems. Through time-based selling, IBM has developed a system to eliminate paper or and avoid duplication of order-entry procedures with the objective of increasing the accuracy of those orders and streamlining contract writing and signing. Altinkemer *et al*. (1998) discussed how BPR would help to improve productivity and hence organizational excellence. In a survey of 37 companies in 17 different industries, it was concluded that the primary reasons for BPR are increased efficiency (internal) and improved customer service (external), (Chan and Peel 1998). All these examples imply that

BPR has the scope for applications in manufacturing/service organizations and that IT is an integral part of BPR.

According to Self (1995), there are three things a manufacturing company needs to do to be able to compete effectively: (i) offer an efficient and well automated manufacturing system that is capable of giving the company an advantage over competitors; (ii) provide a coordinated method of meeting the order-winning criteria; and (iii) reengineer the company's process in such a way that the product meets order-winning criteria and maximizes profit. This area has the potential for future research and applications. Many believe that technology transfer, in the form of automation, is the sole answer to business problems. Nevertheless, automation does get some jobs done faster, but no dramatic improvement in performance results without fundamental or radical process changes. Therefore, radical improvements through factory innovation have more to do with a company's ability to change its processes than simply automating (Hammer and Champy 1993, Veasey 1994). BPR requires altering of company's in-house procedures and practices, which is an essential prerequisite to effective innovation and growth. More often, a change in the industrial culture and infrastructure should be necessary before investment in new plant can take effect.

BPR is a top-down, process-driven approach managed by senior executives, which aims to improve the performance by radical changes in the system over the short term (Ardhaldjian and Fahner 1994). Companies usually have to meet three important goals to achieve effectiveness: (i) a process, not product perspective, (ii) cross-functional coordination or integration, and (iii) consistency between goals and improvement plans (Wickens 1995, Jones *et al*. 1997, Lockamy and Smith 1997). IT is an enabler to the reengineered process, and any reengineering programme must consider the tremendous advantage offered by technologies such as document image processing and expert systems (Childe *et al*. 1994, Morris and Brandon 1993).

The successful implementation of BPR for a radical change in manufacturing strategy requires a change in attitude and the serious involvement of dedicated individuals and teams (Roby 1995). Smith (1995) indicates that a major aspect of BPR is the human element. Therefore, companies should ensure that their employees are suitably motivated and the technology required for training is available, especially for radical change for BPR. In earlier studies, Hall *et al*. (1994) defined three critical determinants of successful BPR projects. Maull *et al*. (1995) conducted a survey of 25 UK companies in order to determine the critical success factors for BPR. Teng (1996) developed a model for strategic perspectives on BPR to enable organizational changes including process changes. Guimaraes *et al*. (1997) tested eight Expert Systems (ES) success factors in terms of their importance to BPR. Paper (1997) presented a case study conducted in Caterpillar where he adheres to a systematic methodology and insists on creativity training, process simplification and improvement. Elahee and Gupta (1998) discussed six major success factors for BPR. Yoon *et al*. (1998) presented eight success factors for expert systems used in BPR. Larsen and Myers (1999) discussed a BPR project in a financial service firm that involves the implementation of ERP software and they defined the success of a BPR project as a moving target, since initial success in the case turned into failure in the long term.

The concepts of time-based competition (TBC) and lean production (LP) are of considerable significance to BPR. TBC is process based and aims to reduce radically the time required for the entire process. The corresponding benefits may include increased productivity, price competitiveness, reduced risks and increased market share. In the 1980s, Total Quality Management (TQM) helped incremental process improvements in manufacturing/service organizations, but in the 1990s it was replaced by BPR using advanced IT. This implies a role for IT and BPR in improving the effectiveness of organizations (Childe *et al.* 1994, Steinberger 1994).

Jones (1995) explained how benchmarking helps to identify and eliminate non-value-added work. Benchmarking is a popular technique that a company can use to compare its performance with other best-in-class performing companies in similar industries. Combining benchmarking and reengineering ensures that the best practices are in use and helps a firm seek out and eliminate steps that waste resources. Soliman and Youssef (1998) discussed the implications of TQM and learning organization on BPR. Their study attempted to determine the minimum BPR costs by seeking the optimal process mapping (PM). Radical changes required by BPR can be achieved by an information system that has to be restructured to support process reengineering. The restructuring of an information system should support functional integration to improve supply chain management and hence improve productivity and quality.

Crowe *et al.* (1997), after studying five US electronics firms, argued that choosing the right BPR project reduces the risk of failure. Two-thirds of BPR projects fail due to lack of poor planning. Kallio *et al.* (1999) studied 32 BPR projects and found that most projects were focused on streamlining current business processes, while only in a few cases were business processes radically redesigned. Based on the results, they developed a framework to help managers choose the most appropriate BPR strategies. In the following section, some of the advanced models are described before their application in BPR are studied. Hipkin and De Cock (2000) analysed four postulates relating to the implementation of new maintenance systems in four organizations and attempted to establish a set of critical success factors in Reliability Centre Maintenance (RCM) and Total Productive Maintenance (TPM) implementation, and to provide some guidelines for their adoption. Humphreys *et al.* (2000) applied Maister's Professional Service Firm Model in an operational manner with the objective of identifying the roles and responsibilities of the purchasing function within an aerospace company and concluded that staff development must be a central theme for the success of BPR.

3. Previous research on modelling and analysis of BPR

Modelling is an essential step in studying the current and proposed structure of business processes from a systems perspective. One of the earlier studies evaluates modelling tools for BPR and introduces modelling techniques and an evaluation procedure for selecting appropriate tools (Tseng and Chen 1995, Kim 1997). O'Neill and Sohal (1999) review the literature covering 1980-1998. They classified the literature based on the nature of BPR tools that incorporate: process visualization, process mapping, change management, benchmarking, and process and customer focus. An attempt has been made here to review the literature on modelling techniques and analysis used in BPR. Table 1 presents the review of the most recent (1993–2000) literature on BPR modelling tools and techniques. The classification of the literature on modelling and analysis of BPR is based on the major tools/techniques used that include: (i) conceptual models, (ii) simulation models, (iii) object-oriented models, (iv) integration definition (IDEF) models, (v) network models, and (vi) knowledge-based models. Table 2 summarizes the tools used in BPR. It can be

Field of application	Techniques/Tools used	Author(s)
Manufacturing systems design	Conceptual models and object transformation process model(OTPM)	Manley (1993)
Manufacturing systems design	Simulation	Mujtaba (1994)
Reengineering hospital operations	Conceptual models	Strasen (1994)
Design of manufacturing systems	IDEF models	Kusiak *et al*. (1994)
Accounting database systems	Object-based and knowledge-based models	Chen *et al*. (1995)
Cooperative supported work	Conceptual models (Strategic Actor Relationships)	Yu and Mylopoulos (1995)
Enterprise applications	Simulation	Meinhardt (1995)
Enterprise applications	Simulation	Drury and Laughery (1995)
General business process	Conceptual models	Kelleher (1995)
Military community hospitals	Conceptual medical group practice models	McGee and Hudak (1995)
Reengineering of software (US Air Force)	Simulation models	Wilkening *et al*. (1995)
Aircraft manufacturing	Knowledge based systems (DSS)	Xia (1995)
Decision support systems	IDEF and QFD	Sarkis and Liles (1995)
Automated query formulation capabilities	Logical schemas (Conceptual Constructs)	Semmel and Winkler (1995)
Redesigned human resources HR function	Conceptual models	Kesler (1995)
Enterprise integration in a competitive manufacturing	Objected-oriented models	Rolstadas (1995)
Car dealer credit operations	Computer simulation	Cvetkovski *et el*. (1996)
Senior management decision on Product/Service portfolio	Object transformation Process model (OTPM), Embedded Computer System (ECS)	Manley (1996)
Manufacturing database	Simulation	Pugh (1996)
Net product development in semiconductor and telecommunication industries	Conceptual models	Malhotra *et al*. (1996)
Manufacturing business structure	Conceptual organizational and information flow models	Thomas and Davies (1996)
General reengineering process	Petri-net-based approach	Van der Aalst and Vanhee (1996)
Business reengineering	Generic model using meta-case techniques	Jarzebek and Link (1996)
Claims processing	AI models and techniques	Yu and Mylopoulos (1996)
Reducing order processing time	ABC analysis	Huttner and Kernler (1996)
Radio infrastructure	European foundation for quality management (EFQM model)	Bowden (1996)
Organizational structure	Conceptual models (process reconfiguration)	Teng *et al*. (1996)
Manufacturing process and labour productivity	Simulation	Lyu (1996)

(*continued*)

Field of application	Techniques/Tools used	Author(s)
Automation of information flow between people and groups	Object flow model and simulation	Hsu and Kleissner (1996)
Intelligent bank reengineering system	Knowledge-based system using IDEF	Min *et al.* (1996)
Work flow management	Work flow reengineering methodology	Sharon *et al.* (1997)
Cash register, utility, postal service	Simulation	Hunt *et al.* (1997)
Selection of BPR strategies and technologies	Decision support system	Crowe *et al.* (1997)
Manufacturing	Project management techniques	Narasimhan and Jayaram (1997)
Hospital ward ordering	Soft system methodology (SSM)	Chan and Choi (1997)
General BPR	Information technology	Wyatt and Kletke (1997)
Business process modelling	Object-oriented models	Wang (1997)
Engineering design process	Object-oriented models	Wright and Yu (1998)
Supply chain	Simulation	Cho *et al.* (1998)
Financial services	Information technology (ERP)	Larsen and Myers (1999)
Printing office	Object-oriented model	Völkner and Werners (2000)
Empirical analysis	IS network models	Bhatt and Stump (2001)

Table 1—*concluded*. A review of BPR modelling techniques developed/applied in recent years (1993–2000).

Techniques/Tools used	Percentage of articles surveyed	Major characteristics of techniques/tools
Conceptual models	14/45 = 31.1	Easy to understand by the 'end-users', total systems modelling, aggregate models with less accuracy
Simulation models	11/45 = 24.4	More accurate modelling, restricted in its modelling capability, difficult to model the strategic implication of BPR
Object-oriented models	7/45 = 15.6	Difficult to understand by the end-users, restricted to a part of the total system, possibility of self-modelling, difficult to consider strategic implications
IDEF models	6/45 = 13.3	Easy to understand, has the advantages of modelling the whole system, does not include the strategic implications
Network models	4/45 = 8.88	More accurate modelling, taking uncertainty in the system, limited in its modelling capability, less user-friendly
Knowledge-based models	3/45 = 6.66	Intelligence systems, user-friendly, limited in its applications

Table 2. Summary of tools/techniques used in modelling and analysis of BPR.

observed that the conceptual and simulation models have been widely used in reengineering business processes.

The overview of the recent literature on BPR modelling and analysis is presented with the following objectives: (i) identify various tools available (ii) provide guidelines for the selection of appropriate tools based on the nature of BPR and corresponding areas, and (iii) suggest some future research directions.

3.1. *Conceptual models*

The conceptual models have been widely employed to understand the concept of BPR and its major enablers. Powell (1994) has developed a conceptual model and a framework for highlighting the role of IT in reengineering. This includes how IT can improve the reengineering of a business process in a more generic term. However, a more specific framework for the use of appropriate IT for reengineering various areas of business organizations is required. For this, first there is a need to define a business process that adds value to customers and, next, select a suitable IT for reengineering.

As information systems are increasingly expected to work with humans cooperatively in complex organizational contexts, conceptual modelling techniques need to be extended to relate information structures and processes to business and organizational objectives. Yu and Mylopoulos (1995) proposed a framework that focuses on the modelling of strategic business processes in their organizational settings. Organizations are viewed as being made up of social actors who are intentional—have motivations, wants, and beliefs—and strategic—they evaluate their relationships to each other in terms of opportunities and vulnerabilities. The framework supports formal modelling of the network of dependency relationships among actors and the systematic exploration and assessment of alternative process designs in reengineering. The semantics of the modelling concepts are axiomatically characterized. By embedding the framework in the Telos, a knowledge representation language, the framework can also potentially serve as an early-requirements phase tool in a comprehensive information system development environment.

Large information systems often require the fusion of multiple databases to achieve desired functionality. Semmel and Winkler (1995) focused on how automated query formulation capabilities may be realized over a set of fused databases. Kesler (1995) presented a model and a detailed process for redesigning human resources (HR) functions by contracting with line executives for new roles and by upgrading the competencies of the human resource management staff while reengineering the HR delivery systems.

Strasen (1994) discussed some of the problems and shortcomings of the process used by many outside consultants to assist hospitals in reengineering their operations. The author calls this process the 'form follows function' process because employees are involved extensively in redesigning job tasks (functions), which in turn change the organization's structure, positions and reporting relationships (forms). The process resulted in documented quantifiable improvements in enhanced quality, service and financial outcomes in the first year of implementation.

Many business-modelling methods do not lead to a precise enough model of the underlying business knowledge. Therefore, a model should be comprehensive enough to allow for a systematic study and precise formulation of the BPR. It should also provide a framework for designing tools to support BPR projects. Jarzabek and Ling (1996) identify information requirements for reengineering based on the commonly used methods and case studies published in the literature. They achieved a required level of tool flexibility by applying meta-CASE techniques and derived the physical schema for the tool repository and generated customized tools from the business model specifications.

Many organizations have realized how important it is to reduce the product development cycle time with the objective of improving flexibility. The flexibility to adapt to changing market needs and to develop innovative products in such an environment is essential for success. This would make new product development arguably one of the most critical cross-functional processes. Traditionally, this process has involved inefficient sequential processing of information and plans between functional specialities. Using tools/techniques such as Quality Function Deployment (QFD) and strategies such as Concurrent Engineering (CE) could overcome this. Malhotra *et al*. (1996) proposed a conceptual framework that facilitates innovation, flexibility, and an understanding of reengineering of the product development planning process. The framework was then refined and finally presented based on feedback from five experts in the high technology electronics industry, and it was also evaluated in the context of prescriptive literature on reengineering and innovation areas.

Successful BPR efforts in many firms have been reported to improve productivity significantly and to reduce staff. However, as the reality of large-scale process change sets in and reengineering failures start coming to the forefront, more careful thought must be given to the change process itself and it is important that senior leaders in the organization develop a high-level strategic perspective on this multifaceted change phenomenon. To help develop this perspective, Teng *et al*. (1996) developed a process reconfiguration model and a framework of organizational change in BPR. The process reconfiguration model shows how various functional activities involved in a business process may be reconfigured through a reengineering initiative. Kim and Kim (1998) proposed a form-based approach for large-scale process reverse engineering. Van Rensburg (1998) introduced a framework for the business process management concept as a holistic engineered description to be used in larger organizations.

From analysing the literature on conceptual models, one can observe that most are focused on strategies and methods for reengineering. In addition, conceptual models are much broader in their approach and deal with information flow and human resource management. In most conceptual models, the systems approach has been used in modelling BPR.

3.2. *Simulation models*

Computer simulation is becoming a common tool in the engineer's toolkit, but the move to simulation is slow in coming. There are still many people in manufacturing, health care, BPR and human factors fields who are not using any sort of simulation software and see no advantage to using this powerful tool. Even in the information age of the 1990s it is still hard for the potential user of simulation to find the necessary facts to keep up with the changing market of computers and simulation software (Drury and Laughery 1995).

Dynamic process models afford the analysis of alternative process scenarios through simulation by providing quantitative process metrics such as cost, cycle time, serviceability and resource utilization. These metrics form the basis for evaluating alternatives and selecting the most promising scenario for implementation (Levas *et al.* 1995).

Many companies are confronting the problem of reorganizing the organizational structure and processes and installing the state of the art information technologies. The adequate design of business processes plays an essential role in dealing with this problem and in reaching the business goals of conversion. Meinhardt (1995) described the starting point for a business-process-oriented introduction of off-the-shelf software in three separate sections: requirement analysis, software implementation and system maintenance.

The United States Air Force's Wright Laboratory and TASC, an information technology firm, developed an environment for reengineering software from one language to another. The approach by Wilkening *et al.* (1995) reengineers a program in the new language by reusing portions of the original implementation and design. They use reverse engineering to facilitate understanding, design recovery, viewing, and navigating of the subject system.

An experiment was conducted in the Management Department at General Motors Institute (GMI), which involved teaching management concepts by creating business models. An important part of this effort is the development of student projects taken from their cooperative experiences. One of these projects is the Car Dealership Credit Operations model. The paper by Cvetkovski *et al.* (1996) described how these operations were modelled using ARENA, a software system, as a class project. Pugh (1996) used a simulation model to evaluate the performance and integrity of a replacement manufacturing database, along with validation tests performed prior to acceptance and implementation.

Kaizen and *automation* are two different approaches to improve the performance of manufacturers. Both approaches have been widely discussed and reported in related literature. Lyu (1996) proposed a framework to integrate kaizen and automation in reengineering a manufacturing process. This study concluded that using an animated simulation model is an important step during process redesign. It is shown that nearly 50% improvement in labour productivity is possible with the streamlined manufacturing process.

Simulation provides a structured environment in which one can understand, analyse, and improve business processes. Hunt *et al.* (1997) looked at three businesses that have found simulation is instrumental in their pursuit of perfection: the US Postal Service, National Cash Register, and a diversified energy corporation. The results were improved productivity and quality of services to customers. Cho *et al.* (1998) suggested a methodology for business process simulation modelling, using Visual C++, to develop simulation models systematically, and an analysis based on the concept of roles and customer–supplier relationships.

Computer simulation models have generally been used at operational level BPR. The simulation models have helped to model the system with the objective of identifying non-value and value adding activities. Subsequently, changes can be made to the system for eliminating non-value-adding activities with the objective of creating wealth to customers. However, analytical models (mostly mathematical) have not received due attention in BPR. Nevertheless, they have a greater role to play in measuring performance and in conducting experiments by suitably modelling the whole operational system and they are less time consuming. This area needs further development. In addition, virtual organization to enhance the agility of organizations is gaining the attention of both researchers and practitioners. This requires identifying optimal pathways to reengineer the business processes.

3.3. *Object-oriented models*

Object-oriented models have become popular in 1990s for taking into account the flexibility and reuse of modelling processes. These models are flexible in terms of modelling any type of manufacturing/service processes. However, they have limitations, such as being difficult to understand by the user or model builder. This type of model can only represent part of the total system and does not consider the strategic implications or choices in the reengineering processes.

A study by Manley (1993) describes how industrial engineers can assist in reengineering worn out, error prone, or obsolescent real-time manufacturing systems by helping computer programmers and communication engineers to ensure that critical information control loops are complete and efficient. Two conceptual models, the Embedded Computer System (ECS) Model and the Object Transformation Process Model (OTPM) are used to guide a modified process flow analysis (PFA) of existing large-scale, complex embedded systems. This modified PFA is called Information Process Flow Analysis.

Hsu and Kleissner (1996) examined technology trends, business benefits, and requirements. They described the logical structure of an open workflow system and positions and designed ObjectFlow software to illustrate reengineering efforts.

In a recent study, Manley (1996) presented a three-phase information system analysis and design methodology to improve continuously enterprise information systems as part of a six-step annual business improvement process. Following the senior management's strategic decisions on next year's product and/or service portfolio content, the interactions between financial, engineering and quality improvement processes are analysed to determine the output quality and timeliness. Concurrently, facilities, equipment, and personnel resources required for individual processes are examined for possible immediate or future improvement. Throughout these analyses, minimum essential information (MEI) requirements are derived using the Object Transformation Process Model (OTPM). Individual OTPM models are linked to help identify all pertinent data sources, information destinations, and timing requirements. The linked OTPM models are mapped onto an Embedded Computer System (ECS) model that defines a physical architecture for improving telecommunication paths between all humans, machines and embedded computers that are components of an integrated process. This approach yields comprehensive logical and physical architectural models that can recursively guide high-leverage enterprise-wide improvement projects over succeeding fiscal years. Völkner and Werners (2000) developed an object-oriented simulation decision support system and used it for the simulation and analysis of the business processes of a municipal printing office.

3.4. *Integration Definition (IDEF) models*

The development of Integration Definition (IDEF) models for analysis of business processes has been motivated by the desire to increase productivity by improving the communication and structure of manufacturing systems. Constructing an IDEF model is only one component of a comprehensive process modelling effort. Kusiak *et al*. (1994) reviewed the current approaches to IDEF modelling in industry, as well as techniques analysing IDEF models. The paper discussed the fundamentals of IDEF0 and IDEF3 with an emphasis on reengineering design and manufacturing processes. IDEF0 is a method designed to model the decisions, actions, and activities of an organization or system. IDEF1 was designed as a method for both analysis and communication in the establishment of requirements. The IDEF3 (Process Description Capture Method) provides a mechanism for collecting and documenting processes.

Mujtaba (1994) describes practical problems encountered in modelling and simulation of complex system interactions in a manufacturing enterprise. In addition to production, the interactions of diverse activities such as sales forecasting, order processing, production planning, material requirements planning, procurement and distribution are considered. A graphical model of the order-to-ship (OTS) process, which consists of the activities that occur between the receipt of orders and the shipment of products within a factory, was built using hierarchical process modelling (HPM), derived from IDEF0.

Sarkis and Liles (1995) presented some issues relevant to the strategic justification of computer-integrated enterprise technologies for small and medium-sized manufacturing enterprises. To address the issue of making a strategic justification or '*business case*' for these technologies, among other requirements an organizational decision-making methodology that incorporates the strategies of the firm is needed. They used a research and development approach that integrates Quality Function Deployment (QFD) and IDEF0 functional modelling to determine the requirements and processes for the justification methodology is presented. This approach has implications for future research and development for similar organizational decision-support processes and BPR.

The Intelligent Bank Reengineering System (IBRS) is designed to assist a bank in choosing and implementing the most appropriate BPR alternative. IBRS's problem-solving approach consists of three stages: generation, evaluation, and choice (Min *et al*. 1996). In the generation stage, IBRS identifies BPR alternatives from previous BPR cases that are represented using IDEF. A constraint satisfaction search is employed to identify candidate BPR alternatives that satisfy the constraints of the bank such as goals, budget constraints, and other situational factors. IBRS evaluates the generated BPR alternatives by workflow and functional economic analyses.

IDEF models are user friendly and have the advantages of modelling the whole system. However, it does not take into account the strategic implications in BPR.

3.5. *Network models*

A methodology for mapping, measuring, tracking and managing commitments in business processes is necessary. An organization's network of commitments can be depicted as a map of interconnected workflow loops. That map can be used as a guide to design work processes and their supporting information technologies in order to manage commitments for customer satisfaction and to measure productivity. A study of a complex scheduling process at George Mason University shows how the mapping notion and the method works (Denning and Medinamora 1995).

The BPR project management can be modelled using PERT/CPM and Flow Charts for controlling the projects both in terms of costs and time scale. A framework based on high-level Petri-nets can be used in BPR modelling and analysis. A Petri net is a graphical and mathematical modelling tool that is able to model concurrent, asynchronous, distributed, and parallel systems. Petri nets have applications in a number of different disciplines including engineering, manufacturing, business, chemistry, mathematics, and even within the judicial system. An approach called '*what, how and by whom*' has been developed to guide the application of the framework in a BPR setting. This approach identifies three important stages in the redesign of a business process. By passing through these stages, a complete Petri-net model of the current (As-is) or proposed (To-be) situation is obtained. Petri-net-based models can be used to verify the correctness and to estimate the performance of the redesigned business process (Van der Aalst and Vanhee 1996).

There has been little research on the development of a comprehensive method to provide full support to the analyst in the course of process modelling. Wang (1997) proposes an approach that is a synthesis of natural language, semantic networks, and objects. An example is used to demonstrate that the proposed approach is an effective method for transforming natural language descriptions into object-oriented diagrams via the application of semantic networks. Larsen and Myers (1999) discussed the application of Enterprise Resource Planning (ERP) in reengineering business processes. Bhatt and Stump (2001) developed a model to examine the interrelationship among the nature of IS networks and business process improvement initiatives and found that top management support is significantly related to both IS dimensions (connectivity and flexibility).

Petri-Net modelling results in more accurate modelling, taking into account the dynamic behaviour of any practical system. However, it has limited modelling ability for real-life reengineering situation, taking into account the complexity, and it is less user-friendly.

3.6. *Knowledge-based models*

Knowledge-based models include Artificial Intelligence (AI) and Expert Systems (ES) and Database Management (DM). In order to facilitate the process of reengineering by minimizing the complexity of the modelling and analysis of BPR, limited knowledge-based models have been developed. However, this area needs further development in order to help companies to reengineer their processes.

Recently, many companies in China have been trying their best to transform their central planning systems into free market economic systems. Some have used BPR to improve their competitiveness in the global market. Xia (1995) presented a case study for BPR in a large aircraft manufacturing company in China. The company attempts to: (i) set up a new planning and scheduling system, (ii) change the production planning from four levels into one level, (iii) set up a new personnel management system, (iv) redesign the assembly process, i.e. improve the equipment and reduce the positions from 19 to 8, and (v) design and implement the computer information systems for supporting all redesigning activities.

The static meta-data view of accounting database management is that the schema of a database is designed before the database is populated and remains relatively fixed over the life cycle of the system. However, the need to support the accounting database evolution is clear: a static meta-data view of an accounting database cannot support the next generation dynamic environment where system migration, organization reengineering and heterogeneous system interoperation are essential. Chen *et al.* (1995) presented a knowledge-based approach and mechanism to support a dynamic accounting database schema evolution in an object-based data-modelling context.

Yu and Mylopoulos (1996) show how distributed intentionality models and ConGolog—a process specification language—aid the redesign of claims processing in an automobile insurance company. The models and their associated tools incorporate a number of AI techniques, including means-end analysis, qualitative reasoning, agent modelling, and theories of action.

Ku and Shu (1996) presented a new method of retrieving cases from a case-base using the K-tree search algorithm. Building an automated CBR (Case Based Reengineering) system relies on representing knowledge in an appropriate form and having efficient case retrieval methods. Using the Intelligent Business Process Reengineering System (IBPRS) architecture as a base, they discussed a model-based case representation approach to solve the knowledge elicitation bottleneck problems.

Knowledge-based models are user-friendly, but have limited applications considering the areas of reengineering.

4. A framework for BPR modelling and analysis

The proposed framework has been presented as a checklist in table 3 to offer some guidelines for choosing appropriate tools/techniques for BPR applications. The guidelines are based on the areas to be reengineered for dramatic improvements in performance.

4.1. *BPR strategies*

Decision making at strategic levels would require intelligent systems to select the appropriate strategies and methods with the objective of making decisions about business location, product portfolio, funding for a project, etc. This requires taking into account the risk involved and the costs and benefits of running the business. At strategic levels, aggregate and fuzzy data are used to make a decision for long-term developments and changes in an organization. The type of decisions requires experience and knowledge in selecting the most suitable methods, technologies and strategies for BPR. Decision Support Systems (DSS), Artificial Intelligence (AI) and Expert Systems (ES) can be used for making decisions at strategic levels. However, the literature survey indicates that there are not many different models designed for this purpose, but rather they are at a different level of applications with narrow objectives such as new product design and development, and production control. Therefore, there is a need for a wider use of DSS, AI and ES for modelling and analysis of BPR strategies. It must also be noted that e-commerce has a tremendous influence on the reengineering business processes. If a company wants to adapt e-commerce, then it must reengineer the whole business process with an objective of succeeding in e-commerce. Firms can employ e-commerce as a strategy for improving their performance through reengineering.

The selection of tools for BPR depends upon (i) the nature of decision areas, (ii) the nature of data to be analysed, and (iii) the background of users. The decision area here is to formulate strategies for reengineering business processes. The nature of data available at the strategic level is generally not accurate at this level of decision making, and therefore models based on a systems approach and conceptual framework could be used to analyse the data. Top management is responsible for this and it can easily understand such models and support the reengineering process. Moreover, '*Gap Analysis*' could be used in formulating strategies for reengineering considering the critical success factors (Slack 1991). Internet and web-based tools can be used for collecting data regarding the implications of both internal and external factors to the organization in formulating strategies for reengineering.

Areas to be reengineered	Tools/techniques used in BPR	Description for application
BPR strategies	Decision support system and Knowledge-based models	DSS, AI and ES can be used to select suitable strategies and methods for reengineering business process. This should be based on a set of performance measures and metrics
Business process system design	Analytical models such as queuing and simulations models	They can be used for system design considering the objective of eliminating non-value adding activities and focusing on value adding activities with suitable changes in organizational structure, information systems and technologies
Project management	PERT/CPM and Flow Charts	They can be used for the implementation of various reengineering processes
Reengineering business process	Activity-based analysis and workflow model including flow chart	They can be used to analyse the business processes and identify the value and non-value-adding activities in order to achieve a dramatic improvement in business performance. They can also be used for the implementation of reengineering business processes
Design of information system for reengineering business process	Object-oriented models and programming	They facilitate a flexible flexible modelling of organizations. This would help to optimize the organizational structure and information flow with the objective of reducing the production cycle time and hence to reengineered business process system
Understanding of the business process system	IDEF Models, EFQM Models, Petri-Net Models	They can be used to model business processes in easy to understand visual forms

Table 3. Guidelines for selecting tools/techniques for BPR.

4.2. *Process design*

The process design includes the design of a manufacturing or service system for producing quality goods and services for the intended markets or customers. The major tasks comprise designing the production system with suitable machines, layout, capacity and human resources. Analytical and simulation models can be used to study the materials flow within and outside an organization. For example, queuing and inventory models or simulation can be used for modelling the material flow in a production system. This would help to decide the type of layout, capacity level and process requirements so that non-value-adding activities can be eliminated along the supply chain. Nowadays, there are several examples of system design software available for the design and development of manufacturing. This software takes into account concepts such as Theory of Constraints (TOC) and Supply Chain Management (SCM). Benchmarking is essential to develop a basis for setting performance standards and process design criteria. There are numerous techniques available (e.g. statistical analysis) for the benchmarking exercise in process design.

For process design, tools such as queuing, or linear programming, models and simulation can be used. In addition, simple flow charts and fish-bone diagrams would be useful for reengineering business processes. Business process design begins with defining what is '*business process*' for an organization that is under consideration and then selects the most critical areas where business processes can be reengineered. Benchmarking could also be used for process design with the objective of implementing best practices for eliminating different forms of waste. For example, if the type of production system is a flow shop, then one can go for both simulation and analytical models. On the other hand, if the situation is a job-shop, then one could go for simulation models. For project type production systems, models such as CPM/PERT are appropriate.

4.3. *BPR project management*

Once the reengineering strategies and methods are determined and the processes are designed, the next step is the implementation, which requires project planning, execution and monitoring. The project management activities can be modelled using PERT/CPM and Flow Charts for controlling the projects both in terms of costs and time scale. The objective of using project management techniques is to achieve effective implementation of the reengineering processes. Project management in BPR requires planning, implementation and controlling. Again, the timetable for a project execution and resource requirements should be determined with the aim of completing the project on time with target results. Planning again needs to consider different alternatives available to implement the reengineering processes. Various trade-offs can be utilized in selecting the best alternatives that would maximize return with minimum investment in various change efforts. Performance of the implementation process should be measured from time to time to ensure that progress is made according to the plan.

A business process reengineering that receives focused attention is expected to be successful. To facilitate this, each reengineering area should be handled from a project management perspective. In addition, reengineering requires cross-functional interaction and hence project management techniques would be helpful to reengineer any business process by eliminating functional barriers. Project management is not only useful for managing a variety of projects, including reengineering in a most cost effective and efficient manner, but it is also applicable for specific project-based business processes that include ship building and construction of a plant.

4.4. *Reengineering*

The reengineering requires identifying the existing activities as value-adding and non-value-adding activities. In the past, most companies used simple techniques such as fish-bone diagrams, cause–effect relationship diagrams, activity-based analysis and management (ABA and ABM). These tools are highly valuable in terms of analysing value adding or non-value-adding activities. These techniques provide easy understanding of the material flow and, to some extent, the information flow within and outside the organization. All the changes are aimed not to target an incremental improvement, but a dramatic improvement in the overall business performance such as market share and profitability. While analysing the production line performance, one can use queuing models for determining the congestion as well as waiting times. Equally, simulation can be used for the purpose of measuring value-adding and non-value-adding activities along the production line. In addition, product-mix decisions can be made with reference to payback period, cash flow, rate of return on investment, etc.

Once the business process is defined and the reengineering team is set up with the necessary resources, the next stage is to reengineer the processes. From the business design and strategies, the major directions and resources are determined. The next step is then to get into the specifics of the reengineering processes. For this, tools such as activity-based analysis, workflow models and flow charts can be used for improving activities that create wealth for customers or stakeholders.

4.5. *Information system design*

The information system should follow business models. The required information system design should be based on business objectives and methods. For the design of management information systems, object-oriented models and programming can be used as it has the required flexibility and it also facilitates experiments under a different set of operating conditions. In addition, AI and ES can be used to design information systems for improving materials flow along the supply chain and hence to increase overall system performance. Nowadays, e-commerce, the intranet and internet play a major role in connecting firms along the supply chain and customers. The business models should not ignore the advances in Information Technology and Information Systems. Agent models (customers, suppliers, employers and management), as proposed by information scientists, can be used for designing the information system (Powell 1994).

Traditional organizations have used manual and paper-based information systems, which are proved to be not so effective in improving the communication between people within the company and with outside parties. For an effective engineering, teamwork and accurate information flow and access to the team are prerequisites for the success. Therefore, tools such as database (storing process information) and enterprise resource planning systems, including MRP, CAD/CAM, CIM, EDI, EFT and SAP, would be useful for supporting the reengineering business processes.

4.6. *Understanding the process system*

Broad-based and simple visual tools, including animated simulation models (with the help of computers), are suitable to explain the process system and highlight the processes that add/do not add value to customers. Sometimes, a simple flow chart explaining the processes may motivate the employees as well as top management to support the idea of reengineering business processes.

There are numerous modelling techniques developed for different decision making environments/situations. In general, the modelling of business processes involves processing of information data and analysing the information flow in an organization. This makes the modelling a very complex process. Therefore, there is a need for modelling a complex system in a more understandable way so that one can develop teamwork for IDEF, EFQM (European Forum for Quality Management) and Petri-net models, which have been widely employed for this purpose. The requirement for educating and training more people who can understand the objectives and methods of such complex systems is obvious.

5. Concluding remarks

In this paper, an attempt has been made to identify and classify the tools/techniques available for modelling and analysis of BPR. Initially, we explained the role of BPR in improving competitiveness in both manufacturing and service organizations. Following this, the definition of a business process was presented with the help of a conceptual model. The importance of modelling and analysis was discussed and, subsequently, a review of modelling and analysis of BPR was presented with the objective of identifying appropriate modelling techniques and tools together with some future research directions. The modelling and analysis of BPR becomes a core part of reengineering. Modelling not only helps to plan reengineering, but also makes implementation of necessary changes to the organization and other related resources easier. The following are some of the future research directions in the areas of modelling and analysis of BPR:

- Considering the nature of information available and people participating in the process of formulating strategies, developing DSS, DEA, Gap Analysis, AHP, AI and ES for making strategic decisions for BPR is greatly justified.
- At the beginning of any business process reengineering tasks, understanding of the systems and identifying suitable pathways are important. This would encourage the involvement of all employees of the organization in BPR. Therefore, developing conceptual models for defining what is a business process from the perspective of adding value to goods/services is an important step in BPR.
- Traditional models have always been helpful for representing business systems and in measuring the performance with the objective of selecting suitable strategies and methods for improving productivity and quality. Developing queuing, linear programming and simulation models to represent business processes and then selecting the optimal business process system facilitates adding value to customers with minimum investment.
- Reengineering relies more on eliminating non-value-adding activities. Therefore, activity-based analysis based on activity-based costing (ABC) can be used to identify the value-adding and non-value-adding activities (Tatsiopoulos and Panayiotou 2000).
- Reengineering virtual organizations requires a different approach and tools for modelling and analysis. For example, the information flow model will become a predominant tool. In this situation, there is a need to model the system with the help of object-oriented modelling techniques and programming.
- Organizations lack project planning and management due to resource and other organizational constraints. Hence, the more effective use of project management techniques (CPM/PERT) is the best tool for successfully implementing BPR strategies and methods. Suitable performance metrics and measures should be considered for the purpose of monitoring the reengineering projects.
- Powerful computers facilitate simulation models. Models such as IDEF and EFQM and Petri-nets can be used for understanding the business processes together with optimizing the use information across the supply chain.

- The operating environment of current manufacturing/services has changed the perspective of globalization and the application of Information Technology. Considering these, models need to be developed employing e-commerce, e-manufacturing and e-service environments.
- Suitable modelling techniques have to be identified to facilitate the modelling of virtual organizations or physically distributed organizations with the objective of reengineering the process in such environments. For example, Petri-nets and object-oriented models would be helpful in reengineering business processes.
- Modelling tools should easily be understandable and flexible so that process mapping and benchmarking can be carried out in a more visual manner for an effective reengineering business process. The internet and WWW can be used for benchmarking business processes, including partnerships with other world class companies.

Acknowledgements

The authors are grateful to two anonymous referees and the editor for their constructive and extremely useful comments on an earlier version of the manuscript, which considerably helped to improve the presentation of the paper.

References

Al-Essa, N. E., Ching, R. K. H. and Johnson, P. C., 1996, Investigative study of the role of information technology in business process reengineering. *Proceedings—Annual Meeting of the Decision Sciences Institute*, **2**, 771.

Altinkemer, A., Chaturvedi, A. and Kondareddy, S., 1998, Business process reengineering and organizational performance: an exploration of issues. *International Journal of Information Management*, **18**(6), 381–392.

Ardhaldjian, R. and Fahner, M., 1994, Using simulation in the business process reengineering effort. *Industrial Engineering*, **26**(7), 60–61.

Bhatt, G. and Stump, R. L., 2001, An empirically derived model of the role of IS networks in business process improvement initiatives. *Omega*, **29**, 29–48.

Bowden, P., 1996, From business process reengineering to business process management—using the EFQM model as a focus for management system change. *Quality World*, **22**(6), 409–412.

Bradley, J., Browne, J., Jackson, S. and Jagdev, H., 1995, Business process reengineering (BPR): a study of the software tools currently available. *Computers in Industry*, **25**(3), 309–330.

Chan, S. L. and Choi, C. F., 1997, Conceptual and analytical framework for business process reengineering. *International Journal of Production Economics*, **50**(2–3), 211–223.

Chan, P. S. and Peel, D., 1998, Causes and impact of reengineering. *Business Process Management Journal*, **4**(1), 44–55.

Chen, J. L., McLeod, D. and Oleary, D., 1995, Domain-knowledge-guided schema evolution for accounting database systems. *Expert Systems with Applications*, **9**(4), 491–501.

Childe, S. J., Maull, R. S. and Benette, J., 1994, Frameworks for understanding business process reengineering. *International Journal of Operations and Production Management*, **14**(12), 22–34.

Cho, Y. H., Kim, J. K. and Kim, S. H., 1998, Role-based approach to business process simulation modelling and analysis. *Computers in Industrial Engineering*, **35**(1–2), 343–346.

Collins, P. and Reynolds, B., 1995, Reengineering a European supply chain. *Logistics Focus*, **3**(2), 2–6.

Crowe, T. J., Rathi, K. and Rolfes, J. D., 1997, Selecting business process reengineering projects strategically. *Computers & Industrial Engineering*, **33**(1–2), 157–160.

Cvetkovski, B. J., Nutkowitz, M. T. and Morrison, K. R., 1996, Modeling car dealership credit operations using ARENA as a business process reengineering demonstration. *Computers and Industrial Engineering*, **31**(1–2), 335–338.

Davenport, T. H. and Short, J. F., 1990, The new industrial engineering: information technology and business process redesign. *Sloan Management Review*, Summer, pp. 11–17.

Davies, M. N., 1994, Back-office process management in the financial services: a simulation approach using a model generator. *Journal of the Operational Research Society*, **45**(12), 1363–1373.

Denning, P. J. and Medinamora, R., 1995, Completing the loops. *Interfaces*, **25**(3), 42–57.

Drury, C. E. and Laughery, K. R., 1995, Fundamentals of using micro saint in manufacturing, health care, human factors and business process reengineering. *Winter Simulation Conference Proceedings*, IEEE, Piscataway, NJ, USA, pp. 420–426.

Elahee, M. N. and Gupta, V. K., 1998, Quest for success in business process reengineering: research propositions and implications. *Proceedings—Annual Meeting of the Decision Sciences Institute*, Vol. 3, pp. 1599–1601.

Elzinga, J., Horak, T., Lee, C.-Y. and Bruner, C., 1995, Business process management: survey and methodology. *IEEE Transactions on Engineering Management*, **42**(2), 119–128.

Francis, A. and McIntosh, R., 1997, The market, technological and industry context of business process re-engineering in the UK. *International Journal of Operations & Production Management*, **17**(4), 344–364.

Giaglis, M. and Paul, R. J., 1996, It's time to engineer re-engineering: investigating the potential of simulation modelling for business process redesign. In B. Scholz-Reiter and E. Stickel (eds), *Business Process Modelling* (Berlin: Springer-Verlag), pp. 313–1332.

Guimaraes, T., Yoon, Y. and Clevenson, A., 1997, Empirically testing ES success factors in business process reengineering. *International Journal of Production Economics*, **50**(2–3), 245–259.

Gunasekaran, A. and Nath, B. N., 1997, The role of advanced information technology in business process reengineering. *International Journal of Production Economics*, **50**(2,3), 91–104.

Hales, H. L. and Savoie, B. J., 1994, Building a foundation for successful business process reengineering. *Industrial Engineering*, **26**(9), 17–19.

Hall, G., Rosenthal, J. and Wade, J., 1994, How to make reengineering really work. *The McKinsey Quarterly*, No. 2, pp. 107–128.

Hammer, M., 1990, Reengineering work: don't automate, obliterate. *Harvard Business Review*, July–August, 104–112.

Hammer, M. and Champy, J., 1993, *Reengineering the Corporation* (London: Nicholas Brealy).

Hansen, G. A., 1997, *Automating Business Process Reengineering: Using the Power of Visual Simulation Strategies to Imptove Performance and Profit* (Englewood Cliffs, NJ: Prentice-Hall).

Hewitt, F., 1995, Business process innovation in the mid-1990s. *Integrated Manufacturing Systems*, **6**(2), 18–26.

Hipkin, I. B. and De Cock, C., 2000, TQM and BPR: lessons for maintenance management. *Omega*, **28**(3), 277–292.

Humphreys, P., McIvor, R. and McAleer, E., 2000, Re-engineering the purchasing function. *European Journal of Purchasing & Supply Management*, **6**(2), 85–93.

Huttener, W. and Kernler, H., 1996, Business process reengineering with standard software. *ZWF Zeitschrift für Wirtschaftlichen Fabrikbetrieb*, **91**(5), 212–215.

Hsu, M. C. and Kleissner, C., 1996, Object flow—towards a process management infrastructure. *Distributed & Parallel Databases*, **4**(2), 169–194.

Hunt, K. L., Hansen, G. A., Madigan, E. F., Jr. and Phelps, R. A., 1997, Simulation success stories: business process reengineering. *Winter Simulation Conference Proceedings*, IEEE, Piscataway, NJ, pp. 1275–1279.

Im, I., El Sawy, O. A. and Hars, A., 1999, Competence and impact of tools for BPR. *Information & Management*, **36**, 301–311.

Jarazabek, S. and Ling, T. W., 1996, Model-based support for business reengineering. *Information & Software Technology*, **38**(5), 355–374.

Jones, E. K., 1995, Reengineering the maintaining function: adapt to change but don't lose sight of sound maintenance principles. *Plant Engineering*, **49**(2), 64.

Jones, T. M., Noble, J. S. and Crowe, T. J., 1997, Example of the application of production system design tools for the implementation of business process reengineering. *International Journal of Production Economics*, **50**(2–3), 69–78.

Kallio, J., Saarinen, T., Tinnila, M. and Vepsalainen, A. P. J., 1999, Drivers and tracers of business process changes. *Journal of Strategic Information Systems*, **8**, 125–142.

Kenlaw, W., 1995, Transformation = Reengineering + Automation. *Sales & Marketing Management*, **147**(4), S-21.

Kennedy, C., 1994, Reengineering: the human costs and benefits. *Long Range Planning*, **27**(5), 64–72.

Kesler, G. C., 1995, A model and process for reengineering the HRM role, competitiveness, and work in a major multinational corporation. *Human Resource Management*, **34**(2), 229–252.

Kim, C. S., 1997, Evaluation of data modeling tools for business process reengineering. *Proceedings—Annual Meeting of the Decision Sciences Institute*, **2**, 593–595.

Kim, K.-H. and Kim, Y.-G., 1998, Process reverse engineering for BPR: a form-based approach. *Information & Management*, **33**, 187–200.

Ku, S. and Suh, Y. H., 1996, An investigation of the K-tree search algorithm for efficient case representation and retrieval. *Expert Systems with Applications*, **11**(4), 571–581.

Kusiak, A., Larson, T. N. and Wang, J. R., 1994, Reengineering of design and manufacturing process. *Computers & Industrial Engineering*, **26**(3), 521–536.

Larsen, M. A. and Myers, M. D., 1999, When success turn into failure: a package-driven business process reengineering project in the financial services industry. *Journal of Strategic Information Systems*, **8**, 395–417.

Levas, A., Boyd, S., Jain, P. and Tulskie, W. A., 1995, Panel discussion on the role of modeling and simulation in business process reengineering. *Winter Simulation Conference Proceedings*, IEEE, Piscataway, NJ, USA, pp. 1341–1346.

Lockamy, A., III and Smith, W. I., 1997, Strategic alignment approach for effective business process reengineering: linking strategy, processes and customers for competitive advantage. *International Journal of Production Economics*, **50**(2–3), 141–153.

Love, P. E. D., Gunasekaran, A. and Li, H., 1998, Putting an engine into re-engineering: toward a process-oriented organization. *International Journal of Operations & Production Management*, **18**(9), 937–949.

Lyu, J., 1996, Case study—applying kaizen and automation to process reengineering. *Journal of Manufacturing Systems*, **15**(2), 125–132.

Mahapatra, R. and Lai, V., 1996, Business process reengineering—a competitive necessity. *Proceedings—Annual Meeting of the Decision Sciences Institute* (Atlanta, GA: Decision Sciences Institute), Vol. 2, pp. 589–591.

Malhotra, M. K., Grover, V. and Desilvio, M., 1996, Reengineering the new product development process—a framework for innovation and flexibility in high technology firms. *OMEGA–International Journal of Management Science*, **24**(4), 426–441.

Manley, J. H., 1993, Information Process Flow Analysis (IPFA) for reengineering manufacturing systems. *Computers & Industrial Engineering*, **25**(1–4), 273–276.

Manley, J. H., 1996, Enterprise information system modeling for continuous improvement. *Computers & Industrial Engineering*, **31**(1–2), 273–276.

Maull, R. S., Weaver, A. M., Childe, S. J., Smart, P. A. and Bennett, J., 1995, Current issues in business process reengineering. *International Journal of Operations & Production Management*, **15**(11), 37–52.

McGee, W. M. and Hudak, R. P., 1995, Reengineering medical treatment facilities for tricare—the medical group practice model. *Military Medicine*, **160**(5), 235–238.

Meinhardt, S., 1995, Process-oriented implementation of enterprise applications. *Wirtschaftsinformatik*, **37**(5), 487–499.

Min, D. M., Kim, J. R., Kim, W. C., Min, D. W. and Ku, S., 1996, IBRS—Intelligent Bank Reengineering Systems. *Decision Support Systems*, **18**(1), 97–105.

Morris, D. and Brandon, J., 1993, *Reengineering your Business* (New York: McGraw-Hill).

Mujtaba, M. S., 1994, Simulation modeling of a manufacturing enterprise with complex material, information and control flows. *International Journal of Computer Integrated Manufacturing*, **7**(1), 29–46.

Narasimhan, R. and Jayaram, J., 1997, Application of project management principles in business process reengineering. *Production and Inventory Management Journal, Third Quarter*, **38**(3), 44–50.

O'Neill, P. and Sohal, A. S., 1998, Business process reengineering: application and success—an Australian study. *International Journal of Operations & Production Management*, **18**(9/10), 832–864.

O'Neill, P. and Sohal, A. S., 1999, Business Process Reengineering: a review of recent literature. *Technovation*, **19**, 571–581.

Paper, D., 1997, Value of creativity in business process reengineering. *Proceedings of the Hawaii International Conference on System Sciences*, **3**, 290–297.

Peppard, J. and Rowland, P., 1995, *The Essence of Business Process Reengineering* (Hertfordshire, UK: Prentice-Hall Europe).

Powell, R. K., 1994, Information technology helps reengineer research. *Marketing News*, **28**(5), 11, 14.

Pugh, G. A., 1996, Validation of a replacement manufacturing database. *Computers & Industrial Engineering*, **31**(1–2), 285–288.

Roby, D., 1995, Uncommon sense: lean manufacturing speeds cycle time to improve low-volume production at Hughes. *National Productivity Review*, **14**(2), 79–87.

Rolstadas, A., 1995, Enterprise modeling for competitive manufacturing. *Control Engineering Practice*, **3**(1), 43–50.

Sage, A. P., 1995, Systems engineering and systems management for reengineering. *Journal of Systems Software*, **30,** 3–35.

Sarkis, J. and Liles, D. H., 1995, Using IDEF and QFD to develop an organizational decision support methodology for the strategic justification of computer-integrated technologies. *International Journal of Project Management*, **13**(3), 177–185.

Self, A., 1995, Company reengineering: a prerequisite for growth. *Assembly Automation*, **15**(1), 15–17.

Semmel, R. D. and Winkler, R. P., 1995, Integrated reengineering database to support data fusion. *Journal of Systems & Software*, **30**(1–2), 127–135.

Sharon, L. T., Bitzer, M. and Kamel, M. N., 1997, Workflow reengineering: a methodology for business process reengineering using workflow management of technology. *Proceedings of the Hawaii International Conference on System Sciences*, Vol. 4, pp. 415–426.

Slack, N., 1991, *The Manufacturing Advantage* (London, UK: Management Books 2000).

Smith, B., 1995, Process reengineering: the toughest challenge. *HR Focus*, **72**(2), 24.

Soliman, F. and Youssef, M. A., 1998, The role of SAP software in business process reengineering. *International Journal of Operations & Production Management*, **18**(9/10), 886–895.

Steinberger, R. L., 1994, Expert systems for minimum scope estimating in the process industries. *Transactions of the American Association of Cost Engineers*. SI4.1–SI4.9.

Strasen, L., 1994, Reengineering hospitals using the function follows form model. *Journal of Nursing Administration*, **24**(12), pp. 59–63.

Swami, 1995, Building the business using process simulation. In C. Alexopoulos, K. Kang, W. R. Lilegdon and D. Goldsman, (eds), *Proceedings of the 1995 Winter Simulation Conference of the Society for Computer Simulation*, San Diego, CA, pp. 1081–1086.

Tatsiopoulos, I. P. and Panayiotou, N., 2000, The integration of activity based costing and enterprise modeling for reengineering purposes. *International Journal of Production Economics*, **66**(1), 33–44.

Teng, J. T. C., Grover, V. and Fieldler, K. D., 1996, Developing strategic perspectives on business process reengineering—from process reconfiguration to organizational change. *OMEGA—International Journal of Management Science*, **24**(3), 271–294.

Tseng, M. M. and Chen, Y., 1995, Modeling approach for business process reengineering. *Proceedings of SPIE—The International Society for Optical Engineering*, **2620**, 24–31.
Thomas, P. V. and Davies, A., 1996, Remodeling a company via systems reengineering. *International Journal of Operations & Production Management*, **16**(7), 14–19.
Van der Aalst, W. M. P. and Vanhee, K. M., 1996, Business process redesign—a Petri-net-based approach. *Computers in Industry*, **29**(1–2), 15–26.
Van Rensburg, A., 1998, A framework for business process management. *Computers in Industrial Engineering*, **35**(1–2), 217–220.
Veasey, P. W., 1994, Managing a program of business reengineering project in a diversified business. *Long Range Planning*, **27**(5), 124–135.
Vernadat, F. B., 1996, Enterprise integration—on business process and enterprise activity modeling. *Concurrent Engineering-Research & Applications*, **4**(3), 219–228.
Völkner, P. and Werners, B., 2000, A decision support system for business process planning. *European Journal of Operational Research*, **125**, 633–647.
Wright, D. T. and Yu, B., 1998, Strategic approaches to engineering design process modelling. *Business Process Management Journal*, **4**(1), 56–71.
Yoon, Y., Guimaraes, T. and Clevenson, A., 1998, Exploring expert system success factors for business process reengineering. *Journal of Engineering and Technology Management—JET-M*, **15**(2–3), 179–199.
Yu, E. S. K. and Mylopoulos, J., 1995, From E-R to A-R—modeling strategic actor relationships for business process reengineering. *International Journal of Intelligent & Cooperative Information Systems*, **4**(2–3), 125–144.
Yu, E. S. K. and Mylopoulos, J., 1996, AI models for business process reengineering. *IEEE Expert*, **11**(4), 16–23.
Wang, S. H., 1997, A synthesis of natural language, semantic networks, and objects for business process modeling. *Revue Canadienne des Sciences de l Administration—Canadian Journal of Administrative Sciences*, **14**(1), 79–92.
Wickens, P., 1995, Getting the most out of your people. *Personnel Management*, **1**(5), 28–30.
Wilkening, D. E., Loyall, J. P., Pitarts, M. J. and Littlejohn, K., 1995, A reuse approach to software reengineering. *Journal of Systems & Software*, **30**(1–2), 117–125.
Wyatt, K. E. and Kletke, M. G., 1997, Model illustrating the impact of telecommunications technology on business process reengineering. *Proceedings—Annual Meeting of the Decision Sciences Institute*, **2**, 590–592.
Xia, G. P., 1995, Business Process Reengineering—a case study. *Computers & Industrial Engineering*, **29**, 367–369.