Dynamic Process Modelling for Business Engineering and Information Systems Evaluation

George M. Giaglis

A Thesis Submitted for the Degree of Doctor of Philosophy

Department of Information Systems and Computing

Brunel University

May 1999

Στους γονείς μου, Μιχάλη και Πολυξένη, και την αδελφή μου, Έλενα.

ACKNOWLEDGEMENTS

Any research activity constitutes a social process based on collaboration. As the outcome of such activity, this dissertation embodies the help, ideas, effort, and criticisms of a number of people to whom I owe a great deal of thanks.

First of all, I would like to express my gratitude to my two supervisors: **Professor Ray J. Paul** for his invaluable advice, encouragement, and support through this research, and **Professor Georgios I. Doukidis** for introducing me to scientific research and for being enthusiastic and supportive throughout these years. This thesis would not have been possible without their endless and generous support. I cannot thank them enough.

Special thanks also go to **Dr. Nikos Mylonopoulos** of Loughborough Business School for sharing my research interests and helping me to crystallise my thoughts and clarify my views through many intellectually inspiring conversations. Thanks, Nikos.

I am also indebted to all the people from J&J Hellas (especially **Dr. Georgios Ioannidis**) and Ramma Ltd., who made me feel welcome and supported the empirical part of this work throughout, and to all my colleagues in the **Heltrun** research group of the Athens University of Economics and Business for their invaluable assistance throughout the first case study. I would also like to acknowledge the assistance (through ideas, support, and criticism) offered at various stages of this work by **Professor Bob O'Keefe**, **Dr. Vlatka Hlupic**, **Julie Eatock**, and **Alan Serrano**.

I also acknowledge the support of **Bodossakis Foundation** and **Onassis Foundation**, both of them in Athens, for financially supporting my doctoral studies.

Also, many thanks to all my friends who did their best to keep me sane over these years and who have all contributed to this thesis in their individual and unique ways. They are too many to name, but you all know who you are. Thanks.

My final acknowledgements, to my parents, my sister, Niki, Sofi, and Sonali must be of a rather different sort. In ways which I will probably be the last to recognise, each of them has also contributed intellectual ingredients to my work. But they have also, in varying degrees, done something perhaps more important: they have allowed this work to go on and even encouraged my devotion to it. Anyone who has struggled with a project similar in nature and magnitude to a PhD thesis will recognise that this must occasionally have cost them. I cannot thank them enough.

DECLARATION

The following papers have been published (or have been accepted for publication) as a direct or indirect result of the research discussed in this dissertation:

Journal Papers:

1. Giaglis, G.M. (1999) A Taxonomy of Business Process Modelling and Information Systems Modelling Techniques, *International Journal of Flexible Manufacturing Systems*, forthcoming.
2. Giaglis, G.M. (1999) On the Integrated Design and Evaluation of Business Processes and Information Systems, *Communications of the AIS*, forthcoming.
3. Giaglis, G.M., Paul, R.J. and Hlupic, V. (1999) Integrating Simulation in Organisational Design Studies, *International Journal of Information Management, 19, 3*, pp. 219-236.
4. Giaglis, G.M., Paul, R.J. and Doukidis, G.I. (1999) Assessing the Impact of Electronic Commerce on Business Performance: A Simulation Experiment, *Electronic Markets, 9, 1-2*, pp. 25-31.
5. Giaglis, G.M., Paul, R.J. and O'Keefe, R.M. (1999) Discrete Simulation for Business Engineering, *Computers and Industrial Engineering, 37, 1-2*, pp. 199-202.
6. Paul, R.J., Giaglis, G.M. and Hlupic, V. (1999) Simulation of Business Processes, *American Behavioral Scientist, 42, 10*, pp. 1551-1576.
7. Giaglis, G.M., Paul, R.J. and Doukidis, G.I. (1999) Dynamic Modeling to Assess the Business Value of Electronic Commerce, *International Journal of Electronic Commerce, 3, 3*, pp. 35-51.
8. Giaglis, G.M., Mylonopoulos, N.A. and Doukidis, G.I. (1999) The ISSUE Methodology for Quantifying Benefits from Information Systems, *Logistics Information Management, 12, 1-2*, pp. 50-62.
9. Giaglis, G.M., Paul, R.J. and O'Keefe, R.M. (1999) Research Note: Integrating Business and Network Simulation Models for IT Investment Evaluation, *Logistics Information Management, 12, 1-2*, pp. 108-117.
10. Giaglis, G.M., Paul, R.J. and Doukidis, G.I. (1997) Simulation for Intra- and Inter-Organisational Business Process Modelling, *Informatica, 21, 4*, pp. 613-620.

Papers in Edited Books:

11. Giaglis, G.M. (1999) Transformation of Static Process Models into Dynamic Simulations: Issues and Considerations. In Scholz-Reiter, B. Stahlmann, H.D., and

Nethe, A. (Eds.), *Process Modelling*, Springer-Verlag, Berlin (ISBN 3-540-65610-3), pp. 161-176.

12. Giaglis, G.M. and Paul, R.J. (1996) It's Time to Engineer Re-engineering: Investigating the Potential of Simulation Modelling in Business Process Redesign. In Scholz-Reiter, B. and Stickel, E. (Eds.), *Business Process Modelling*, Springer-Verlag, Berlin (ISBN 3-540-61707-8), pp. 313-332.

Papers in Refereed Conference Proceedings:

13. Giaglis, G.M., Paul, R.J. and Serrano, A. (1999) Reconciliation of Business and Systems Modelling via Discrete Event Simulation. In the *Proceedings of the 1999 Winter Simulation Conference*, Phoenix, Arizona, December.
14. Giaglis, G.M. (1999) Modelling the Impact of Information Systems in Business Process Simulation Models. In Ades, M. (Ed.), *Proceedings of the 1999 Advanced Simulation Technologies Conference (Industrial and Business Simulation Symposium)*, San Diego, California, April, pp. 172-177.
15. Serrano, A., Giaglis, G.M. and Paul, R.J. (1999) Technical Issues Related to Integrating Modelling of Business Processes, IS and Computer Networks. In Brooks, L. and Kimble, C. (Eds.), *Proceedings of the 4th UKAIS Conference*, York, April, pp. 429-437.
16. Eatock, J., Giaglis, G.M. and Paul, R.J. (1999) Motivation for Integrating Computer Network Simulation with Business Process Simulation. In Brooks, L. and Kimble, C. (Eds.), *Proceedings of the 4th UKAIS Conference*, York, April, pp. 407-415.
17. Eatock, J., Serrano, A., Giaglis, G.M. and Paul, R.J. (1999) A Case Study on Integrating Business and Network Simulation for Business Process Redesign. In Al-Dabass, D. and Cheng, R. (Eds.), *Proceedings of UKSIM'99: Conference of the United Kingdom Simulation Society*, Cambridge, April, pp. 114-118.
18. Giaglis, G.M. (1999) Integrated Simulation of Business Processes and Information Systems. In Al-Dabass, D. and Cheng, R. (Eds.), *Proceedings of UKSIM'99: Conference of the United Kingdom Simulation Society*, Cambridge, April, pp. 119-125.
19. Giaglis, G.M., Paul, R.J. and O'Keefe, R.M. (1999) Combining Business and Network Simulation Models for IT Investment Evaluation. In the *Proceedings of the 32nd Hawaiian International Conference on System Sciences*, Hawaii, January, IEEE Computer Society, Los Alamitos, CA.
20. Giaglis, G.M. and Paul, R.J. (1998) The Evaluation of Investments in Electronic Commerce. In Hoadley, E.D. and Bensabat, I. (Eds.), *Proceedings of the 4th*

Americas Conference on Information Systems, Baltimore, Maryland, August, pp. 299-302.

21. Giaglis, G.M. and Doukidis, G.I. (1998) BPR in Support of Electronic Commerce: A Case Study. In Wanger, R.R. (Ed.), *Proceedings of the 9th International Conference on Database and Expert Systems Applications*, Vienna, August, IEEE Computer Society Press, pp. 655-660.
22. Giaglis, G.M., Paul, R.J. and Doukidis, G.I. (1998) Dynamic Modelling to Assess the Business Value of Electronic Commerce. In Doukidis, G.I, Cricar, J. and Novak, J. (Eds.), *Proceedings of the 11th International Bled Electronic Commerce Conference, vol. 1: Research*, Bled, Slovenia, June, pp. 57-73.
23. Paul, R.J., Hlupic, V. and Giaglis, G.M. (1998) Simulation Modelling of Business Processes. In the *Proceedings of the 3rd UKAIS Conference*, Lincoln, 15-17 April, pp. 311-320.
24. Giaglis, G.M., Paul, R.J. and Doukidis, G.I. (1996) Simulation for Intra- and Inter-Organisational Business Process Modelling. In Charnes, J.M., Morrice, D.J., Brunner, D.T. and Swain, J.J. (Eds.), *Proceedings of the 1996 Winter Simulation Conference*, San Diego, CA, December, pp. 1297-1304. Reprinted in *Informatica, 21, 4*, pp. 613-620.
25. Giaglis, G.M. (1996) Modelling Electronic Data Interchange Through Simulation: An Industry-Wide Perspective. In Bruzzone, A.G. and Kerckhoffs, E.J.H. (Eds.), *Proceedings of the 8th European Simulation Symposium, vol. I*, Genoa, Italy, October, pp. 199-203.
26. Mylonopoulos, N.A., Doukidis, G.I. and Giaglis, G.M. (1995) Information Systems Investments Evaluation Through Simulation: The Case of EDI. In Clarke, R., Gricar, J. and Navak, J. (Eds.), *Proceedings of the 8th International Conference on EDI and Interorganisational Systems*, Bled, Slovenia, June, pp. 12-26. Reprinted In the *Proceedings of the 5th Hellenic IT Conference, vol. 2*, Athens, Greece, December, pp. 727-740.
27. Mylonopoulos, N.A., Doukidis, G.I. and Giaglis, G.M. (1995) Assessing the Expected Benefits of EDI Through Simulation Modelling Techniques. In Doukidis, G., Galliers, R., Jelassi, T., Krcmar, H. and Land, F. (Eds.), *Proceedings of the 3rd European Conference on Information Systems*, Athens, Greece, June, pp. 931-943.

ABSTRACT

This research is concerned with the pre-implementation evaluation of investments in Information Systems (IS). IS evaluation is important as organisations need to assess the financial justifiability of business change proposals that include (but usually are not limited to) the introduction of IS applications.

More specifically, this research addresses the problem of benefits assessment within IS evaluation. We contend that benefits assessment should not be performed at the level of the *IS application*, as most extant evaluation methods advocate. Instead, to study the dynamics and the interactions of the IS applications with their surrounding environment, we propose to adopt the *business process* as the analytic lens of evaluation and to assess the impacts of IS on organisational, rather than on technical, performance indicators.

Drawing on these propositions, this research investigates the potential of dynamic process modelling (via discrete-event simulation) as a facilitator of IS evaluation. We argue that, in order to be effective evaluation tools, business process models should be able to explicitly incorporate the effects of IS introduction on business performance, an issue that is found to be under-researched in previous literature.

The above findings serve as the central theme for the development of a *design theory* of IS evaluation by simulation. The theory provides prescriptive elements that refer both to the *design products* of the evaluation and the *design process* by which these products can come into reality. The theory draws on a set of *kernel theories* from the business engineering domain and proposes a set of *meta-requirements* that should be satisfied by business process models, a *meta-design* structure that meets these requirements, and a *design method* that provides guidance in applying the theoretical propositions in practice.

The design theory is developed and empirically tested by means of two real-life case studies. The first study is used to complement the findings of a literature review and to drive the development of the design theory's components, while the second study is employed to validate and further enhance the theory's propositions. The research results support the arguments for simulation-assisted IS evaluation and demonstrate the contribution of the design theory to the field.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. INTRODUCTION

This Chapter serves as an overall introduction to the research that has culminated in this dissertation. It sets the background, defines the context, and explains the rationale, thus providing a basis for discussing the research work and interpreting its results in subsequent Chapters.

The research described in this dissertation is concerned with the applicability of discrete-event simulation in the contexts of engineering business processes and evaluating investments in Information Systems (IS). To set the scene for the subsequent analysis, this Chapter begins with a definition and an introductory discussion of these background areas, before proceeding to an overview of the potential uses and limitations of discrete-event simulation in these contexts. The detailed aims and objectives of the research are presented next, followed by a discussion of the methodological issues underpinning the empirical part of the work presented in this dissertation. The Chapter ends by outlining the dissertation structure to assist the reader in positioning each subsequent Chapter within the overall research framework.

1.1. Research Background

1.1.1. Business Process Change

To claim that the business environment is no longer stable may be a cliché, albeit still a valid one. Most contemporary organisations have to operate within complex social, political, economical, and technological settings (Scott-Morton 1991), characterised by such phenomena as the globalisation of national economies, reduced barriers to market entry, intensification of competition, greater customer expectations, and the rise of a post-industrial Information Society (Castells 1996).

In order to survive and prosper in such a turbulent environment, organisations are forced to adapt themselves to the new conditions by reshaping the way they operate (Rockart and Short 1989, Huber 1984). To this end, widespread attention has recently been paid, both by researchers and practitioners, to the development of methods, techniques, and tools that will help enterprises achieve change (Vedin 1994, Kettinger et al 1997). These ongoing efforts have resulted in the emergence of a multitude of, so called, *change management* approaches (Carnall 1995). The term has been used to collectively refer to theoretical or practical approaches that have been proposed to assist enterprises to plan, manage, and co-ordinate organisational change initiatives.

Probably one of the most well known amongst these approaches, is *Business Process Re-engineering (BPR)*. The concept of BPR was firstly introduced by Hammer (1990), Davenport and Short (1990), and Venkatraman (1991). It was later further popularised by Davenport (1993) and Hammer and Champy (1993) who defined BPR as '*the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed*'.

BPR has arguably been the most popular and sweeping change management approach of the past decade. A survey conducted by Deloitte & Touche in 1993 among 534 Chief Information Officers (CIO) in various industries found that 85% of them had been involved in at least one BPR project (Hayley et al 1993). The same survey five years later shows that BPR still remains an important business tool for IS managers (Deloitte & Touche 1998).

However, BPR is not the only change management approach available. Another approach that has gained considerable popularity is *Continuous Process Improvement (CPI)* (Harrington 1991). CPI's main difference from BPR is that CPI advocates a more incremental approach to business change by focusing on the gradual identification of opportunities and implementation of changes, in an attempt to ensure smooth and trouble-free transition from the old to the new business environment. As opposed to the radical nature of a typical BPR project, CPI is an evolving activity that helps organisations to continuously refine and improve their processes in small steps.

Despite such differences in scope and emphasis, most of the change management approaches that have been developed in the last decade share a common characteristic that differentiates them from their older counterparts: they advocate an alternative perspective on how businesses should be studied and improved. According to this perspective, businesses should not be analysed in terms of the functions in which they can be decomposed or in terms of the products they produce, but in terms of the key *business* *processes* that they perform. The shift from functional-based to process-based organisational design has been said to constitute a major paradigm shift in business and management science and therefore approaches like BPR have been characterised as a business revolution by their early advocates (Hammer 1990, Davenport and Short 1990).

But what exactly is a business process? Hammer and Champy (1993), in their best-seller book, define a process as '*a set of activities that, taken together, produces a result of value to a customer*'. In an equally influential work, Davenport (1993) defined a process as '*a structured, measured set of activities designed to produce a specified output for a particular customer or market*'. Earl (1994) defined a process as '*a lateral or horizontal organisational form that encapsulates the interdependence of tasks, roles, people, departments, and functions required to provide a customer with a product or a service*'. Table 1 categorises some definitions that have been given to business processes according to the fundamental unit of analysis of a process (the smallest identifiable element within a process), the primary objectives anticipated by process execution, and the mechanisms (resources) that the process uses to transform its inputs into meaningful outputs.

SOURCE	UNIT OF ANALYSIS	OBJECTIVES	RESOURCES
Davenport & Short (1990)	Task	Achieve a defined business outcome	*Not specified*
Harrington (1991)	Activity	Add value and provide an output to an internal or external customer	*Not specified*
Davenport (1993)	Activity	Produce a specified output for a particular customer or market	*Not specified*
Hammer & Champy (1993)	Activity	Produce value to the customer	*Not specified*
Talwar (1993)	Activity	Achieve a pre-specified type or range of outcomes	*Not specified*
Earl (1994)	*Not specified*	Provide a product or service to a customer	Tasks, roles, people, departments, functions
Ould (1995)	*Not specified*	Achieve a specific goal	People, machines
Alter (1996)	Step or Activity	Create value for internal or external customers	People, information and other resources

Table 1. A Comparison of Business Process Definitions

As opposed to the traditional functional-based or product-based decomposition of an organisation, a business process is a dynamic ordering of work activities across time and place, with a beginning, an end, and clearly identified inputs and outputs. Processes are generally independent of formal organisational structure and may involve the co-operation of different functions, divisions, business units, and may even span across entire organisations. Figure 1 presents some examples of such processes and illustrates the typical relationship between processes and the vertical organisational structures they cut across (for example, departments).

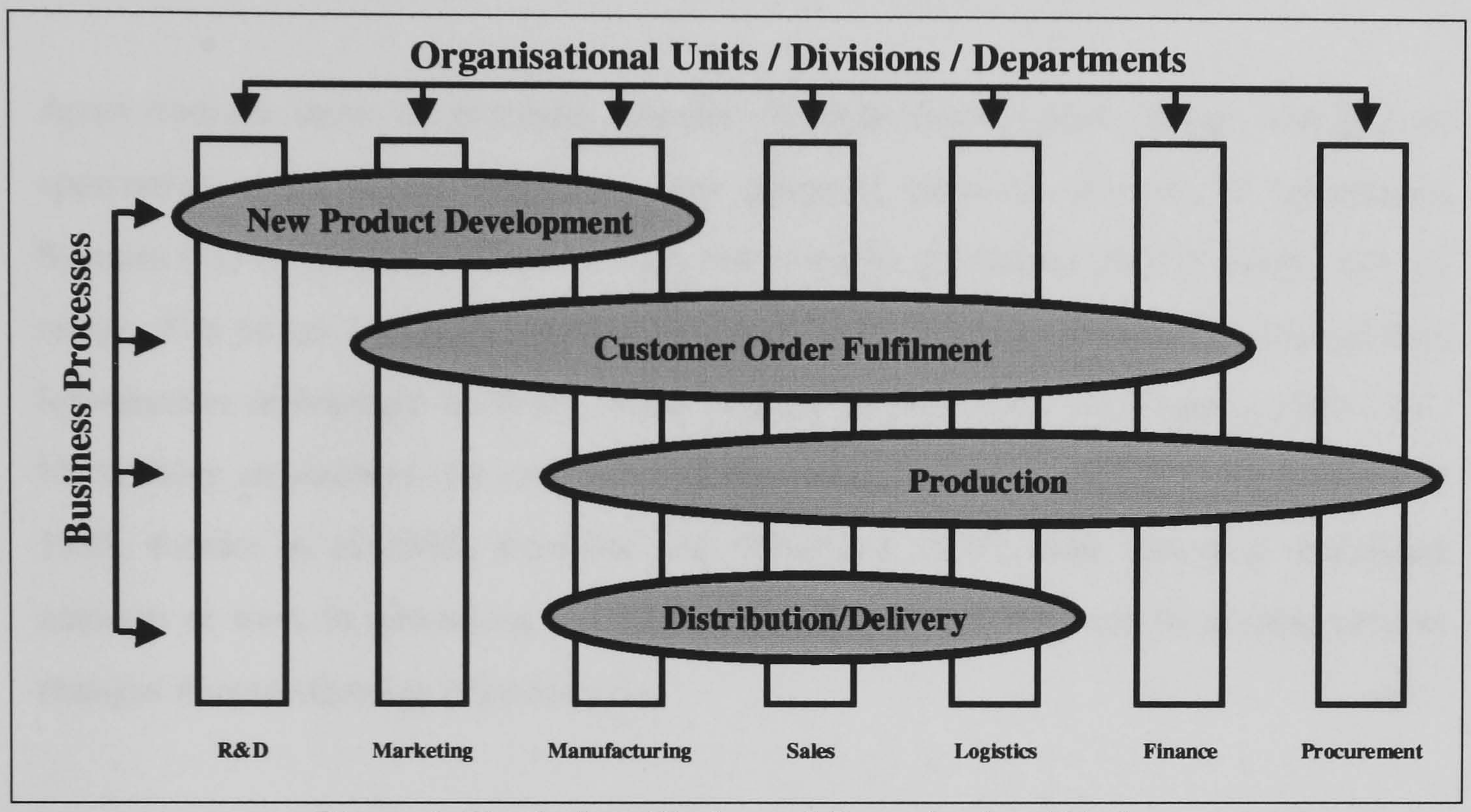


Figure 1. Vertical vs. Horizontal Organisational Design

The perceived need for a shift from a functional to a process perspective in organisational design stems from the fact that, despite the changes in contemporary economic and social environments, management values and principles developed during the industrial revolution (especially Adam Smith's idea of the '*division of labour*') still determine the organisational structure of many modern firms (Venkatraman 1991, Giaglis and Paul 1996). This has resulted in companies being organised around functional units (departments or divisions), each with a highly specialised set of responsibilities. In such a form of vertical organisation, units become centres of expertise that build up considerable bodies of knowledge in their own subjects, but even the simplest business tasks tend to cross functional units and require the co-ordination and co-operation of different parts of the organisation (Blacker 1995). Hammer and Champy (1993) have used the term 'functional silos' to refer to the inflexible and inward-looking perspective of such vertical structures, and argue that such structures naturally tend to inhibit creativity and innovation within the organisation. A process perspective can, amongst others, facilitate better co-ordination and management of functional interdependencies (Rockart and Short 1989). Buzacott (1996) used formal queuing theory models to assess the alleged superiority of process-based structures over their functional-based counterparts and concluded that the arguments of process-based organisational design advocates are indeed valid, especially in the context of information-intensive processes and office/service work environments.

1.1.2. The Role of Information Systems (IS) in Business Process Change

Apart from the focus on processes, another characteristic of recent change management approaches is the heavy importance they generally place on the role of Information Systems (IS) in enabling process change. For example, Davenport (1993) asserts that '*by virtue of its power and popularity, no single business resource is better positioned than information technology to bring about radical improvement in business processes*'. Many other researchers (for example, Galliers 1993, Grover et al 1994, Raymond et al 1995, Fielder et al 1995, Fuglseth and Gronhaug 1997) have dedicated significant amounts of work in addressing the critical role of IS in enabling and facilitating process changes in contemporary organisations.

The reasons for such a heavy emphasis on Information Systems are not difficult to understand. During the last two decades, an unprecedented rate of development in computer hardware and software has created new opportunities for organisations to collect and analyse data, convert them into useful information, and utilise this information as a strategic resource able to bring competitive advantages (Porter 1985). This has given rise to new methods of conducting business that would have been unthinkable only a few years ago, for example electronic commerce (Kalakota and Whinston 1996).

As a result of the growing strategic importance of Information Technology in organisations, the field of *Information Systems* has separated itself from *Computer Science* and has emerged as an autonomous academic discipline, steadily growing in size and importance. Sprague and McNurlin (1993) articulate the mission of IS as being '*to improve the performance of people in organisations through the use of information technology*'. This definition (deliberately combining people, organisations, and technology) serves well to demonstrate the inherently multidisciplinary nature of the IS field, being very much a social, rather than a wholly technical, science (Hirschheim 1992). Foundations of Information Systems can be found, amongst others, in management science, organisational theory, decision theory, systems theory, mathematics, and the behavioural sciences (Tricker 1992). Land (1992) argues that Information Systems are essentially social systems of which information technology is but one aspect. IS can be thought of as having three major influences or dimensions (Farhoomand 1987):

a) *Technical Dimension*, referring to the degree that technological advances and choices can affect the impact of IS on business performance.

b) *Organisational Dimension*, referring to the relationships of IS with the organisational structures and processes they are intended to support.

c) *Behavioural Dimension*, referring to the impact of IS on individual or group work patterns.

In practical terms, the proliferation of IS has resulted in enormous investments in such systems by most organisations (Business Week 1987). However, not all businesses have always been able to enjoy commensurate financial returns. Indeed, the widespread use of IS has coincided with lower macroeconomic figures of productivity and profitability in both the manufacturing and service sectors (Baily and Chakrabarti 1988, Roach 1991). Brynjolfsson (1993) has used the term '*IT productivity paradox*' to describe the alleged inability of IS to deliver in practice the benefits they promise in theory.

In an effort to explain this paradox, some researchers have pointed that IS have been mainly used to automate existing processes rather than as an opportunity for business process change (Hammer and Champy 1993). In other words, business processes are seldom structured with the possibilities of new technologies in mind and therefore the full potential of IS cannot always be realised. Even worse, other researchers argue that most organisations have never designed their business processes at all, but existing processes have rather evolved over time (Hansen 1994). Due to this *ad hoc* evolution, many processes are far from being streamlined, cost effective, and aligned with the overall organisational goals and strategy (Hammer and Champy 1993).

These observations have spawned significant amounts of research towards addressing the *alignment* of business process change and Information Technology introduction in organisations. In the context of this dissertation, the term '*business engineering*', introduced by Meel and Sol (1996), will be used to refer to this dual design strategy. Business engineering can be defined as the *integral* design of organisational processes and the Information Systems to support them. In other words, business engineering aims at the intersection between the domains of *process-based organisational design* and *IS* *development*, and is also concerned with *IS evaluation*, which can be defined as the process of ensuring the alignment of process and system designs. Figure 2 illustrates the relationship between business engineering and its underlying reference disciplines. In the following section we will outline the nature of business engineering in more detail. A more detailed discussion of each of the underlying disciplines of business engineering will be provided in Chapter 2 of the dissertation.

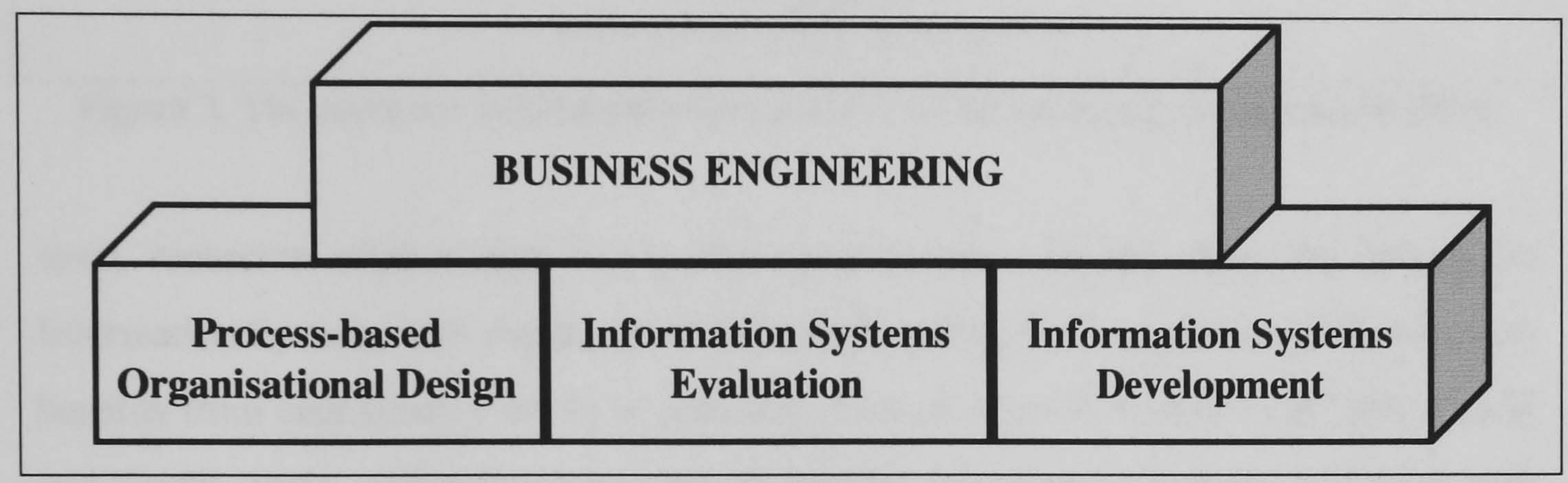


Figure 2. The Field of Business Engineering

1.1.3. Business Engineering

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 (Figure 3). On 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. For example, the proliferation of the Internet in recent years has given rise to a multitude of new, previously unthinkable, ways of conducting business (on-line shopping, virtual marketing/advertising, and electronic distribution of products, to name but a few) (Bakos 1998).

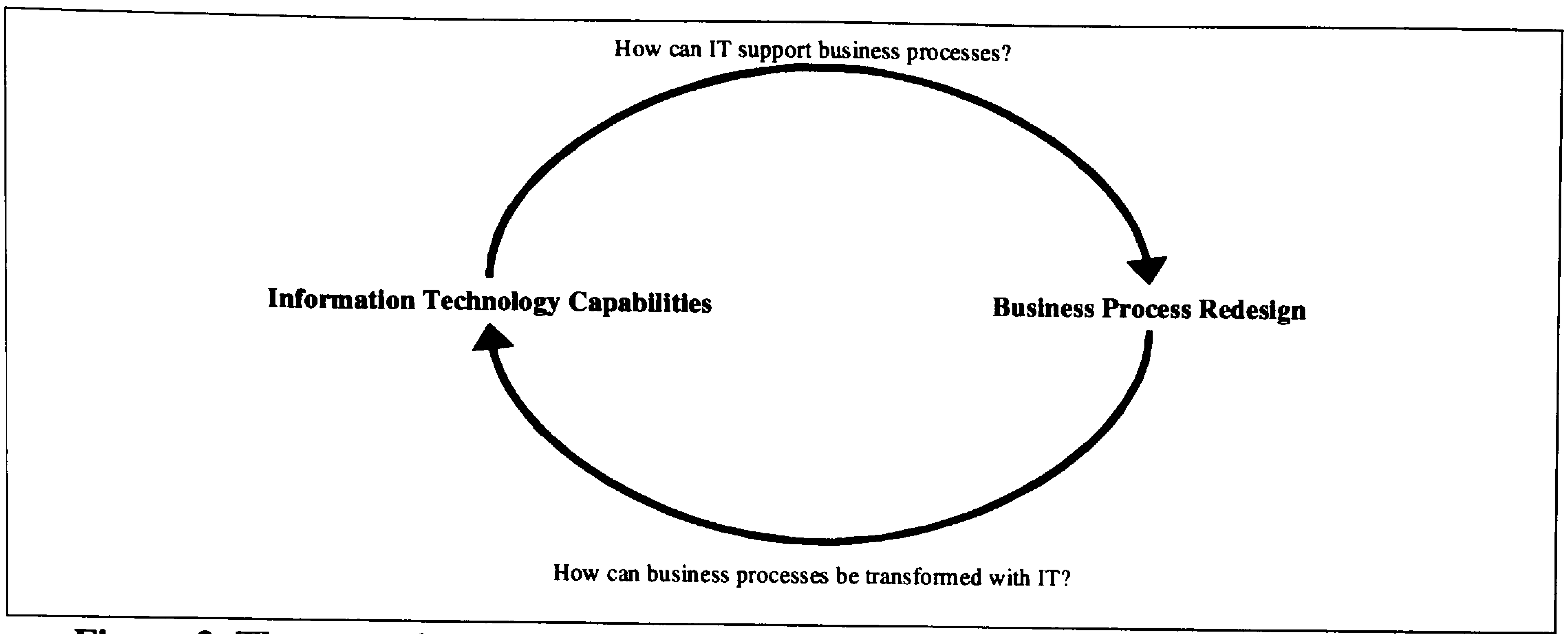


Figure 3. The recursive relationship between IT and BPR (Davenport and Short 1990)

Such recursive relationships imply that organisations should align the design of Information Systems with the design of the corresponding business processes if maximum benefits from their synergy are to be achieved (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). Existing methodologies, techniques, and tools to support IS design and development concentrate primarily on the detailed level of designing the system itself, adopting the *IS project* as their fundamental unit of reference (see Chapter 2 for a more detailed discussion on the limitations of existing IS development methodologies). As a consequence, IS development is mostly concerned with technical system details, ignoring (rather taking as granted) the organisational context in which the proposed system will operate. Galliers (1993) asserts that current practices in most organisations reinforce this isolation: '*[managers] are often happy in the mistaken belief that information technology can be left to technologists, and many of the latter [would be] happier to have information systems planning and development more concerned with technological issues than business imperatives, with as little as possible involvement from business executives*'.

To suggest that process designs be developed independently of the Information Systems that will support them is to ignore valuable tools for shaping processes (Davenport 1993).

Business engineering takes a broader view of both Information Systems and business processes and of the relationships between them. According to this view, IS should be viewed as a more than automating or mechanising force, but rather as an enabler of fundamental changes in the way business is done. Such a broad perspective can have a profound effect on business engineering approaches, as will be argued in more detail in Chapter 2.

Before closing this introductory presentation of the background areas of this research, it is worth discussing briefly the nature of *IS evaluation* since it constitutes the fundamental topic that this research addresses. A more detailed discussion will then follow in Chapter 2.

1.1.4. IS Evaluation

Only a few years ago, computers and Information Technology were seen largely as a support function that facilitated, but did not importantly influence, the operations of most firms. The IS budget was typically controlled as were other expense categories, like electricity and heat, in terms of year-to-year changes and the percentage relationship to sales revenues or some other similar ratio. During that era, investments in Information Systems were frequently justified on the basis of anticipated efficiency gains (for example, cost displacement or labour productivity increase), with little attention being paid to the potential for other benefits of a more intangible and strategic nature (King et al 1988). This focus of IS justification was consistent with the limited role that IS could play in most organisations in that era.

However, recent years have witnessed an explosion of IS development and use. Concurrent with the proliferation of computers in the organisation, came the realisation that investments in Information Systems were growing rapidly (Strassman 1985, Weill and Olson 1989, Gurbaxani and Mendelson 1990, Willcocks 1992a) and that Information Systems could now provide operational, tactical, and strategic advantages, rather than merely enhance efficiency (Earl 1988). The magnitude and importance of IS investments shifted the attention of many researchers to developing methods and techniques for assessing the contribution of IS to their host organisations or, in other words, to *evaluating* investments in Information Systems (Farbey et al 1993).

Despite the apparent importance of IS evaluation for organisations, the topic remains somewhat under-researched (Farhoomand 1987, Willcocks 1992a). Davenport (1993) argues that most of the research on IS evaluation is highly anecdotal and the analysis is rarely rigorous. In his highly critical work, Strassman (1990) points out that if one read what experts have been saying about IS investments they would become severely discouraged. While much intellectual effort has been devoted to creating structured methods to aid the *development* of IS (in a rather technology-centric sense), the same does not seem to hold true for the *evaluation* of investments in such systems (in a business-centric sense). Indeed, the majority of decisions for IS introduction in organisations seems to be taking place without a detailed *a priori* appraisal of the expected costs and organisational benefits (Farbey et al 1992).

One of the primary reasons for the difficulty in evaluating Information Systems is that the business benefits associated with the introduction of an IS are inherently hard to understand and predict, let alone quantify and measure. Indeed, the problem of *measurement* has been mentioned as one of the main reasons that have contributed to the inability of organisations to evaluate IS in the same manner as other capital investments (Weill and Olson 1989, Ballantine et al 1994, Farbey et al 1993).

The research described in this dissertation is aimed primarily at addressing the aforementioned measurement problems of IS evaluation in the context of business engineering. More specifically, it focuses on investigating ways in which the application of discrete-event simulation can assist organisations in overcoming the problems of measuring and assessing the expected impacts of *business process changes* and *IS-enabled changes* in an *integrated* fashion. In the remainder of the dissertation, we will use the terms *structural* and *informational* changes to distinguish between these two categories of organisational change. In the following section we will turn to an introductory discussion of the potential role of discrete-event simulation in business engineering.

1.2. Simulation of Business Processes and Information Systems

1.2.1. Business Process Modelling (BPM) and IS Modelling (ISM)

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).

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 (MacArthur et al 1994), especially when there is a need to combine BPM and ISM in an integrated activity (i.e. during business engineering). Various different BPM/ISM techniques have been proposed. Although the research described in this dissertation is focusing on investigating the potential of a specific technique, namely discrete-event simulation, as a tool for business engineering and IS evaluation, a detailed review of other BPM/ISM techniques was also undertaken in order to gain a better understanding of their advantages and limitations in this context. This review is presented in Appendix A of this dissertation.

1.2.2. Business Process Simulation (BPS)

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.

Shannon (1975) has defined simulation[1] 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 involve the operation of some complex system on which direct experimentation may be impractical on grounds of cost, time or some human restriction. Simulation models provide a potentially powerful tool for conducting controlled experiments by systematically varying model parameters and observing the effects of changes in model behaviour (Pidd 1992).

Computer-based simulation has been used as a vehicle for modelling and analysis in a wide number of application areas. Within organisations, manufacturing systems is probably the most well known application area of simulation use (Hollocks 1992), albeit not the only. The increasing importance of the service sector in national economies (Roach 1991) has shifted attention from manufacturing and production processes towards the administrative and managerial tasks performed in organisations. Moreover, the proliferation and widespread attention being paid to change management approaches, like BPR, has created a 'market' for organisational modelling techniques (Warren 1996), and simulation has naturally emerged as a prominent candidate application. As a result, amongst the recently developing application areas of simulation, is the modelling of and experimentation with 'soft' business processes (as opposed to 'hard' manufacturing applications). In this dissertation, we will use the term *Business Process Simulation* or *BPS* to refer to the application of simulation for modelling such 'soft' business processes.

---

[1] Simulation can have many forms (for example, discrete-event simulation, continuous simulation, system dynamics, Monte-Carlo simulation, qualitative simulation, etc.). Within this dissertation, the term 'simulation' will refer to *discrete-event simulation*, unless stated otherwise.

The very definition of simulation reveals its theoretical potential as a tool for business engineering. 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. Some characteristics of simulation that make it suitable for BPM include (Law and Kelton 1991, Pidd 1992, and Paul and Balmer 1993 provide excellent introductory discussions on the benefits of simulation in general):

a) Simulation modelling is by definition process-oriented (Law and Kelton 1991), while process-based organisational design is by definition systems-oriented (Denna et al 1995). A process in simulation terminology is defined as a time-ordered sequence of interrelated events which describes the entire experience of an 'entity' as it flows through a 'system' (Law and Kelton 1991), a definition closely related to those of business processes presented earlier. Therefore, simulation is well suited for process-based organisational design without a need for any significant adaptation of existing techniques and terminology.

b) Simulation allows for estimating the performance of an existing system under some projected set of operating conditions. As a result, simulation can help to define deficiencies early in the design process when correction is easily and less expensively accomplished.

c) Alternative proposed system designs or alternative operating policies for a single system can be compared via simulation to see which best meets a specified requirement.

d) In a simulation we can maintain much better control over experimental conditions than would generally be possible when experimenting with the system itself. Even more importantly, in most organisations experimentation with the actual business processes is normally impossible on the grounds of cost, time, and disruptions to the business operations (Hansen 1994).

e) Simulation allows decision-makers to obtain a 'system-wide' view of the effects of 'local' changes in a system and allows for the identification of implicit dependencies between parts of the system (Pruett and Vasudev 1990).

f) Simulation, especially when combined with graphical animation and interaction capabilities, facilitates better understanding of a system's behaviour and of the impact of proposed changes, and allows for better communication of results (Hurrion 1986, Law 1991). Managers and non-specialists can view a graphical layout of the proposed changes and understand the anticipated benefits more efficiently than would be possible with other modelling tools (for example, static flowchart models or spreadsheet financial analyses).

g) Finally, simulation encourages a cultural shift in the way modelling is perceived in an organisation, by means of continuous measurement and evaluation of business activities. MacArthur et al (1994) have argued that once in use, simulation models encourage a culture of measurement that supports continuous process improvement within the business environment.

Existing research on BPS has predominantly taken the form of practical examples that demonstrate the potential uses of simulation in the context of process change (for example, Bruno et al 1995, Lee and Elcan 1996). Some work has also been directed to the development of generic theoretical propositions for the suitability of simulation modelling as a tool in change management projects (Hansen 1994, MacArthur et al 1994). A detailed description and a critical appraisal of the existing state-of-the-art in BPS will be presented in Chapter 2.

Despite the ability of simulation to address some of the issues associated with business process change in general, very little research or application has been directed towards addressing the more specific problems associated with *IS-enabled* process change or, in other words, business engineering. As argued above, Information Systems are perhaps the most critical enabler of changes in contemporary organisations. It is therefore natural to expect that process modelling techniques should be capable of *explicitly* addressing the impacts of Information Systems on business processes if they are to be useful tools for business engineering. While BPS is maturing as an application area, *Simulation of Information Systems (SIS)* has only very recently been included in the agenda of both simulation and IS researchers (Warren 1996).

1.2.3. Simulation of Information Systems (SIS)

Many business process change initiatives are targeted towards types of processes that manipulate basically informational rather than physical components (Davenport 1993). Inasmuch as Business Process Simulation (BPS) focuses on and addresses such *information-intensive* processes, it differs significantly from other similar application areas, particularly simulation of manufacturing systems (Gladwin and Tumay 1994). Simulation of manufacturing systems is mainly concerned with the manipulation of *physical* entities (for example, raw materials and products moving through a production line), the route of which is relatively easy to follow through the modelled system. Moreover, the resources that usually exist in such systems are also tangible, tractable, and measurable (for example, machines, equipment, conveyors, and workstations), and therefore allow for relatively easy observation and representation of the modelled phenomena. Indeed, this may have been the major reason for the apparent success of simulation as a modelling technique in such application areas.

The difference of information-intensive processes is that they are mainly characterised by the flow of intangible components representing various forms of knowledge and information around a system that itself consists mainly of human and Information System resources. These entities and resources, as opposed to those typically present in manufacturing systems, are significantly more difficult to observe and analyse. For example, informational entities (such as invoice data held in an Information System), can be created, transformed, distributed, viewed, and deleted at any time during the system life cycle, and they can be present at more than one location at the same time.

Despite a few theoretical and practical advances in BPS, very little attention to date has been paid in addressing the exact nature in which the effects of Information Systems can be incorporated in BPS models. Even in the few published articles that deal with the matter (for example, Warren and Stott 1992), the simulation of Information Systems is treated at the level of technical system specifications rather than the level of organisational performance impact.

This lack of research in SIS seems surprising given the importance of information in general, and IS in particular, for most contemporary business processes. In more and more businesses, especially in the service sectors, the end product is a unit of information (consulting services, insurance companies, and media organisations, to name but a few). Even in non-service organisations, many operational and managerial processes yield predominantly informational outputs (examples include customer service processes, human resource management, and financial processes, amongst others). Finally, even when a process deals primarily with tangible elements, it is likely that Information Systems are used to support some aspects of the process execution. Inventory management processes and customer order fulfilment processes fall within this category.

This dissertation will be mainly concerned with investigating ways and methods in which discrete-event simulation can address *structural* and *informational* changes in business process models, and thus be used as an effective vehicle for IS evaluation in the context of business engineering. The next section will articulate the aims and objectives of the research in more detail.

1.3. Research Objectives

The research described in this dissertation is primarily concerned with the issues identified in the preceding sections regarding the need to align business process design and Information Systems design. Treating *structural* and *informational* changes as a whole implies a need for an integrated approach to IS evaluation by simulation in the context of business engineering (MacArthur et al 1994). Although BPS is increasingly gaining recognition as a powerful facilitator of business process design, existing research has generally failed to address the incorporation of IS impacts in simulation models, hence potentially limiting the applicability of simulation for business engineering.

Centred around these issues, the primary aim of this research is to investigate the potential of discrete-event simulation modelling as a means to support IS evaluation and be an effective facilitator of business engineering in contemporary organisations. Figure 4 illustrates the potential applicability of discrete-event simulation in this context.

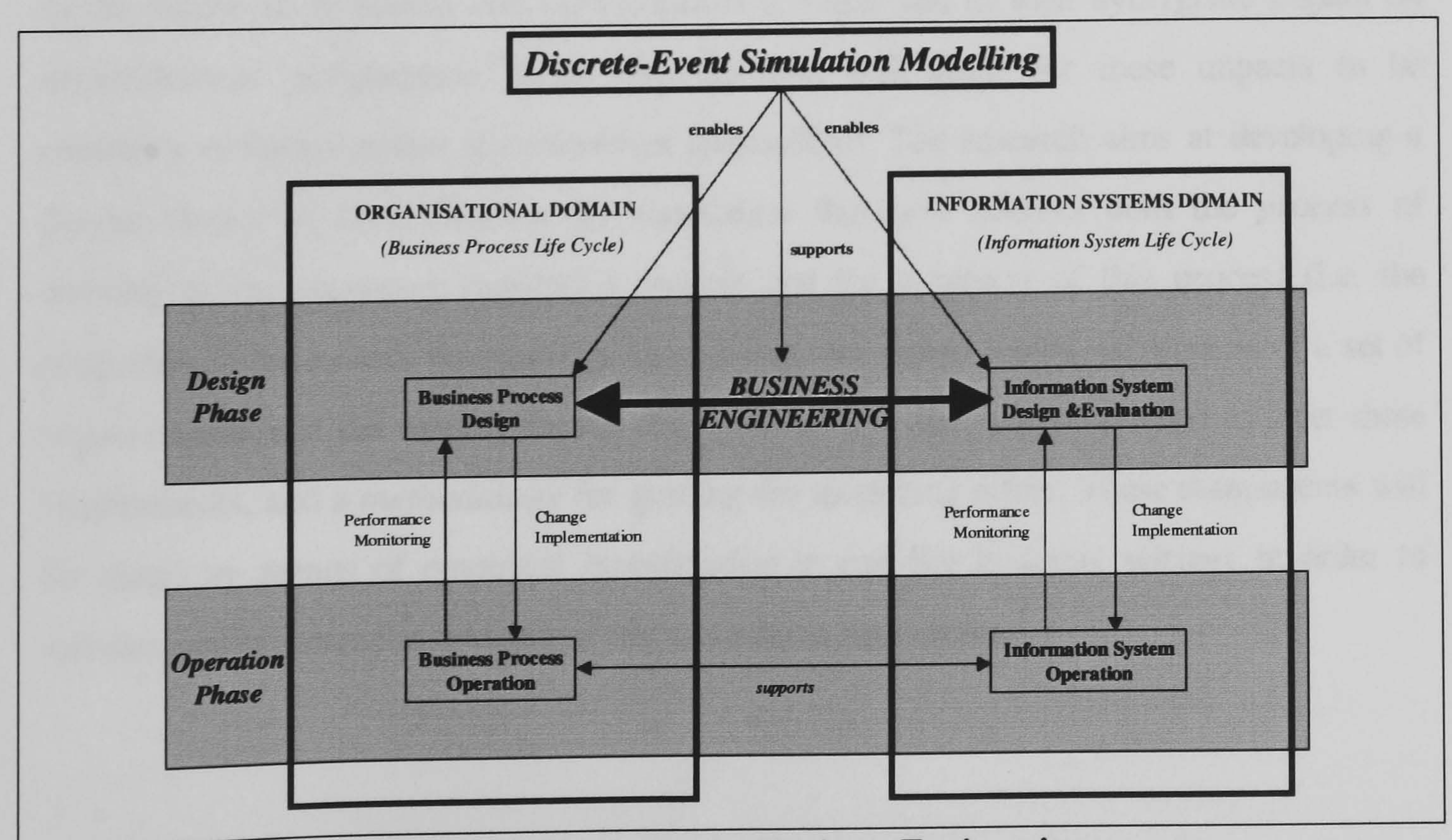


Figure 4. Simulation for Business Engineering

More specifically, the work described in this dissertation takes an *organisational view* of Information Systems aimed at providing a systemic and dynamic evaluation of the effects of a proposed IS on its host organisation. The approach involves the creation of a discrete-event simulation model of organisational processes before the introduction of the proposed Information System. The Information System is then 'superimposed' on the model of the organisation in terms of its anticipated effects on the organisational processes. The model, and hence the Information System, is then evaluated in terms of high-level organisational performance measures and against alternative scenarios for business process redesign enabled by Information Technology.

This approach to IS evaluation by simulation is not intended to replace existing methodologies for structured IS development and IS evaluation, but rather to be used as a complement to them in order to overcome some of their inherent shortcomings. As will be argued in Chapter 2, most extant methodologies for IS development and evaluation necessarily adopt an increasingly narrower viewpoint as they proceed through the various steps they include, focusing more and more on the details of the Information System itself, and neglecting the organisation and its own requirements. The work described here addresses this problem by remaining at a high level of abstraction throughout the evaluation process to ensure that an organisational-wide perspective is always maintained.

To address this requirement, the research focuses on establishing a sound understanding of the nature of structural and informational changes and of their synergistic impact on organisational performance. Such understanding will allow for these impacts to be explicitly modelled within discrete-event simulations. The research aims at developing a *design theory* of *IS evaluation by simulation* that will address both the *process* of arriving at the necessary simulation models and the *products* of this process (i.e. the properties of the models themselves). To this end, the design theory will consist of a set of *requirements* that the models should satisfy, a *design* that is hypothesised to meet these requirements, and a *methodology* for guiding the modelling effort. These components will be tested by means of empirical investigation in real-life business settings in order to validate and enhance the findings of our theoretical hypotheses.

In this context, the research is expected to contribute towards:

a) Developing theoretical and practical mechanisms for addressing some of the most important problems in process-based organisational design, IS development, and IS evaluation. These problems are related to the *integral* design and analysis of business and IS structures and the problem of pre-implementation IS evaluation.

b) Providing support for the design and development of business process simulation models capable of encompassing the effects of Information Systems on organisational performance.

c) Supporting the process of effectively utilising such simulation models within business engineering projects by providing context-specific methodological guidelines for simulation-assisted IS evaluation.

1.4. Research Methodology

The issue of selecting an appropriate methodology for Information Systems research has been the subject of extensive debate amongst prominent IS researchers. Certain schools of thought advocate the use and appropriateness of empirical research methods drawn from the natural sciences, adopting a positivist stance based on the inductive-experimental method and beliefs about the need of experimental confirmation of theses (Kuhn 1970).

However, most IS researchers advocate that, since Information Systems is essentially a social science field, IS epistemology[2] should draw from the social sciences to identify appropriate methods for conducting useful and valid research. They argue that the positivist stance of the natural sciences, namely that knowledge is 'apodeictic' (i.e. provable), needs to be replaced by a 'post-positivist' one that is concerned more with belief about knowledge (Hirschheim 1992). As Galliers (1992a) puts it '*research that produces conclusions that are accepted by the academic community as an improvement on our previous level of understanding (whether these conclusions are incontrovertible or not) is not only acceptable, but perhaps even preferred in [the Information Systems] context*'.

---

[2] *Epistemology* refers to our theory of knowledge, in particular how knowledge is acquired. Its sources can be traced back to philosophers of ancient Greece who classified knowledge into two types: 'doxa' (that which is believed to be true) and 'episteme' (that which is known to be true). Science, they believed, is the process of inquiry that transforms 'doxa' into 'episteme'.

An interesting part of post-positivist thought is its belief in what might be termed 'methodological pluralism' – the assertion that there is no one correct method of science but many methods (Polkinghorne 1983). Arguably, within the Information Systems domain, one could hardly envisage a single research method with universal applicability to the whole range of problems to which IS research may be applied (Banville and Landry 1989, Galliers 1992b). The choice of a particular method or set of methods will necessarily depend on the particular topic studied, the objectives of the research, and the broader context in which it is being performed.

A detailed discussion of issues of methodological approaches and related matters goes beyond the scope of this dissertation. However, taking into account that Information Systems make sense only in the context of the purpose to which they are being put (Land 1992, Checkland and Scholes 1990), we would generally place increased importance on field-based research methods rather than purely laboratory-based ones when undertaking research related to the organisational effect of Information Systems. This point has, perhaps more than any other, influenced the choice of methodological approach followed in this research.

To identify pertinent research methods for our work, we used a taxonomy of Information Systems research methods proposed by Galliers (1992b). This taxonomy (illustrated in Table 2) reflects the likely suitability of a given research method in the context of a particular research topic under study (although it should be stressed that the taxonomy is intended to provide guidelines only, instead of strict prescriptions for methodological choice).

Focus / *Methods*	Society	Organi-sation	Individual	Techno-logy	Methodo-logy	Theory Building	Theory Testing	Theory Extension
Theorem Proof	No	No	No	Yes	**Yes**	No	**Yes**	Possibly
Lab Experiment	No	Possibly	Yes	Yes	No	No	**Yes**	Possibly
Field Experiment	Possibly	**Yes**	Yes	Yes	**Yes**	No	**Yes**	Possibly
Case Study	Possibly	**Yes**	Possibly	No	**Yes**	**Yes**	**Yes**	Possibly
Survey	Yes	**Yes**	Possibly	Possibly	**Yes**	**Yes**	Possibly	Possibly
Forecasting	Yes	**Yes**	Possibly	Possibly	**Yes**	**Yes**	Possibly	Possibly
Role Playing	Possibly	**Yes**	Yes	Yes	**Yes**	**Yes**	Possibly	No
Subjective	Yes	**Yes**	Yes	Possibly	**Yes**	**Yes**	No	No
Descriptive	Yes	**Yes**	Yes	Possibly	**Yes**	**Yes**	Possibly	Possibly
Action Research	Possibly	**Yes**	Possibly	No	**Yes**	**Yes**	**Yes**	Possibly

Table 2. A Taxonomy of Information Systems Research Methods (Galliers 1992b)

The greyed columns in Table 2 represent the research dimensions of the topic under investigation in this dissertation. As already argued in the preceding section, we will be concerned with building and testing a design theory of IS evaluation by simulation that will enable modelling and analysis of the organisational impact of a proposed Information System in the context of business engineering. Therefore, the *organisational dimension*, the *methodological approach*, and the *theory building and testing perspective*, seem the pertinent focal points for choosing an appropriate set of methodological approaches for our research. Mapping the dimensions of these research objectives to the range of research methods available, the *case study* and the *action research* approaches seem to be the ones that satisfy our requirements and can better serve our research goals. In addition, these methods have come to be accepted by the IS community as the most representative methods of what might be called a 'paradigm' (Kuhn 1970) for IS research (Farhoomand 1987, Hamilton and Ives 1982). It was therefore decided that a combination of these research methods would be pursued. A more detailed discussion on the reasons for the adoption and the usefulness of each of these research methods will be presented in Chapters 3 and 5, where these methods are employed for the empirical parts of the work discussed in this dissertation.

To set these methods within a comprehensive research framework that would allow for perceiving the research problems identified earlier in an effective and appropriate manner, the research approach advocated by Galliers (1992b) was selected. The particular approach (illustrated in Figure 5) satisfies the need for methodological pluralism by providing a balanced combination of both empirical and interpretivist methodologies in a manner that satisfies two important requirements:

a) It places the research within the context of existing knowledge in the field and therefore allows for building new knowledge that can contribute towards increasing and improving the intellectual basis of the field.
b) It enables the identification of research limitations and future opportunities that can be further pursued by future research to extend the knowledge acquired here.

The generic structure of Galliers's research approach is illustrated in the left part of Figure 5, while the right part of the same Figure maps the approach to the structure of this dissertation. This structure will be discussed in detail in the following section.

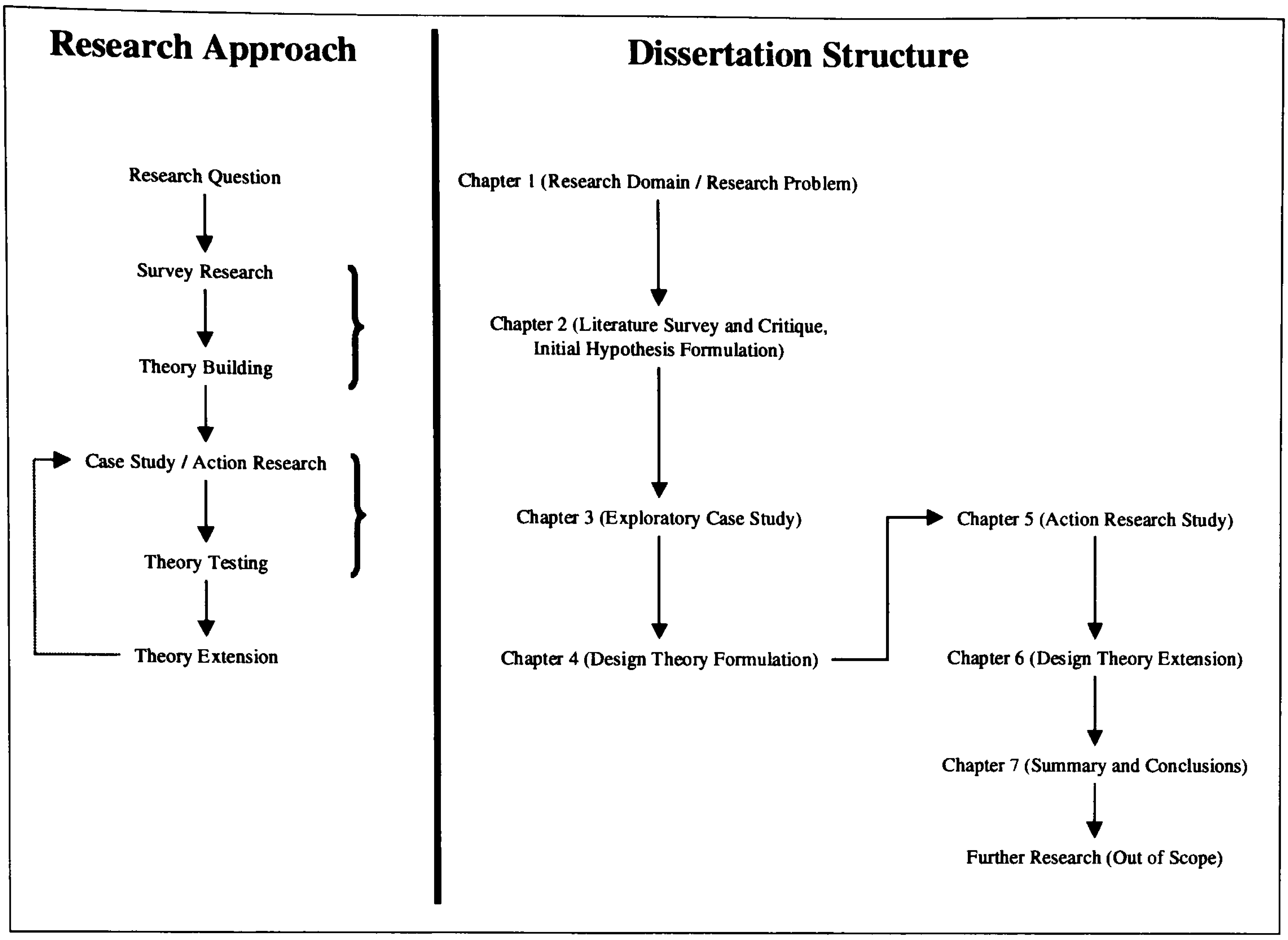


Figure 5. An Approach to IS Research (Galliers 1992b) vs. the Dissertation Structure

1.5. Dissertation Outline

This dissertation is structured in seven Chapters, each one addressing a distinct point in carrying out this research, based on and reflecting the underlying research strategy articulated above. The first Chapter (*Introduction*), set out to present a brief account of the research background, by addressing some of the key concepts that will be discussed in detail in the rest of this volume. Furthermore, this Chapter introduced the objective and scope of this research, as well as the methods chosen, in order to inform the reader about the contents and structure of the work.

Having discussed the basic concepts and drivers of the research, Chapter 2 (*Background Research Material*) will provide a more in-depth, critical analysis of the evolution of methodologies for process-based organisational design, IS development, and IS evaluation, thus addressing all the reference disciplines of business engineering. The Chapter draws together some thoughts about the nature of these disciplines and the need to further develop thinking in the area. It is suggested that a major problem in IS evaluation is that as Information Systems pass through the various stages of their development life cycle, there is a natural and acceptable tendency for them to be defined in greater and greater detail. This trend of '*reductionism*', however, is a move away from the high-level business issues the initial specification of the system was intended to address. The Chapter concludes with the view that IS should be evaluated in terms of their impact on the host organisation and its processes, rather than solely on their technical dimension. The Chapter also introduces, in broad terms, the concept of employing business process simulation to alleviate some of the problems identified in the literature review. The arguments presented provide an initial basis for the articulation of the theoretical propositions to be discussed in Chapter 4.

However, before developing these propositions in detail, an empirical case study is employed in order to complement, validate, and enhance the findings of the literature review. Chapter 3 (*Case Study I*) explores some of the issues of *IS evaluation by simulation* in a practical setting, by discussing the process and the findings of a simulation study addressing the potential benefits of introducing Electronic Data Interchange (EDI) applications in companies across a whole industrial sector. The Chapter reports the process of carrying out the study and developing the simulation models, and critically appraises the results obtained. The findings of this exploratory empirical work serve to complement and reinforce the theoretical findings of Chapter 2, and hence provide an additional basis for the development of the theoretical propositions to be discussed in the next Chapter.

Chapter 4 (*A Design Theory for IS Evaluation by Simulation*) discusses the development of theoretical and methodological propositions for IS evaluation by simulation. The concept of Information System Design Theories (ISDT) (Walls et al 1992) is employed to guide the articulation of the design theory components. The Chapter describes the underlying assumptions and foundations of the theory, together with the rationale behind its development, and the theory's constituent parts. These parts consist of a set of *meta-requirements* that simulation models should meet if they are to be useful aids in IS evaluation, a *meta-design* that is hypothesised to address these requirements, and a *design method* providing specific guidelines for structuring and carrying out the model development effort. Finally, a set of *testing hypotheses* is presented in order to assess the theory's validity and contribution.

Chapter 5 (*Case Study II*) discusses a more comprehensive and detailed real-life study of IS evaluation by simulation. This time the study is carried out on the basis of the theoretical propositions of the design theory. The action research method is employed to facilitate increased participation and in-depth understanding of the issues under investigation. The study assesses the anticipated effects of introducing *informational* and *structural* changes within and between two collaborating organisations. Emphasis is mainly placed on the representation of the proposed IS within the simulation model, the use of simulation for assessing the expected impact of IS on business performance, and the potential of the findings to drive an informed financial appraisal of the investment proposals.

Chapter 6 (*Theory Evaluation and Extension*) reflects on the results of this empirical work to assess the potential of the design theory to support IS evaluation in the context of business engineering. Drawing on the added insight gained by the second study results, and contrasting the findings with those of the first case study, the design theory presented in Chapter 4 is further elaborated into a more detailed approach to IS evaluation by simulation. The implications of the design theory are also discussed to highlight theoretically and practically attractive areas for further development.

Finally, Chapter 7 (*Summary and Conclusions*) summarises the thesis of this dissertation, presenting the major conclusions reached, as well as possible limitations of the approach, and highlights possible avenues for further research.

1.6. Summary

This Chapter provided the forum for an introductory discussion of the issues that will be the subject of further analysis in this dissertation. An introduction to the concepts and basic ideas behind the issue of IS evaluation in the context of business engineering was presented. This was followed by an initial account of the potential role of discrete-event simulation in addressing (at least some of) the IS evaluation problems.

In addition, the aim of this introductory Chapter was to elaborate the objectives and expected outcomes of this research, in order to prepare the reader for the detailed discussion of each particular aspect and phase of the work that will follow. In this context, the purpose of this Chapter was to set the 'roadmap' for the whole journey, ensuring that the reader is properly equipped before he or she embarks on it.

CHAPTER 2. BACKGROUND RESEARCH MATERIAL

The purpose of this Chapter is to provide a detailed analysis and critical appraisal of the areas introduced in Chapter 1 as the context and supporting technique for this research (business engineering and discrete-event simulation respectively). To fulfil this role, the Chapter begins with a review of extant approaches to the reference disciplines of business engineering, namely process-based organisational design, IS development, and IS evaluation. Since the existing body of work in some of these areas (especially IS development) is overwhelming, the work presented here does not aim to provide an exhaustive analysis of these subjects. Instead, the contents of, and level of description of the material in, this Chapter have been selected to provide a relevant contextual framework for an understanding of the theoretical propositions and empirical research work to be presented in subsequent Chapters. A critique of the relevant literature is also included to explain some of the underlying limitations of current approaches. The Chapter concludes with identifying a need for further research work towards the development of a *design theory of IS evaluation by simulation* and postulates an initial set of attributes for such a theory.

2.1. Process-based Organisational Design (POD)

2.1.1. Introduction

As discussed in Chapter 1, business engineering can be defined as the *integrated* design of organisational processes and Information Systems. Business engineering researchers (for example Keen 1991, Scott-Morton 1991, Galliers 1993, Grover et al 1994, Venkatraman 1994, Fielder et al 1995) have argued against the notion of introducing IS in organisations for the *automation* of existing processes within the boundaries of traditional functional areas (Davenport 1993). Instead, they contend that IS should be introduced for business process *transformation* (Venkatraman 1991). The underlying basis for this proposition is simple: while automation of existing processes may increase the speed at which they are executed, it is based on the questionable assumption that these processes are satisfactory (Fielder et al 1995). Such an approach can have considerable drawbacks: Harrington (1991) asserts that automating an inefficient process will simply produce a 'faster mess'. Business engineering takes a step back and looks at ways in which business goals can be supported by ***redesigning*** the existing process while *at the same time* considering how Information Systems can support the new process (Galliers 1993). By approaching business design and IS design in such an integrated fashion, we can take advantage of the improved co-ordination, communication, and information manipulation capabilities of Information Systems (Keen 1991, O'Brien 1993).

These principles have spawned much research on the role of IS in business process change (Scott-Morton 1991, Venkatraman 1994, Fielder et al 1995). The essence of such thinking is based on the belief that the real power of Information Systems does not lie in their ability to just automate business processes, but rather in their potential to transform work by breaking implicit business rules and assumptions (Davenport 1993). This '*disruptive*' power of technology (Hammer and Champy 1993) can explain its ability to alter the competitive position of firms (Porter 1985, King et al 1988) and to deliver strategic organisational benefits (Earl 1988).

However, in order to be used in such a beneficial manner, IS should not be treated as a purely technical or technological matter (Hirschheim 1992, Land 1992) and, hence, should not be designed and implemented only in the aftermath of business process change. Rather, Information Systems should be envisaged, studied, and evaluated *together* with the study and evaluation of the business processes they are intended to support.

2.1.2. Methodologies for Process-based Organisational Design

Against the backdrop of social, economic, political, and technological changes faced by modern firms, the above concepts quickly caught the attention of business practitioners and researchers alike. Fuelled by an increasing demand for organisational change, the last decade has witnessed the development of an overwhelming number of methodologies, techniques, and tools for supporting process change projects. Kettinger et al (1997) provide a detailed review and critical appraisal of such methods. This appraisal can reveal an interesting fact: although Information Systems are usually mentioned as a critical enabler of process change, the *integration* of IS design, development, and evaluation into business process change methods has generally failed to attract the attention of researchers. To illustrate this point, we will present two renowned methods of business process change and discuss the limitations of their applicability for business engineering.

The two methods to be reviewed are Davenport's (1993) framework for process innovation and Kettinger et al's (1997) Stage-Activity BPR framework. The former is presented as an example of an early framework for business process change, developed by one of the movement's first advocates. Davenport's framework has significantly influenced the development of (and in a sense encompasses) a number of subsequent BPR methodologies. The Stage-Activity framework, on the other hand, was chosen because it represents a widely acknowledged example of a holistic BPR methodology (a BPR project 'archetype' according to its developers), having been developed as a synthesis of a wide number of existing BPR methodologies. Therefore, these two methods can be considered as a 'representative sample' of the majority of extant approaches to business process change.

Davenport (1993) has proposed a high-level framework to guide the implementation of business process change (illustrated in Figure 6). According to this framework, the *first* step in a process change project should be to identify the processes that are performed by the organisation so as those that are more suitable for redesign can be selected. The *second step* in the framework is concerned with identifying the organisational elements that could enable the introduction of changes in the selected processes (change levers). Davenport distinguishes between three main such elements: Information Technology, human resources, and organisational structure.

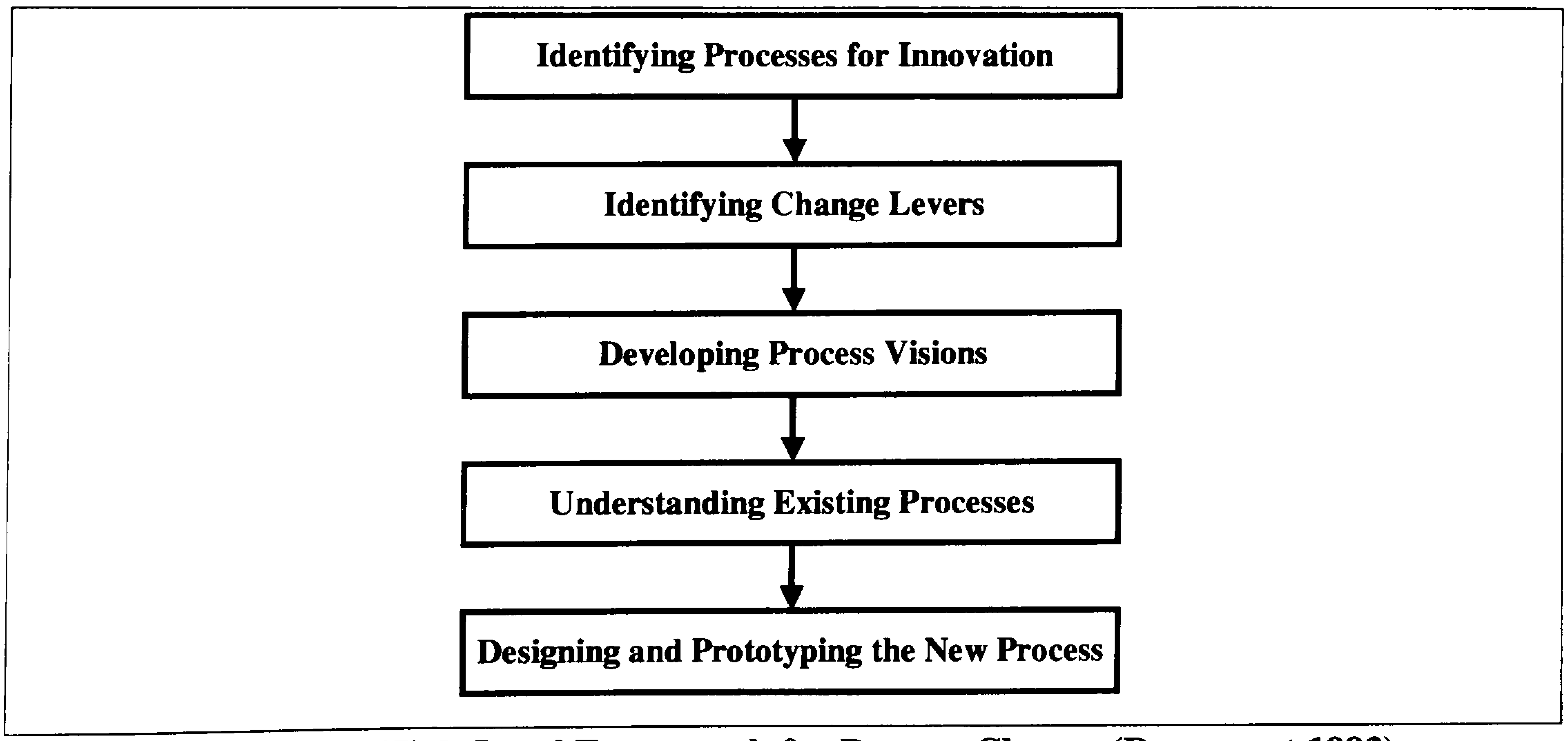


Figure 6. A High-Level Framework for Process Change (Davenport 1993)

Business process change can only be meaningful if it improves businesses in a way that is consistent with their strategy (Fiedler et al 1995, Galliers 1993). Therefore, it is essential for every company that engages in a process change project to have formulated a clear business strategy that will inspire a vision to all parts of the business. This is the objective of the *third step* in the framework. The vision should consist of specific, measurable objectives for process performance and attributes of the future process state in order to provide the necessary linkage between strategy and action.

The *fourth step* involves gaining a detailed understanding of the way existing processes are performed in order for problems and pitfalls to be identified and not repeated. According to the results of process analysis, the redesign team should be able to produce a number of alternative processes, which are comparatively evaluated in the *fifth step* before deciding on a particular solution. Once the decision-making process is complete, the organisation needs to formulate a migration strategy towards the selected solution and start implementing the new organisational structures and systems that will support the new processes.

Kettinger et al (1997) followed a different approach in developing the Stage-Activity (S-A) framework for BPR. Having at their disposal a wide number of previously developed methodologies, techniques, and tools for BPR, the authors attempted to synthesise them into an empirically derived framework for carrying out BPR analyses. This framework is illustrated in Figure 7.

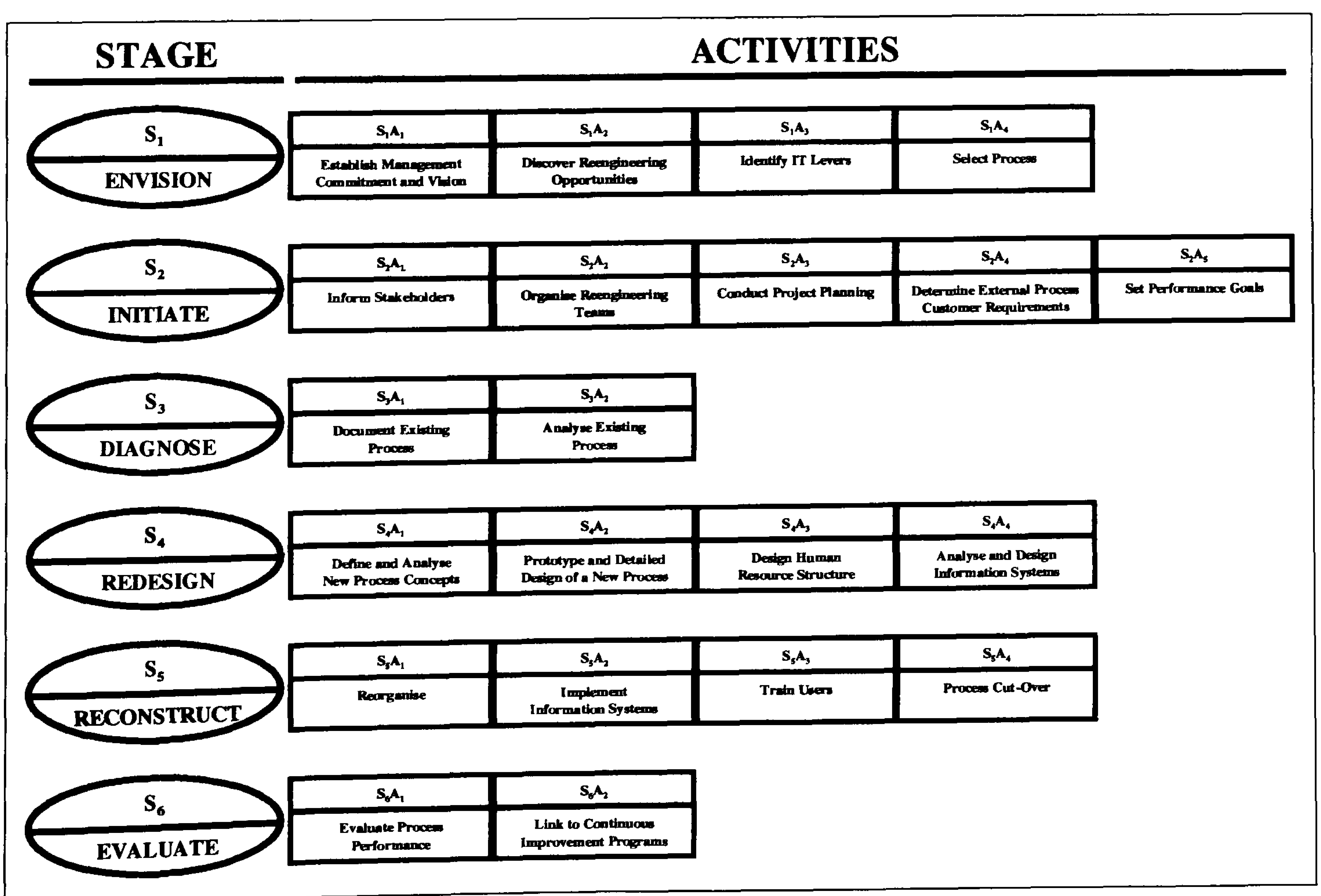


Figure 7. Stage-Activity BPR Methodology (Kettinger et al 1997)

The six stages in the S-A framework can be described as follows:

a) *Envision*: This stage typically involves engendering the support of top management, and creating a task force authorised to target a process for improvement based on a review of business strategy and IT opportunities.

b) *Initiate*: This stage encompasses the assignment of BPR project teams, setting performance goals, project planning, and stakeholder/employee notification and 'buy-in'.

c) *Diagnose*: This stage is classified as the documentation of the current process in terms of process attributes such as activities, resources, communication, roles, IT, and cost. Analysis of the process aims at identifying root causes for problems and non-value-adding activities.

d) *Redesign*: In this stage a new process design is developed (after a consideration of alternatives), documented, and prototyped. This stage also involves the design of the Information Systems to support the new process.

e) *Reconstruct*: This stage relies heavily on change management techniques to ensure smooth migration of the organisation to the new situation. Information Systems are implemented during this stage.

f) *Evaluate*: The last stage involves monitoring the new process performance to assess the success of the BPR project, as well as ensuring continuous change is maintained after the end of the project.

Apart from its much more detailed nature, the S-A framework does not differ notably from Davenport. Both frameworks emphasise the stages of understanding existing processes, as well as designing and prototyping new ones. However, the role of Information Systems in enabling change is acknowledged in more detail in the S-A framework, by placing specific attention on designing (activity S_4A_4), and implementing (activity S_5A_2) new Information Systems.

2.1.3. A Critique of Approaches to Process-based Organisational Design

Further to the two examples discussed above, a wide number of methodologies for process change have been proposed in the literature (for examples, see Furey 1993, Harrison and Pratt 1993, Wastell et al 1994, Klein 1994). In almost all of these approaches, Information Systems are mentioned, in one way or another, as one of the primary enablers of change in contemporary firms. However, individual approaches differ in the order in which they advocate that design of business processes and Information Systems should be undertaken. Conventional wisdom holds that business processes should first be planned in abstract without reference to specific technological enablers of changes (for example, Harrington 1991). Information Systems can then be designed to fit the chosen process structures.

Business engineering is however supposed to take a more holistic approach to planning business change, ensuring that business processes are not designed without reference to the opportunities that Information Systems can bring to business analysts. Although theoretically attractive, such an integrated perspective is far from easy to achieve in practice. As argued in Chapter 1, business analysts and IS specialists have usually distinct roles and levels of authority in organisations. Most business engineering methodologies reinforce this distinction by either concentrating exclusively on the business process level (earlier methods, for example Davenport's framework) or by failing to realise the complexity of IS design and development (later methods, for example Kettinger et al's framework). Davenport, for example, identifies IS as one of the three main enablers of business change, but makes no specific reference to integrating IS design and process design. Recognising this limitation, the S-A framework makes explicit provision for IS design and development within a process change project, albeit confining them in only two out of a total of twenty-one steps that should be performed in a process change project.

Since IS design and development are typically so complicated endeavours that they usually form complex organisational projects of their own, the challenge for business engineering is to bring process design and IS design together without adding to the, already high, complexity of each task alone. One way to achieve this objective is by incorporating *high-level* IS design into business process design projects and leaving the technical details of IS implementation to be managed in the aftermath of process change decisions. Such an approach has two advantages. On the one hand, it ensures that a focus on the *alignment* of organisational and IS structures is always maintained, allowing business managers to assess the organisational impact of *structural* and *informational* changes in an integrated fashion. On the other hand, it drives the complexity of designing detailed IS structures out of the process change endeavour, allowing decision-makers to concentrate on *organisational*, rather than *technical*, factors when designing and evaluating changes. As will be argued later in this Chapter, such an approach presents significant advantages for the IS specialists as well.

Acknowledging this need, the research presented in this dissertation is primarily concerned with addressing the potential of discrete-event simulation models to allow for assessing the organisational impact of *structural* and *informational* change proposals *within the same simulation model.* To be an effective facilitator of business engineering, business process simulation models should allow organisations to model their processes and incorporate in these models, in an explicit and direct manner, the effects that Information Systems will have on business performance. Such incorporation should be achievable without the need to specify in advance the implementation details of these Information Systems. Indeed, the use of BPS for business engineering should be feasible when the proposal for an IS is still in its early stages, for example during the feasibility study or initial design stages.

Having discussed the problems of business engineering from the business change perspective, in the following sections we will argue that problems of a similar nature can emerge in the IS domain as well. To illustrate this point, we will turn to a review of existing approaches to IS development and evaluation and how the shortcomings of these approaches can be addressed through the use of simulation.

2.2. Information Systems Development (ISD)

2.2.1. Introduction

During the earlier eras of computing, the implementation of Information Systems was typically conducted without the aid of explicit methodologies to guide development efforts. However, the proliferation of Information Systems in the last two decades has naturally resulted in increasingly complex systems being built to support core business activities. To assist in achieving maximum efficiency in building and using such systems, a number of structured methodological approaches to IS development have been developed (for example the Structured Systems Analysis and Design Methodology or SSADM, Downs et al 1992). The aim of such approaches is to provide a systematic, stepwise development framework to structure the development process and ultimately lead to 'better' Information Systems.

Our aim in the context of this dissertation is not to present each IS development methodology in detail. However, in order to gain a better understanding of the underlying assumptions of these methodologies and the limitations they may impose on practical business engineering, it is necessary to provide a brief overview of their principles. Since the components of structured IS development methods collectively comprise what is commonly referred to as the Systems Development Life Cycle (SDLC) (Avison 1997), we will present an overview of the SDLC in the next section. The discussion that follows is applicable to SDLC and hence to the majority of structured IS development methods that follow the SDLC paradigm.

2.2.2. Methodologies for IS Development

A typical archetype of the SDLC is illustrated in Figure 8 (Turban et al 1996). The definitions of the various steps in the SDLC, as discussed below, are revealing of the close relationship, yet practical incompatibility, between extant approaches for business process change and IS development.

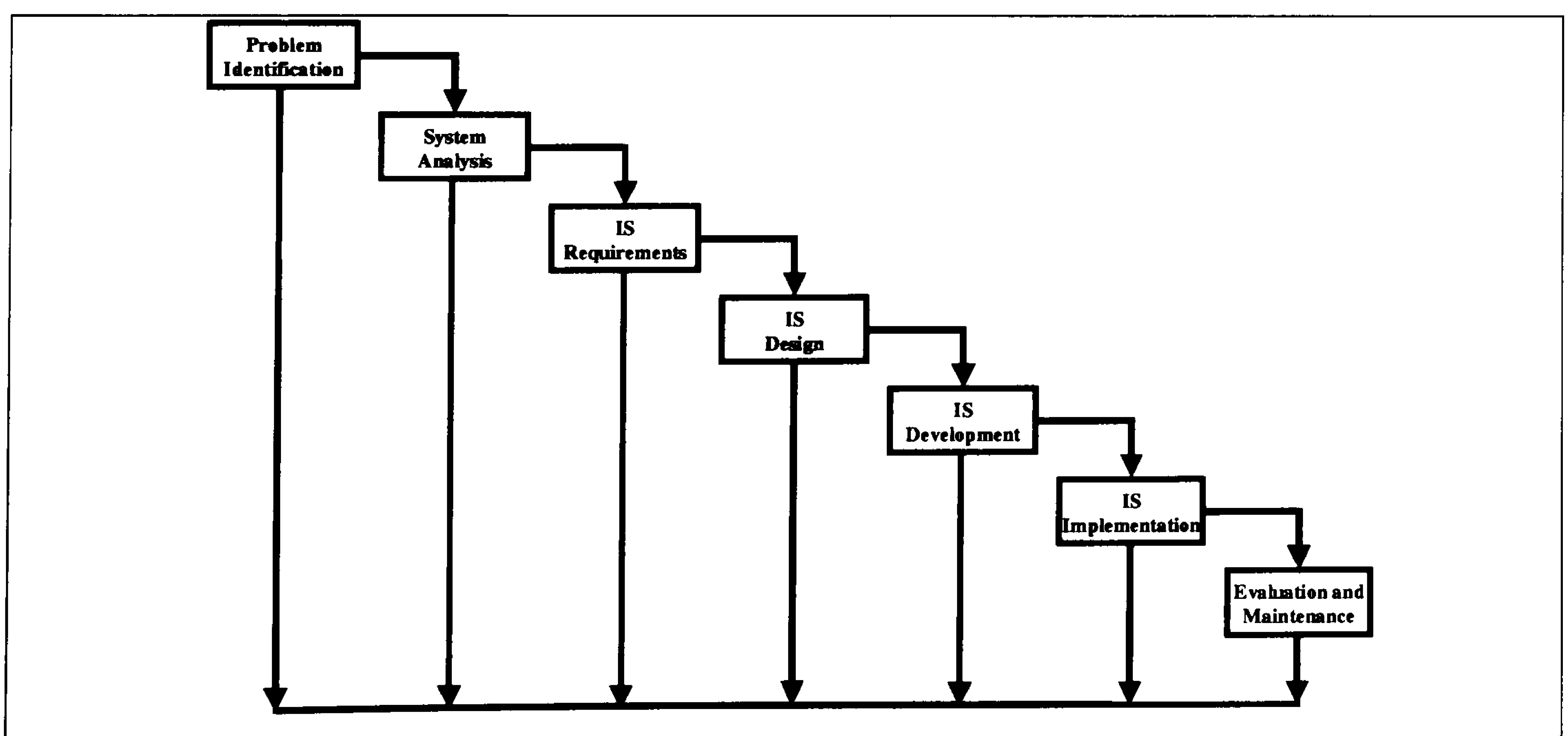


Figure 8. The System Development Life Cycle (Turban et al 1996)

The steps of the SDLC can be briefly described as follows:

a) *Problem Identification.* The impetus for initiating an IS development project is to identify business problems or opportunities, and to envisage some action necessary to address them (Turban et al 1996). This stage is sometimes called the 'feasibility stage' because its objective is to define the system to be developed in broad terms and to articulate criteria for its justification (usually in the form of monetary costs and benefits).

b) *System Analysis*. Existing systems need to be thoroughly analysed and documented before designing, developing, and implementing changes. Most methodologies employ some kind of diagrammatic technique to aid the analysis process, such as flowcharting.

c) *IS Requirements*. Once problems with the existing system are identified and documented, the information requirements of the new system can be determined. A commonly used technique at this stage is data flow diagramming (DFD), which provides a means for describing the structure of information flows that the Information System is expected to address (see Appendix A).

d) *IS Design*. The design of the Information System involves the translation of requirements obtained during the previous step into detailed system specifications. Essentially, the process of IS design involves the detailed specification of database structures, user interfaces, and other system elements that are mostly technology-specific.

e) *IS Development*. This step consists of building and/or purchasing computer programs, installing hardware and software, customising operations, and so on. The end product is an operable and reliable system that actualises the original design objectives.

f) *IS Implementation*. This step is mainly concerned with the conversion of the old system (computerised or not) to the newly developed one, and involves issues such as system integration, data migration, user training, and so forth.

g) *Evaluation and Maintenance*. The final step is concerned with reviewing the degree to which the new system provides effective and efficient solutions to the initial problems, and maintaining the system during its life span.

2.2.3. A Critique of Approaches to IS Development

Of course, the SDLC, when applied in practice, does not usually take the linear form that the aforementioned discussion may imply. Nor do all individual IS development methodologies follow exactly the same approach to system development. However, for the purpose of this research, we will be concerned only with the general features and common underlying concepts of IS development methodologies. Therefore, the SDLC will suffice to clarify our arguments regarding the inadequacy of IS development methodologies to capture the entirety of factors necessary for a holistic approach to business engineering.

Probably the first remark to be made about IS development is the inherently complex nature of the activity of designing and implementing Information Systems, especially when their nature is critical to the organisation and its success in the marketplace. As far as business engineering is concerned, this complexity implies that it may not be effective, or even feasible, to integrate IS development within business process change as many of the process change methods advocate (for example, the S-A framework discussed earlier). This point reinforces our earlier argument for incorporating only the high-level organisational impacts of IS in business process design and leaving the low-level technical implementation details for later.

Another observation that could be made about SDLC-based IS development methods is that they perpetuate the distinction between the business and the IS domain, as argued in Chapter 1. Most structured approaches to IS development begin with an implicit assumption that the business domain issues are resolved and the system is to work in a stable and well-defined business environment, where the only issue is to identify the 'correct' requirements for the new IS (Paul 1993). As a result, not enough attention is generally being paid to investigating the interactions of the IS to be developed with the business processes it will naturally affect. Wolstenholme et al (1993) have described such approaches to IS development as 'reductionist'. According to the authors, a top-down approach to IS development may be necessary to ensure the decomposition of a complex problem into smaller, more manageable tasks, but it can pose a potential danger for the effectiveness of the final system. As system development proceeds, the focus is steadily moving away from high-level organisational issues towards more detailed sub-problems concerned with the IS itself. Such a paradigm for IS development necessarily separates and treats in isolation business processes and Information Systems. At no later point in the system development life cycle are these organisational facets re-united in order to identify possible redundancies or sub-optimal designs arising from this artificial separation.

Sceptics may argue that the systems development life cycle allows ample scope for consideration of business process changes in the early stages of the life cycle (for example, problem identification and system analysis). Indeed, the 'textbook' approach to IS development expects that the system analyst will redesign, or at least address, business processes prior to the development of the IS (Alter 1996, Galliers 1993). However, Davenport (1993) warns against the potential inadequacy of this approach to yield practical results. It is unlikely that system analysts will be granted the necessary degree of organisational authority by senior management to make, or even recommend, fundamental changes in business processes (Fielder et al 1995). Even if the system analysis team intends to address such issues, it is most likely that they will not be able to do so due to organisational politics or other reasons beyond their jurisdiction (Davenport and Stoddard 1994).

A final point can be made regarding the evaluation of IS in most traditional system development methodologies. SDLC-based approaches tend to view IS evaluation as a post-implementation activity only (addressed only in the last step of the system development life cycle). Although clearly important, such an assessment comes too late to have any real impact on the development process and can only benefit future versions of the Information System. What may be additionally needed, is an explicit focus on the pre-implementation (*ex ante*) evaluation of the Information System (for example, within the *problem identification* or *system analysis* stages). Such an evaluation should abstract away from technical details and focus on justifying the need for, and the costs and benefits associated with, the development of a system in terms of its impact on business processes and organisational performance. Some authors have gone one step further to suggest that IS evaluation is so important that the whole IS development process '*should be seen as an inquiry supporting IS assessment*' (Iivari 1988).

Summarising, we can conclude that most IS development approaches, although starting from a sound viewpoint, focus too narrowly on the Information System as an independent artefact and quickly abstract away the organisational environment to which this artefact will ultimately be applied. We argue that the SDLC-based approaches to IS development generally fail to grasp the wider picture and rationale for IS development, and therefore are insufficient tools for business engineering. What may be needed is a reverse of the process of progressively decomposing the problem in order to determine information requirements and design the Information System. When the system is evaluated, the high-level real-world picture should be reconstructed in order to ensure that the aggregate effect of the Information System on the business processes is evaluated. By studying the organisational processes that the Information System is expected to affect, the managers, system designers, and users can evaluate the real impact of the system on business performance. Furthermore, such an approach can facilitate the evaluation not only of Information System-induced (*informational*) changes, but also of changes in the business processes that will accompany the new system (*structural* changes). Therefore, such an approach is consistent with the requirements of business engineering, namely the *integrated* design of business processes and Information Systems.

2.2.4. Recent Trends in IS Development

Recognising the desirability of bringing the IS development process closer to the needs of the real-world organisation, a number of more recent, non SDLC-based, methodological approaches to IS development have emerged. In the interest of completeness of presentation, we will briefly discuss some of these approaches here.

The *prototyping* approach aims at improving interaction between software engineers and system users by developing limited-scale archetypes of a system before its full-scale implementation (Boar 1984). By implementing such prototypes, system designers can demonstrate the functionality and interfaces of the system to the end users, and obtain early feedback on additional user requirements. Prototypes can be developed with the aim of being discarded during the full-scale development process, or they can be enhanced, by a process of iterative conversion, to form the total IS solution, an approach that is sometimes referred to as *evolutionary IS development* (Arthur 1992).

Another approach that has been developed in order to bring IS experts and end users together, is *Joint Application Development* or *JAD* (Kettelhut 1997, Purvis and Sambamurthy 1997). JAD requires the formal assignment of users as members of the development team to speed up the development process and improve the likelihood of user acceptance of the Information System. Other methodological approaches for IS development also aim at addressing the problem of lack of communication between the organisational and software engineering domains. For example, the *Jackson System Development* (*JSD*) methodology (Jackson 1988), the *ETHICS* methodology (Mumford and Weir 1979), and the *Multiview* methodology (Avison and Wood-Harper 1990), all aim at increasing participation and introducing 'soft' problem solving methods, like the

Soft Systems Methodology (*SSM*) (Checkland 1981, Checkland and Scholes 1990), in the system development life cycle.

Perhaps the most important element, and common point, in most of the aforementioned IS development methodologies is the fact that they combine generic problem-solving techniques with proven IS-specific methods and they adopt a 'socio-technical' view of business systems (Mumford and Weir 1979) to overcome the limitations of the technical focus of the SDLC paradigm. Such approaches can facilitate a more holistic view of the IS development process, and thus they can be said to start from a valid viewpoint in addressing some of the problems associated with the communication between IS developers and IS users. However, they hardly provide any explicit support for evaluating the business performance impact of IS-induced changes. To address this problem of business engineering, we argue that IS development methodologies need to place more attention to the problem of assessing the effect of an Information System on its host organisation. To this end, a number of focused approaches to *IS evaluation* have been developed. We will turn to a discussion of these approaches in the following section.

2.3. Information Systems Evaluation (ISE)

2.3.1. Introduction

The use of methodological approaches to IS development has undoubtedly contributed to the creation of more flexible Information Systems. However, many systems still fail to fulfil the needs of their users and the organisations that adopt them (characteristic and well-publicised examples of IS failures can be found in Oz 1994 and Beynon-Davies 1995). IS failure can translate to huge financial losses due to the large capital investments most organisations make in Information Technology. By 1991, UK company expenditure on IS was exceeding £10 billion per year, equivalent to an average of over 1.2% of annual turnover (Willcocks 1992a). At the same time, research studies suggested that at least 20% of this expenditure was wasted and between 30% and 40% of IS projects realised no net benefits, however measured (Willcocks and Lester 1991).

As a result of these cautionary figures, IS specialists and business managers have historically expressed increasing concerns regarding their ability to evaluate their investments in Information Systems prior to committing organisational resources in IS implementation (Raymond et al 1995). Dickson et al (1984) surveying the most prevalent concerns of IS managers, found both '*Measuring and improving IS effectiveness/productivity*' and '*Aligning the IS organisation with that of the enterprise*' ranking very high in IS managers' lists. Seven years later, Watson and Brancheau (1991) reviewed and compared the key concerns of IS executives in USA, Europe, Australia, and Singapore and arrived at similar findings. In a recent comprehensive review, Smithson and Hirschheim (1998) have concluded that '*IS evaluation clearly remains a thorny problem*'.

IS evaluation is important for many reasons. Organisations need to justify their investments in IS before committing time and money to their implementation, because of the large percentage of capital consumed by these investments and the need to prioritise between heterogeneous investment proposals competing for scarce organisational resources (Strassman 1985). Managers also need to have a better understanding of the impact of IS on organisational performance. Such understanding can help an organisation better utilise resources and improve its position vis-à-vis its competitors (Clemons 1991). On the other hand, failure of such understanding may have disastrous consequences such as inappropriate resource allocation and competitive disadvantage (Farbey et al 1993). Viewed in systems terms, evaluation provides the basic feedback function to managers as well as forming a fundamental component of the organisational learning process (Smithson and Hirschheim 1998). Finally, evaluation provides the benchmarks of what is to be achieved by the IS investment. These benchmarks can later be used to provide a measure of the actual implementation success of IS projects (Farbey et al 1992).

The evaluation of an IS investment may be carried out in virtually every step in the system's life cycle. In the earlier stages (before project approval), evaluation is concerned with setting targets and predicting outcomes in terms of costs, benefits, and potential risks. This phase of evaluation is usually referred to as *ex ante* evaluation (Farbey et al 1993). Once a proposal has gained acceptance it becomes a project and the attention of evaluation shifts progressively from prediction to project management and control. Once a system is implemented and is ready for operational use, evaluation may be concerned with assessing the system in terms of functionality and performance. Finally, when the system has been operational for some time, *ex post* evaluation may be carried out to ensure that planned benefits are being realised and to identify any unforeseen benefits or costs that need to be managed (Kumar 1990). Since our stated objective is to study IS evaluation in the context of business engineering, this research will focus on *ex ante* IS evaluation problems. Therefore, the term 'IS evaluation' within this dissertation will be used to refer to this type of investment appraisal, unless stated otherwise.

IS evaluation in this context differs from the post-implementation appraisal of a developed system both in purpose and in context. The objective of *ex ante* evaluation is to assess the organisational impact of a system that does not yet exist (at best, it is in the feasibility study or early design stages). Therefore, the evaluation cannot generally be based on real data about performance and organisational impact (as post-implementation evaluations may be able to do) and has to be based on assumptions, forecasts, and judgements. The need for such assumptions makes the *ex ante* IS evaluation a complex and problematic task, albeit a very important one in the context of business engineering.

Ex ante IS evaluation has long been considered a difficult and elusive domain for IS researchers and many reasons have been offered to explain the difficulties in evaluating IS investments. Table 3 summarises some of the most commonly cited difficulties (data have been collected from Willcocks 1992b, Farbey et al 1993, Lederer and Prasad 1993, and Brown 1994). The Table indicates that the major difficulties in IS evaluation relate either to benefit assessment or to the methodological approaches used. This is not surprising. The costs associated with developing a particular Information System are relatively easier to measure, at least the direct ones, usually during the feasibility study. However, in comparative terms, it is significantly more difficult to obtain hard evidence of the expected benefits of an IS. Indeed, benefit assessment is widely acknowledged as an increasingly important component of evaluation (Weill and Olson 1989, Ballantine et al 1994, Brown 1994). Before discussing the potential roles of discrete-event simulation in supporting benefit assessment in IS evaluation, it is worth considering some widely used IS evaluation techniques and their limitations.

COST-RELATED REASONS

- Estimating the cost and time to develop new applications is difficult and unreliable.
- Human and organisational costs are often neglected during evaluation.

BENEFIT-RELATED REASONS

- IS benefits may include intangible, indirect, or strategic advantages that are inherently difficult to express in quantitative (especially monetary) terms.
- IS benefits are indirect to business and therefore indistinguishable from other confounding factors (for example, people, processes, and strategy).
- Many applications are targeted at achieving second-order effects that are difficult to predict and measure.
- Fractional IS savings cannot be aggregated to provide realistic savings on an organisation-wide scale.
- The planning horizon (for which benefits *must* be assessed) may be longer than the forecasting horizon (for which benefits *can* be assessed).
- Organisations may simply be unaware of the potential benefits of innovative new systems.

RISK-RELATED REASONS

- The life span of IS is uncertain due to technological obsolescence and changing requirements.
- IS impacts depend on a number of external factors that may lie outside the sphere of organisational control.

METHODOLOGY-RELATED REASONS

- Financial and accounting techniques may be inappropriate for assessing IS investments.
- Usually IS is part of a wider business reorganisation and hence IS investments cannot be evaluated out of the context of the overall change.
- Tasks left out of the IS scope must also be evaluated as they can contribute significantly to overall costs.

POLITICAL REASONS

- Project champions tend to underestimate costs and overestimate benefits.

Table 3. The Difficulties of IS Evaluation

2.3.2. Methodologies for IS Evaluation

In the absence of a definite theory of IS investment appraisal (Powell 1992, Hitt and Brynjolfsson 1994), a multiplicity of methods and techniques for deciding on the desirability and priority of IS investments have been proposed. While an exhaustive review of all IS evaluation methods is outside the scope of this research, in the following paragraphs we will briefly review some characteristic examples of the most widely acclaimed and used methods for IS evaluation. Examples of other methods are presented in Sassone (1987) (the Time Savings Times Salary method), Clemons (1991) (strategic IS appraisal method), and Hochstrasser (1993) (Quality Engineering). For more thorough reviews of IS evaluation methods, the interested reader can refer to Hirschheim and Smithson (1988), Powell (1992), Farbey et al (1993), and Smithson and Hirschheim (1998).

Despite their individual differences, all methods can be analysed with respect to a number of important characteristics (Farbey et al 1993). Firstly, methods differ considerably in their *complexity*. Some require large amounts of data, which may themselves be difficult to collect. Other methods are conceptually difficult to understand or require a great degree of expertise and experience to use properly. Yet some other methods require considerable resources to be used successfully. Secondly, methods vary with respect to the *ease of communication* (for example, how easily they can be learnt, understood, and communicated to those who will ultimately take the investment decision). Thirdly, methods also vary in their degree of *precision and quantification*. While some methods attempt to predict cash flows and provide exact numerical values on which to base decisions, others provide only a ranking of alternatives without precise quantification. Finally, methods can be assessed according to the *facilities* they provide. For example, some methods attempt to deal with risk by employing sensitivity and 'what-if' analyses for the evaluation of alternative scenarios, while other methods permit comparison between IS and non-IS projects that compete for investment capital. Table 4 summarises the characteristics of the IS evaluation techniques discussed in the remainder of this section according to these criteria.

Method	Complexity	Communication	Quantification	Facilities
DCF Methods (NPV, ROI, IRR)	• Easy to understand • Large amounts of data required • Focus only on cash flows	• Easy to learn • Easy to communicate	• Precise • Only monetary values	• Some risk analysis (discount factor)
CBA, SESAME	• Similar to DCF • Intangibles taken into account	• May involve controversy and discussion	• Similar to DCF	• Similar to DCF
ROM	• Low data requirements	• Difficult to learn, apply, and communicate	• Precise (accounting data)	• Targeted to MIS • Suitable only for *ex post* evaluation
IE	• Large amounts of data required • Considerable expertise and resources required	• Difficult to learn and apply	• Precise measurement of tangibles, as well as ranking and rating of intangibles	• Considerable risk analysis at all levels
MOMC methods, Value Analysis	• Medium data requirements • Focus on subjective measures of utility	• Subjective and exploratory methods, involving discussion and controversy	• Subjective, non-monetary measures	• Stakeholder analysis
Prototyping	• Limited-scale system development required	• Based on real data on system impacts	• Precise	• Congruent with IS development
Simulation	• Large amounts of data required	• Expertise required in applying • Easy to communicate	• Precise (numerical) estimates	• What-if analysis • Sensitivity analysis • Experimental control

KEY: DCF = Discounted Cash Flow; NPV = Net Present Value; ROI = Return on Investment; IRR = Internal Rate of Return; CBA = Cost-Benefit Analysis; ROM = Return on Management; IE = Information Economics; MOMC = Multi-Objective, Multi-Criteria

Table 4. A Comparison of IS Evaluation Methods

The most widely used methods for IS evaluation are the classic financial/accounting methods for investment evaluation, namely methods that are based on the notion of *Discounted Cash Flows (DCF)*. These methods, including *Net Present Value (NPV)*, *Return on Investment (ROI)*, and *Internal Rate of Return (IRR)*, are based on estimating and comparing the outflows (costs) and inflows (benefits) of a proposed investment using some discount factor to compute the present value of future monetary estimates. DCF-based methods have the advantage of being widely used and tested in a variety of investment evaluation settings and therefore general management is usually quite familiar with both their process and outcomes. However, a major drawback of these methods is that they focus exclusively on the estimation of cash flows and hence they tend to be based on data that satisfy accounting criteria and can be legitimised by appearing in financial statements (Farbey et al 1993). Thus, they are not generally suitable for evaluating investments that are expected to yield primarily intangible, indirect, or strategic benefits of a non-quantifiable, at least in monetary terms, nature (Brown 1994).

A variant of DCF-based methods that has attracted considerable attention in IS evaluation is *Cost-Benefit Analysis (CBA)*. CBA is based on the same theoretical principles as DCF-based methods, but tries to overcome the problem of valuing intangibles by assigning a monetary value for *each* element contributing to the costs and benefits of an IS project (including intangibles). However, to achieve this, the method is necessarily based on surrogate measures for intangible costs and benefits and may involve considerable controversy and discussion (Farbey et al 1993). A variant of CBA is *SESAME* (Lincoln 1986), in which the payback from the IS project is derived by computing what the costs would have been if the same functionality of the proposed system had been delivered by non-computer-based methods. The net benefit is computed by subtracting the cost of the new system from the cost of the alternative (non IS-based) solution.

Strassman (1990) has proposed *Return on Management (ROM)* as the most reliable index of the contribution of Management Information Systems to the enterprise. ROM is based on the notion that the real value of Management Information Systems (MIS) is that they enhance managerial productivity and the method is based on measuring the increase in this productivity after the MIS introduction. The advantage of the method is that it concentrates attention to the management process. However, the method is targeted to only a specific kind of IS (Management Information Systems) and is based on estimates that can be computed only after the system is in place. Therefore, the method is mainly applicable to post-implementation investment evaluation.

Information Economics (IE) (Parker et al 1988) is a comprehensive IS evaluation method claimed by its authors to be applicable to all IS evaluation situations. IE encompasses the whole decision making process and employs very detailed tools and techniques for assessing the desirability and priority of IS projects by extending normal Cost-Benefit Analysis by three additional processes (value linking, value acceleration, and job enrichment). Information Economics is concerned with the 'value' of Information

Systems, which is taken to be a larger concept than 'benefits' (Wiseman 1992). The method is, in general, indeed comprehensive in its treatment of costs, benefits, and risks of IS introduction. However, it is also considerably difficult to use as it requires expertise and significant time and resources to carry out the in-depth analyses that it advocates.

Moving away from methods that are primarily based on estimation and measurement, we can identify a second group of evaluation methods of a much more 'qualitative' nature. These methods acknowledge the difficulty of measuring the costs and benefits of a prospective IS and instead focus on involving a wide number of individuals ('stakeholders') in the evaluation process in an effort to facilitate informed, albeit subjective, judgements on the expected value of the IS. For example, *Multi-Objective, Multi-Criteria methods* (Chandler 1982) recognise that there are measures of worth other than monetary values and that even direct measures may have different value for different people. Hence, such methods attempt to approximate a general measure of 'utility', defined as the satisfaction of an individual's revealed preferences. In the case of multiple stakeholders, the 'best' system is the one with the higher aggregate utility. Similarly, *Value Analysis* (Rivard and Kaiser 1989) emphasises 'better information' and 'better decision-making' as the primary benefits of Information Systems and seeks to explore the value added to organisation by such improvements.

Finally, experimental methods such as *prototyping* and *simulation*, have also been proposed as useful methods for IS evaluation. Prototyping can yield real data on which to estimate a system's potential organisational impact at a relatively early stage of IS development. These data can be used as a basis for deciding whether to proceed with a full-scale system development. Hence, a system prototype, apart from its usefulness in *IS development* (argued earlier), can also be a useful tool for *IS evaluation*.

On the other hand, simulation has been mentioned as a promising tool for IS evaluation in a number of studies (for example, Farbey et al 1993, Smithson and Hirschheim 1998), albeit only briefly and without any detailed substantiation of the claims made. The theoretical advantage of simulation is that it allows experiments to be run with alternative system configurations and it can thus provide useful data on which to base investment decisions at a low cost. Moreover, simulation allows for 'what-if' and sensitivity analyses that can help to resolve problems about the robustness of the proposed system in the face of uncertain assumptions. However, despite these claims about the well-known generic advantages of simulation, very few studies have specifically addressed the issue of IS evaluation by simulation in an explicit manner. Before reviewing these studies in more detail, we will turn to a concluding discussion of existing approaches to IS evaluation.

2.3.3. A Critique of Approaches to IS Evaluation

The problems of evaluating and justifying investments in Information Systems are not new. Information Systems have always been taking too long to develop, cost too much to implement and maintain, and are frequently not perceived to be delivering the business benefits which were initially intended (Mahmood 1993, Byrd and Marshall 1997). However, in recent years the changing role of IS in organisations has given new impetus to the problem of IS evaluation (Farbey et al 1993). The high expenditure on IS, the growing usage that penetrates to the core of organisational functioning, together with disappointed expectations about IS impact, have all served to raise the profile of how IS investments can be evaluated. According to Willcocks (1992a), '*IS evaluation is not only an under-developed, but also an under-managed area which organisations can increasingly ill-afford to neglect*'. The increased complexity of IS combined with the uncertainty and unpredictability associated with IS benefits point to the need for improved IS evaluation.

Benefit assessment and methodological approaches have been identified as being amongst the most important problems of IS evaluation (Weill and Olson 1989, Ballantine et al 1994). Despite this, most of the IS evaluation methods presented above focus more on *processing* the relevant data during the decision-making process rather than *generating* the data that will drive evaluation. In other words, they focus on carrying out and managing the process of evaluation and not on the actual measurement of the benefits.

Acknowledging the difficulty of generating reliable estimates of the expected benefits of Information Systems, some researchers attempted to develop methods that would allow for evaluating IS investments *without* the need for such measurements. The result is a number of 'qualitative' IS evaluation methods that, despite any theoretical legitimacy, are very rarely used in practice. Empirical surveys (for example, Willcocks and Lester 1991, Farbey et al 1992, Ballantine et al 1994) have consistently shown that most companies are using variants of a small number of methods, notably generic financial and accounting techniques such as ROI and CBA. The requirement of managers and decision-makers is for simple, general purpose and widely understood measures of value, as well as for methods that allow IS investments to be treated in the same manner as other capital expenditure proposals (Powell 1992). These criteria are satisfied by all standard accounting and financial methods, therefore these methods may be the natural choice for evaluation.

However, to use such methods effectively in evaluating IS investments, we need to articulate ways of *generating* reliable and objective estimates of the expected impacts of a proposed Information System on business performance. Without such data, over-reliance on financial methods can lead to an excessively conservative IS portfolio and an associated loss of competitiveness (Whiting et al 1993). Despite acknowledging the need for benefit measurement in theory (Bacon 1992), IS evaluation researchers have characteristically avoided addressing it in practice. Out of the methods described in the previous section, only the experimental ones (prototyping and simulation) seem to address the issue of *generating* data to be used in subsequent evaluations. A detailed analysis of the potential of prototyping development methods to address the issue of measurement is outside the scope of this research. In the following section, as well as in the remainder of this dissertation, we will be specifically concerned with the potential of discrete-event simulation modelling to alleviate the *measurement problem* of IS evaluation.

However, before turning to a review of simulation-related research in the area, it is worthwhile considering another potential difficulty that existing approaches to IS evaluation may present. This difficulty has to do with the fundamental unit of analysis in evaluating IS investments. In a comprehensive review of research in IS evaluation, Smithson and Hirschheim (1998) have identified five levels on which IS evaluation is conducted:

a) The *macro* level, concerned with evaluating the impact of Information Technology (IT) on macro-economic figures, such as productivity or profitability.
b) The *sector* level, measuring the impact of IT on an industrial sector.
c) The *firm* level, focusing on how Information Systems affect the economic performance of a single organisation.
d) The *application* level, attempting to evaluate the impact of a specific IS application. This level has been the focus of most of the literature on IS evaluation discussed earlier.

e) The *stakeholder* level, attempting to evaluate the impact of IS on individuals that are directly or indirectly affected by the introduction of an IS.

Smithson and Hirschheim (1998) contend that different concepts, frames of reference, and evaluation criteria apply at each of the aforementioned levels and outline the problems of existing approaches to IS evaluation at each level. What seems surprising in their analysis, is that a fundamental unit of IS analysis is completely missing from an otherwise comprehensive review. This unit is the level of the *business process*, focusing on how Information Systems are expected to influence the performance of the business processes they are intended to support. In view of the recent emphasis of IS research on the issues of business process change and business engineering, as discussed earlier in this Chapter, it seems surprising that only a limited number of researchers have addressed IS evaluation at the level of the business process up to date. Such researchers include:

a) Ginzberg (1979) who wrote: '*Changes to processes are the link between changes to information and organisational outcomes. It is only once we understand* how *the new system will be used that its value can be estimated. Thus, efforts to quantify benefits should focus on the changes in organisational processes which will result from changes to information systems*'. It is rather disappointing that, nearly twenty years after this inspiring remark, little further research on the subject has been carried out.
b) Farbey et al (1992) argued for the need to abandon the *IS project* as the fundamental unit of analysis in IS evaluation and adopt the wider concept of the *business process* instead. In particular, the authors assert that '*when the information system is part of a wide ranging set of changes ... it is almost impossible to determine the proportion of any benefit which can be said to stem from any component of the change. It is only possible to evaluate the costs and benefits of the whole package of changes*'.
c) Hochstrasser (1993), commenting on our inability to translate IS impacts into monetary figures, wrote: '*If there is a need to assess the return of the proposed investment, this return can only be specified in terms of improving the quality of business functions and processes*'.
d) Farbey et al (1998), in the editorial of a recent special issue of the European Journal of Information Systems on IS evaluation, report: '*... a major change we have detected is that the big questions are to do with the value added by transformations in which IS/IT plays, maybe, a crucial role, rather than about putting value on to the IS/IT contribution... The traditional unit of evaluation was the application... In*

the future ought we to take a more holistic view in considering the change in all its parts?'.

While we are in complete agreement with the above arguments, we are aware of no IS evaluation method that actually advocates such a perspective for appraising the benefits of an Information System by generating quantitative information regarding the impact of changes on the level of the business process(es) that the IS is intended to support.

We argue that a change in perspective is needed in order to understand and maximise the value of IS in organisations. We need to adopt *process change* as a mediating factor between the IT initiative and economic return. Such thinking could trigger a radically different perspective in the way IS investments are viewed and analysed within an organisation. For example, organisations would not anymore expect an IS investment in itself to provide economic returns for the company and would recognise that only changes in a business process can yield such benefits, while the role of Information Systems is to make a new process design possible (Ward et al 1996). If nothing changes about the way work is done and the role of IS is simply to automate an existing process, business returns could be marginal.

Such a shift in perspective is central to the principles of business engineering and implies similar changes in the perspective and focus of IS evaluation. Adopting a process view of an organisation and recognising that it is the combination of *structural* process changes and *informational* capabilities of IS that delivers organisational value has serious implications for IS evaluation methods. Under this new perspective, IS evaluation should not focus solely on the application to be evaluated but rather on the synergistic relationship between changes on how the work is done (structural changes) and changes on how the work is supported (informational changes).

Based on the above analysis, the purpose of this research is not to develop yet another IS evaluation method. As Powell (1992) argued, '*the field is already a little crowded and ... a new method would be likely to add little*'. Rather, the aim of this research is to complement and support existing methods for IS evaluation by developing mechanisms that will allow organisations to *generate* the quantitative data they need in order to employ these techniques effectively. We argue that by developing simulation models that depict the *business processes* before and after the introduction of an Information System, organisations will be able to measure and compare the expected benefits at the level of the processes that the system is going to affect. These benefits can then be combined with the costs of IS development, migration, and operation into a formal investment evaluation.

However, in order to be used for that purpose, business process simulation (BPS) models have to be capable of addressing, in an explicit manner, the exact nature of IS impact on business process performance. As will be argued in the following section, existing research in business process simulation has not addressed this issue in sufficient detail.

2.4. Simulation of Business Processes and Information Systems

2.4.1. Organisational Change as a Design Problem

The definitions of business processes presented in Chapter 1 can lead to some interesting observations about the nature of business processes:

a) There seems to be an agreement that business processes are decomposed into a number of more elementary steps (usually referred to as *tasks* or *activities*).
b) Processes have specific *beginnings* and *ends*, *inputs* and *outputs*, and they strive to satisfy the expectations of their internal or external customers (i.e. they also have specific *targets*).
c) Processes make use of specific *resources* during their execution (people and Information Systems can be mentioned as typical examples of resources which business processes utilise to attain their objectives).

The above characteristics imply a 'systemic' view of organisations, characterised by identifiable components with complex relationships between them. Organisational processes can be viewed as collections of entities, which interact between themselves and with their external environment in order to achieve specific objectives. This 'systemic' view implies that techniques of systems analysis, like simulation, have the (theoretical) potential to address the problems of organisational design and business change management (Davenport and Stoddard 1994). This argument is also in line with Earl (1994) who advocates that 'processes' are systems concepts and consequently the principles and tools of systems analysis are natural candidates for supporting process-based organisational design. Along the same lines, Hansen (1994) has argued that '*since* *the words* system *and* process *are synonymous, the theories of operations research are as applicable to business processes as they are to any other types of systems*'.

More generally, it can be argued that process-based thinking in the context of organisational change, is primarily a *systems design problem.* 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. Discrete-event simulation is therefore, at least theoretically, well suited for this design purpose.

Of course, simulation is not the only technique that can be used in the context of business process modelling (BPM) and IS modelling (ISM). A wide number of techniques have been developed and used for the same purposes. A detailed review of these techniques, that will assist in clarifying our choice for selecting discrete-event simulation in the context of this research, is presented in Appendix A of this dissertation.

2.4.2. Business Process Simulation (BPS)

Simulation has been mentioned, albeit only briefly, by many researchers as a technique that could be helpful in the context of business process change (for example, Lewis 1993, Ardhaldjian and Fahner 1993). MacArthur et al (1994), in one of the first articles specifically concerned with discrete-event simulation of business processes, investigate the suitability of simulation for BPR projects. The authors argue that simulation is well suited as a *design assessment* tool in the context of evaluating process change alternatives. Furthermore, they contend that the issue of *measurement* of process performance is one of the most important problems in practical BPR application and maintain that simulation is indeed well positioned, at least in theory, to address this problem.

Hansen (1994) also advocates the appropriateness of simulation for BPR, arguing that '*an engineering approach to process reengineering that incorporates modelling and simulation is necessary*'. Similarly, Kettinger et al (1997) argue that there is a need for more user-friendly and 'media-rich' capture of business processes and simulation can accommodate these requirements by providing easy visualisation and allowing team participation in process redesign. Surprisingly though, they mention simulation only as part of the *Define and Analyse New Process Concepts* (activity S_4A_1) and *Prototype and Detailed Design of a New Process* (activity S_4A_2) activities of the S-A framework for BPR. This argument is consistent with the view that BPS research to date has not been targeted at investigating how simulation can effectively support other modelling aspects, especially modelling of Information Systems. To illustrate this argument further, we will present some characteristic applications of BPS in the following section, followed by a discussion of the more specific issue of Simulation of Information Systems (SIS).

2.4.3. Examples of Business Process Simulation Application

The first applications of BPS appeared, rather not unexpectedly, in the manufacturing domain, since manufacturing is the most closely related, and at the same time, well-developed area of simulation use. In one of the earliest examples, Pruett and Vasudev (1990) introduce the concept of MOSES (Manufacturing Organisation Simulation and Evaluation System). According to the authors, MOSES '*is a blend of simulation modelling and information-based management*'. The system is structured around the idea that all manufacturing organisation functions can be categorised into one of four areas: marketing, production, inventory and accounting. The system models these functions, simulates the basic relationships with each other, and shows the immediate effect of a multitude of decisions made with respect to those functions. MOSES provides the opportunity for a manager in charge of one function (for example, inventory) to see the impact his policies might have on the organisation's other major functions (for example, production).

MOSES is innovative because it is one of the first applications extending the traditional manufacturing-oriented focus of simulation to address the co-ordination of managerial functions and production operations. The authors acknowledge that functional sub-units of an organisation should co-operate with each other, instead of competing, and that simulation should allow for 'holistic' decision-making, rather than localised optimisation (an argument in line with MacArthur et al's (1994) propositions, formulated four years later). Despite its advantages, MOSES presented two major limitations. Firstly, the principles of process-based organisational design were still at an embryonic stage when the concept was developed and hence the system advocates a vertical, functional-based organisation of work activities. Secondly, although the authors acknowledge that '*computer technology has provided the prerequisite tools for information-based co-operation*', MOSES provides no guidelines on how to incorporate *informational* changes in simulation models.

While research in BPS progressed, other authors have demonstrated the potential usefulness of simulation in the context of business process change. For example, Bruno et al (1995) discuss the development of an object-oriented simulation model that was applied to a real-life BPR project in Telecom Italy. In a similar setting, Lee and Elcan (1996) present a real-life application of simulation for process re-engineering in the telecommunications industry, where simulation models were developed to help managers gain insight, identify opportunities for change, predict the quantitative impact of re-engineering efforts, and establish tangible management goals. Ninios et al (1995) present the development of an object oriented modelling environment to facilitate the use of industry simulation models. Kim and Kim (1997) discuss the development of a systematic approach to business process redesign that integrates customer-oriented process modelling with computerised visual process simulation, in an effort to reduce the risks of BPR projects. Other practical applications of BPS can be found in Hunt et al (1997), Yarden (1997), Greasley and Barlow (1998), and others.

The above examples show that simulation has already been identified as a suitable tool for business process modelling and has been successfully employed in individual applications. However, the practical applications developed are generally case-specific and lack a substantial degree of theoretical or methodological support (MacArthur et al 1994, Hansen 1994, Meel and Sol 1996).

As practical applications of BPS began to appear, demand for BPS software products also naturally emerged. Simulation software providers were quick to fill the market gap by providing *business simulators*, either as completely new products or as complements to existing, mostly manufacturing, simulators. Examples of such products include *Simprocess* (Jones 1992), *ServiceModel* (Gladwin and Tumay 1994), *BPMAT* (Bhaskar et al 1994), and *SimView* (Dijk et al 1996). These products emphasise mostly the user friendliness aspect, allowing non-simulation experts (e.g. business planners) to develop simulation models without the need of programming. However, Warren et al (1994) have pointed to the inadequacy of off-the-shelf simulation software to achieve appropriate performance measurement in the assessment of alternative process and system designs for BPR. According to MacArthur et al (1994), however, '*the important point is not the precise simulation technology used, ... but rather that the appropriate strategy is taken*'.

The above observations about application examples and existing simulation software support point to the need for further research on the subject of integrated simulation of business processes and Information Systems in the context of business engineering. Most of the research and application up to date has been concerned with addressing *structural* changes in business processes, without specific attention to *informational* changes enabled by the introduction of Information Systems. We argue that informational changes may impose additional requirements for effective simulation modelling and therefore explicit attention to them is necessary within the context of business engineering. To illustrate the argument that BPS, at least in the way it has been practised in the aforementioned examples, cannot effectively accommodate this requirement, we will turn to a review of existing applications of IS simulation.

2.4.4. Simulation of Information Systems (SIS)

One of the earliest articles in which discrete-event simulation was used for the explicit purpose of IS evaluation is presented by Gradisar and Pivk (1993). The authors describe the use of a simulation model for evaluating the costs and benefits associated with the introduction of Electronic Data Interchange (EDI) applications in a shoe company.

However, the authors do not describe the process of model development, and they limit their discussion in presenting the use of the developed models for running two experiments: one scenario depicting the business processes without the aid of the Information System (EDI), and the other scenario representing the same processes after EDI introduction. Since none of the assumptions made are explained, it is not possible to infer how the impact of EDI on business processes was modelled in the second scenario.

In a more recent work, Nissen (1994) was one of the first to advocate the evaluation of IS investments through computer-based representations of the business processes affected by an Information System. Although his work is not explicitly focused on discrete-event simulation (the author advocates a knowledge-based modelling environment allowing for symbolic process modelling), the Virtual Process Measurement (VPM) methodology presented emphasises the modelling of, and experimentation with, alternative organisational processes and Information Systems for the purposes of redesign.

In a similar fashion, Swami (1995) discusses the application of simulation in modelling the 'order to delivery' process of a fictitious company, to illustrate the suitability of simulation in BPR projects. The author discusses, albeit only briefly, the issue of introducing Information Technology (including Automatic Call Distribution Systems and databases) to redesign the process. However, no mention is made on how the effects of IS applications can be modelled in simulation experiments. The author confines the analysis on the reduction of processing times made possible by these applications (i.e. *automation*) and avoids discussing other, perhaps more intangible and indirect, effects of the Information Systems (i.e. *transformation*).

Perhaps the most important and focused discussions of research in the area of integrated BPS/SIS emerged out of a number of working conferences on the subject of '*Dynamic Modelling of Information Systems*' (Sol and Crosslin 1992). The ideas of these researchers stemmed from the acknowledgement that traditional static approaches to IS modelling (see Appendix A) were not capable of representing the dynamic properties of Information Systems effectively. Despite the validity of these underlying principles, early researchers in the area generally failed to acknowledge the need for adopting a 'holistic' view to IS modelling, that would emphasise the issue of organisational alignment of Information Systems. Instead, they mostly followed the 'reductionism' paradigm, focusing on performance modelling of the underlying technical system (Warren and Stott 1992) or with integrating modelling approaches with structured systems analysis and design techniques (Tardieu 1992). As such, their approaches shared the limitations of existing approaches to structured IS development and evaluation (discussed earlier in this Chapter), and, naturally, they failed to attract widespread attention from the academic community (Verbraeck 1992).

Recognising these limitations, some researchers pointed to the need for better understanding of the organisational value of IS (Thomasma and Chen 1992, Verbraeck 1992). Their propositions were recently re-popularised by a new stream of research in the subject, much more concerned with modelling the *organisational*, rather than the *technical*, dimension of Information Systems (Warren et al 1997). The emergence of this research direction is reflected in the mini-tracks on *Modelling the Dynamics of Organisations and Information Systems* of the annual Hawaii International Conference on System Sciences (Bots et al 1994, Vogel et al 1996, de Vreede et al 1997, de Vreede et al 1998, de Vreede et al 1999), and the first journal special issue (of *Simulation and Gaming*) to deal explicitly with the subject of *Simulation of Information Systems (SIS).* Warren (1996), in the editorial of this issue, argues in favour of the development of simulation models that abstract away the particulars of Information Technology and other physical processes to concentrate on the Information System as an agent of organisational change. Warren argues that SIS is a field in youthful state and argues that simulation is already mature in modelling the computer-based portion of an Information System (i.e. networks, algorithms, and architectures), but not the people and the procedures.

In one of the most critical articles addressing business engineering, Meel and Sol (1996) provide an introductory discussion to the use of simulation for the integrated modelling and analysis of business processes and Information Systems. The authors argue that, despite numerous isolated success stories, simulation-supported business engineering has so far achieved little theoretical and methodological support. The authors report on a four-year action research project, where two case studies were employed to explore the potential of simulation for business engineering. Drawing on the findings of these studies, the authors discuss a theoretical approach based on socio-technical design (Mumford and Weir 1979), a methodology for employing simulation in the context of business engineering, as well as a prototype simulation environment for regression-based experimental design of BPS models. They conclude that, despite promising early results, the application of simulation for integrated business process and IS modelling, lacks methodological support which would ensure a minimum level of rigor, facilitate structuring, planning, and monitoring, and assist in codifying experience and ideas.

Opdahl and Sindre (1996) approach the same problem from a different angle and discuss a method for developing simulation models of Information Systems that are capable of representing the non-informational elements of the IS-supported business processes as well. The authors contend that, despite its great potential, simulation is hardly used in mainstream IS development, because, amongst others, the techniques used in IS design and development do not provide enough support for simulation model development. To address this limitation, the authors propose a framework for developing simulation model specifications based on Data Flow Diagrams and Entity-Relationship diagrams (see Appendix A).

Finally, Painter et al (1996) take the matter of integrating BPS and SIS a step further and present a methodology for integrating simulation models of business processes, Information Technology applications, and computer networks. The authors advocate an approach where integrated business models of these three types would effectively assist impact assessment at any stage (business process, IS application, or network infrastructure). The IDEF3 technique (see Appendix A) is used for model development at all levels. Extensive use of the decomposition mechanism is employed to accommodate for the different levels of abstraction between models. A rather complex methodology is also presented, consisting of very detailed steps for model specification, development, implementation, experimentation, and analysis.

In terms of software support, a limited number of attempts have been made for providing capabilities for IS modelling within business process simulators. In one of the earliest examples, Cochran and King (1993) discuss the use of symbolic modelling using the *DECmodel* software. The authors present an approach for modelling IS applications within a business process model, but they limit their approach to the representation of *existing* systems rather than modelling the impact of *new* ones. As a result, the approach does not provide any insight on how the impact of informational changes, at the pre-implementation stage, can be effectively modelled in business simulations. However, the authors point to the usefulness of such a system, arguing that it would allow for developing and communicating functional system specifications directly from dynamic simulations. Such an approach would allow developers to achieve a higher degree of understanding of how the systems they develop fit within the business processes they are intended to support.

Summarising this review of existing work in the area of integrated BPS/SIS, we can deduce that most authors have pointed to the theoretical efficacy of simulation to support business engineering, as well as to the potential benefits for both business planners and IS designers should such an integration prove achievable. However, despite individual applications and isolated demonstrations of such an approach, it has also been identified that the subject is still at a relatively early stage of development and it still lacks theoretical rigour and legitimacy. Acknowledging this limitation, the research presented in this dissertation will be mainly concerned with developing such a theoretical basis, in the form of a *design theory* of IS evaluation by simulation. The following section will summarise the findings of reviewing the background research material presented in this Chapter, and will also outline the rationale and constituent elements of the proposed theoretical approach.

2.5. A Critique of the Literature

The purpose of this section is to summarise the conclusions reached earlier through reviewing the existing state-of-the-art in the fields of process-based organisational design, IS development, IS evaluation, and BPS/SIS. By synthesising these conclusions, it will be possible to articulate in more detail and depth the objectives of the empirical research work and the theoretical propositions to be presented in the remainder of the dissertation.

Process-based Organisational Design (POD)

It seems to be widely accepted that the adoption of a *process-based* view of organisations can deliver significant benefits to the study and redesign of organisational structures. Further to representing the 'natural' way of describing work (Earl 1994), processes lend themselves better to analysis and measurement. While there is no way of measuring or improving a static hierarchical structure in any absolute sense (Davenport 1993), processes are amenable to measurement in a variety of dimensions (cost, time, and output quality, to name but a few).

The importance of Information Systems as an enabler of organisational change, coupled with the recursive relationships between IS and business processes, necessitate that processes and systems are considered and designed *together*. Although theoretically attractive, such an integrated perspective is far from easy to achieve in practice, and extant methodologies for business process change have generally failed to address this issue to a satisfactory degree. The challenge for business engineering is to bring process design and IS design together without adding to the, already high, complexity of each task alone.

A potential strategy for addressing this need could involve incorporating high-level IS design and IS evaluation into business process design, and leaving the technical details of IS implementation to be addressed in the aftermath of business engineering decisions. Table 5 summarises the findings from the review of the process-based organisational design literature.

POD.1. There is a need to *integrate* the design of organisational procedures and Information Systems (*business engineering*).

POD.2. Adopting a horizontal, *process* perspective may facilitate more efficient analysis and design strategies.

POD.3. Extant business process change methodologies fail to address the balance between the need for and the complexity of IS design.

POD.4. It may be desirable to integrate high-level (*organisational*) IS design into business process design, and leave low-level (*technical*) IS design out of scope of business engineering.

Table 5. Findings from the Process-based Organisational Design (POD) Domain

Information Systems Development (ISD)

The design and implementation of Information Systems is generally a complex and laborious exercise for most contemporary organisations. It may not be desirable (or even feasible) to incorporate such design into business process change in its entirety. A strategy where IS design is treated along two dimensions (one concerning the organisational impact of IS, and the other concerning the technical implementation details) may be more appropriate.

This observation is further exacerbated by acknowledging that although most extant IS development methods begin by stressing the importance of understanding the real-world operation that the IS will support, they quickly become absorbed in the definition of individual functions and detailed requirements ('reductionism'). Such a paradigm for IS development necessarily separates and treats in isolation business processes and Information Systems, despite the fact that they are in reality closely inter-related.

Furthermore, extant IS development methodologies pay only limited attention to the *ex ante* evaluation of Information Systems, at least as far as their organisational impacts are concerned. What may be needed is a reverse of the process of progressively decomposing IS development into smaller, more technical, tasks. Instead, when the system is evaluated, the high-level real-world picture should be reconstructed in order to ensure that the overall impact of the Information System on the business processes is evaluated. Such an approach could assist towards maintaining a 'holistic' organisational viewpoint (and thus alleviate the problems of reductionism), without at the same time over-burdening the business change project with unnecessary complexities.

Table 6 summarises the findings from the review of the IS development domain. It is worth pointing to the similarity of findings with those reported above from the process-based organisational design domain, all pointing to the need for improved IS evaluation in the context of business engineering.

ISD.1.	IS development is a complex process, which may be difficult to fully integrate into business process change exercises.
ISD.2.	Extant IS development methods generally adopt a 'reductionist' approach, which is incompatible with the high-level goals and objectives of business process change.
ISD.3.	Extant IS development methods do not generally pay enough attention to the importance of, and the difficulties associated with, *ex ante* IS evaluation.
ISD.4.	It may be desirable to integrate IS evaluation into business process design, adopting a 'holistic', organisational view of Information Systems.

Table 6. Findings from the IS Development (ISD) Domain

Information Systems Evaluation (ISE)

Smithson and Hirschheim (1998) note that '*developments in both the business and organisational context, and the IS context itself, have made IS evaluation even more necessary and, yet, even more difficult*'. IS evaluation is necessary due to the high level of organisational investments in IS, and the need of managers to have a better understanding of the impact of IS on organisational performance. IS evaluation is difficult for many reasons, the primary ones relating either to benefit measurement or to the methodological approaches used.

Benefit assessment is inherently complex due to the very nature of IS benefits, consisting in many cases of difficult to measure intangible, indirect, and strategic effects. Despite this difficulty, few IS evaluation methods focus on *generating* numerical data that are necessary for carrying out formal investment appraisals. Such data are however necessary, since most organisations continue to use generic, financial investment appraisal techniques for assessing the desirability and priority of IS investments. Experimental methods (for example, systems prototyping and simulation) seem to be capable of producing such data regarding the organisational value of IS.

Regarding the methodological approaches used, most approaches to IS evaluation use the *IS project* (or the *IS application*) as the fundamental unit of analysis for studying evaluation issues. However, contemporary IS are increasingly integrated together, making it even more difficult to disentangle a single system for evaluation. This may render the demarcation of boundaries around individual systems for the purposes of evaluation a meaningless exercise. We argue that IS evaluation should be driven by the needs of the organisation in which the IS will be applied. We therefore advocate adopting a high-level, organisational perspective of the problem of IS evaluation, and we propose to substitute the IS project with the *business process* as the fundamental unit of analysis in IS evaluation.

Table 7 summarises the findings from the review of the IS evaluation domain. Coupled with the findings above, these findings point to the need for employing techniques like discrete-event simulation to support IS evaluation in the context of business engineering.

ISE.1.	IS evaluation is important, due to the high investments in IS and the critical role of technology in improving business performance.
ISE.2.	IS evaluation is difficult, mainly due to reasons related to benefit assessment and the methodological approaches used.
ISE.3.	Extant IS evaluation methods focus primarily on the level of the *IS project* in isolation, without paying explicit attention to the interactions of the IS with the real-world organisation (*business processes*).
ISE.4.	There exists a need for supporting the *data generation* phase of evaluation, especially related to *benefits assessment*. Experimental methods, like simulation, seem to offer a promising approach.

Table 7. Findings from the IS Evaluation (ISE) Domain

Business Process Simulation/Simulation of Information Systems

Organisations can be viewed as *purposeful systems* (Ackoff and Emery 1972), and hence techniques of systems analysis can be effective tools in studying existing business structures and designing new ones. Discrete-event simulation seems to provide ample potential for overcoming the problems and satisfying the requirements identified above related to process-based organisational design, IS development, and IS evaluation. For example, simulation models can naturally represent a *process-based* organisational perspective, and they can be used to drive formal IS evaluation exercises by *generating* objective, numerical data regarding the expected organisational benefits of Information Systems.

Although the idea of applying modelling and simulation for IS evaluation is not new, the approach followed in this research differs from earlier works both in terms of *purpose*, as well as in terms of *implementation*. Regarding *purpose*, most of the existing research and application of BPS/SIS up to date, as shown from the examples presented earlier in this Chapter, has been concerned either with evaluating aspects of the *technical* performance of Information Systems, or with addressing only the *structural* aspects of changes in business processes. We argue that *informational* changes, i.e. organisational impacts of Information Systems, may impose additional requirements for building and for using simulation models, and that further research is needed on investigating the implications of such requirements. Regarding *implementation*, we argue that simulation models should focus on the expected impacts of Information Systems at the level of the *business* *process*, and they should be concerned only with the high-level, organisational, impacts of such systems. For the purposes of business engineering, simulation models do not need to embody low-level, technical, details of IS specifications. Such details can be left to IS specialists once the high-level organisational decisions for *structural* and *informational* changes have been taken.

Towards a Design Theory for IS Evaluation by Simulation

To achieve the objectives stated above, the research presented in this dissertation aims at articulating theoretical and methodological approaches to IS evaluation by simulation, in an attempt to provide a systematic and structured approach to the problem, codify existing and new knowledge, and guide organisations in approaching similar situations in practice.

At the conceptual level, we envisage the development of simulation models that are driven by the intended business goals and IS designs, and are able to represent the business processes expected to be changed and the anticipated impacts of Information Systems on these processes. Once implemented, such models can then be used to experiment with alternative future scenarios for business and IS change. The two sets of control variables available to the decision-makers are the configuration of the proposed Information System (*informational changes*) and the organisational arrangements regarding the structures and operations surrounding it (*structural changes*).

Such a simulation effects a 'virtual' implementation of the proposed system. By measuring the performance of the relevant business operations without the Information System and with alternative scenarios regarding it, one can collect the necessary quantitative information needed to conduct further investment appraisal using established financial or other methods. Moreover, the simulation modelling process itself and the subsequent experimentation with alternative system and business configurations, can constitute additional learning processes which can improve the understanding of the implications of the system to the business domain. Such understanding can be beneficial for business managers and IS specialists alike, and therefore it can also be useful in bringing the organisational and the software engineering domains together, thus contributing to the goals of business engineering in a practical manner.

To achieve the aforementioned goals, we need to develop conceptually sound and empirically validated instruments for inquiry into organisational and informational systems (Bots et al 1994). These instruments should be capable of guiding the *process* of developing simulation models for IS evaluation and should also specify the properties of the models themselves (i.e. the design products). To this end, we propose the development of a *design theory of IS evaluation by simulation* that will address both of the above aspects in an integrated and rigorous fashion. The development of the detailed propositions that will form such a design theory, will be discussed in detail in Chapter 4.

2.6. Summary

In this Chapter, we have examined in detail the role that Information Systems play in facilitating business process change. We have also outlined some of the problems associated with IS development and IS evaluation, and we argued for the potential of discrete-event simulation to address these problems. But we have yet to consider how simulation could be effectively employed for this purpose.

The next Chapter will be concerned with exploring the concepts discussed here in a practical manner, by means of a real-life case study of IS evaluation by simulation. Coupled with the theoretical conclusions presented in this Chapter, the empirical insight gained by the case study will inform the process of articulating a detailed theoretical approach to IS evaluation by simulation in Chapter 4.

CHAPTER 3. CASE STUDY I: SECTORIAL EDI EVALUATION

You cannot measure what is not defined. You also cannot tell whether you have improved something if you have not measured its performance

(Strassman 1985)

This Chapter documents the process and findings of an empirical study that was pursued to validate and enhance the results of the background material review discussed in the previous Chapter, and further inform the objective of developing a design theory for IS evaluation by simulation.

Before presenting the case study in detail, we will discuss briefly the reasons for adopting the *case study* method in the context of this research. This discussion complements the general discussion on *Research Methodology* of Chapter 1.

3.1. The Case Study Method: Role and Significance

Defining the method, Yin (1994) advocates that '*a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident*'. Therefore, the case study is a method well suited for addressing phenomena over which the researcher has little or no control, as it attempts valid, 'scientific' inferences from events outside the laboratory. Case studies can be classified as *exploratory*, *descriptive*, or *explanatory*, depending on the purpose of research (Yin 1994). The case study to be presented in this Chapter is mainly an exploratory one, as it is concerned more with the empirical exploration of the theoretical issues addressed in Chapter 2, and it is not based on a concrete set of already developed theoretical propositions. Based on the results of this case study, a number of such theoretical propositions will be developed (Chapter 4), and will be further tested in more detail in a second case study/action research analysis, to be discussed in Chapter 5.

In general, case studies are considered flexible and unobtrusive research tools, capable of delivering 'rich' data (Eisenhardt 1989). Galliers (1992b) advocates the use of the case study method in IS research because case studies are able to capture 'reality' in greater detail, and hence they are highly suitable tools for studying the organisational dimensions of the phenomena under investigation. Case studies can also be used to analyse more variables than would be possible with most other research methods (Yin 1994). These are significant advantages for the preliminary, explorative stages of Information Systems research.

On the minus side, case studies are by nature restricted to studying only a single case (or at most a limited number of cases), thus raising potential questions about the generalisability of results. However, Yin (1994) points to the fallacy of this argument, arguing that case studies are generalisable to theoretical propositions and not to populations or universes. In this sense, a case study does not represent a sample, and the researcher's goal is to formulate and expand theories (*analytic generalisation*) and not to enumerate frequencies (*statistical generalisation*). Other potential disadvantages of case studies include the lack of variable control and the possibly different interpretations given to real-world events by individual researchers.

Despite these potential limitations however, many researchers have argued in favour of case studies and the method has been frequently found to be the most popular empirical method for research in Information Systems (Hamilton and Ives 1982, Farhoomand 1987). Due to such popularity, a rich literature has been developed for IS-specific case design (Lee 1989), case analysis (Benbasat et al 1987), and theory building (Eisenhardt 1989).

Within the context of this research, a case study offers the opportunity of contrasting and complementing the 'distilled wisdom' of the literature review presented in Chapter 2 with first hand experiences of IS evaluation in its 'natural' setting: real-world organisations. The research method's usefulness in our case is further enhanced by the very nature of the particular study situation. The objective of this case study was to evaluate the potential of introducing Electronic Data Interchange (EDI[3]) applications between organisations across

[3] EDI can be defined as the inter-organisational, application-to-application exchange of business documentation in a standard automated way (Emmelhainz 1993). It is increasingly becoming a popular way of carrying out business transactions, due to the wide range of benefits that are ascribed to it, at both an operational and a strategic level. The use of EDI is expected to be the dominant form of business communication between companies in several markets during this decade (Nygaard-Andersen and Bjorn-Andersen 1994).

a whole industrial sector. The main focus of IS evaluation was to estimate the potential gains in inventory reduction enabled by EDI for the organisations involved. At the same time, the study aimed at investigating opportunities for business process redesign, enabled by the introduction of EDI, for these organisations. The combination of these factors (IS evaluation in the context of business process change, focus on benefits assessment, and the need to evaluate the IS at the level of the business process), provided a rich setting where the whole spectrum of the issues identified in the previous Chapter as pertaining to business engineering and IS evaluation could be further explored. Thus, the case study was deemed adequate in providing qualified insights for informing the stated objective of developing a design theory for IS evaluation by simulation.

3.2. Study Background

The case study discussed in this Chapter was part of a wider research project, funded by the TEDIS programme of the European Commission. TEDIS itself aimed at '*expanding the use of pan-European EDI in a co-ordinated way*' (TEDIS 1996). The project, which was sponsored by the *Social and Economic Impact* domain of TEDIS, aimed at '*developing the analysis of the impact of EDI on the industrial, social and economic fabric of Western Europe*' (TEDIS 1993). The part of the project to which the case study refers aimed at assessing the expected operational benefits of EDI in the textile/clothing sector in Greece. The main purpose of the simulation exercise was to provide tangible and quantitative measures of the alleged ability of EDI to facilitate inventory reduction in the organisations that use it as part of their ordering and logistics processes. Figure 9 illustrates the relationships between the TEDIS programme, the overall project, and the case study.

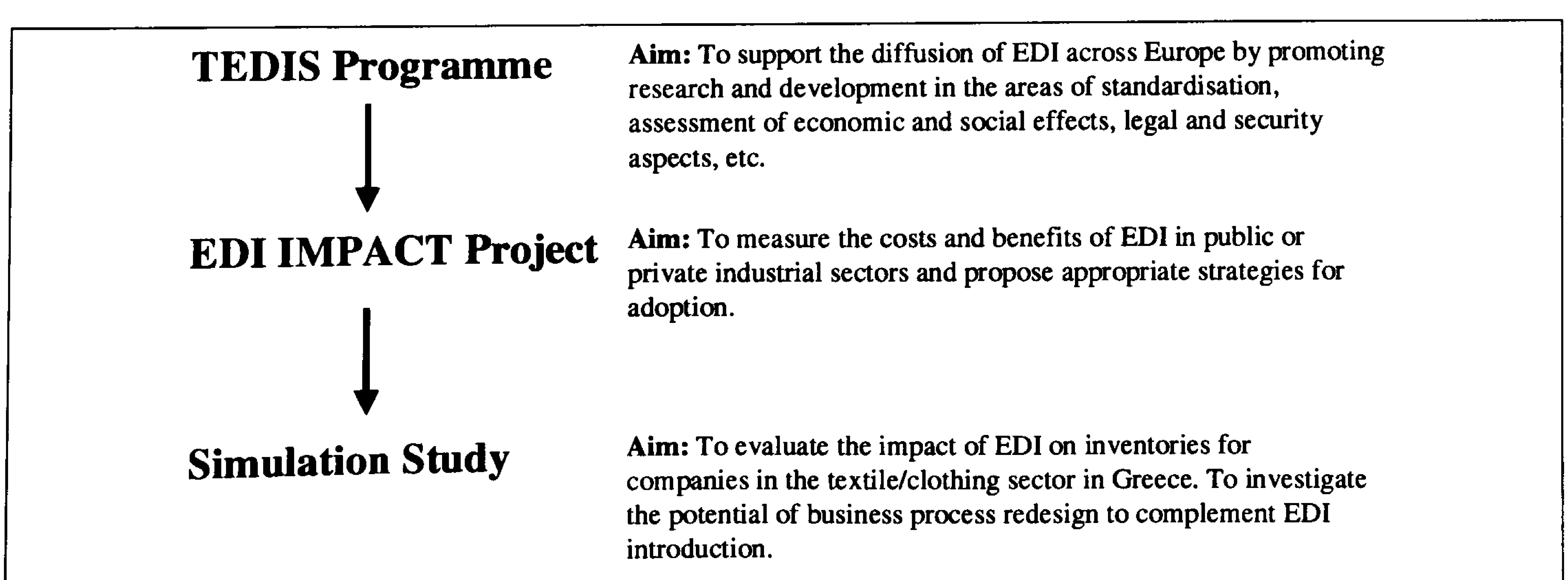


Figure 9. Case Study Background

3.2.1. The Profile of the Textile/Clothing Sector in Greece

The textile/clothing sector occupies a rather profound position in Greek industry, benefiting from low production costs and high quality of materials and products. As a result, it accounts for around 3% of the country's Gross Domestic Product (GDP) and can boast a sixth place in the world regarding total textile production (OECD 1995). The sector is highly fragmented, consisting of many (mostly small-sized and family-owned) companies, which can be thought of as belonging to a three-level value chain: textile material suppliers (spinners, knitters, weavers, dyers, and so on), clothing manufacturers, and retailers. The typical structure of the sector's value chain is depicted in Figure 10.

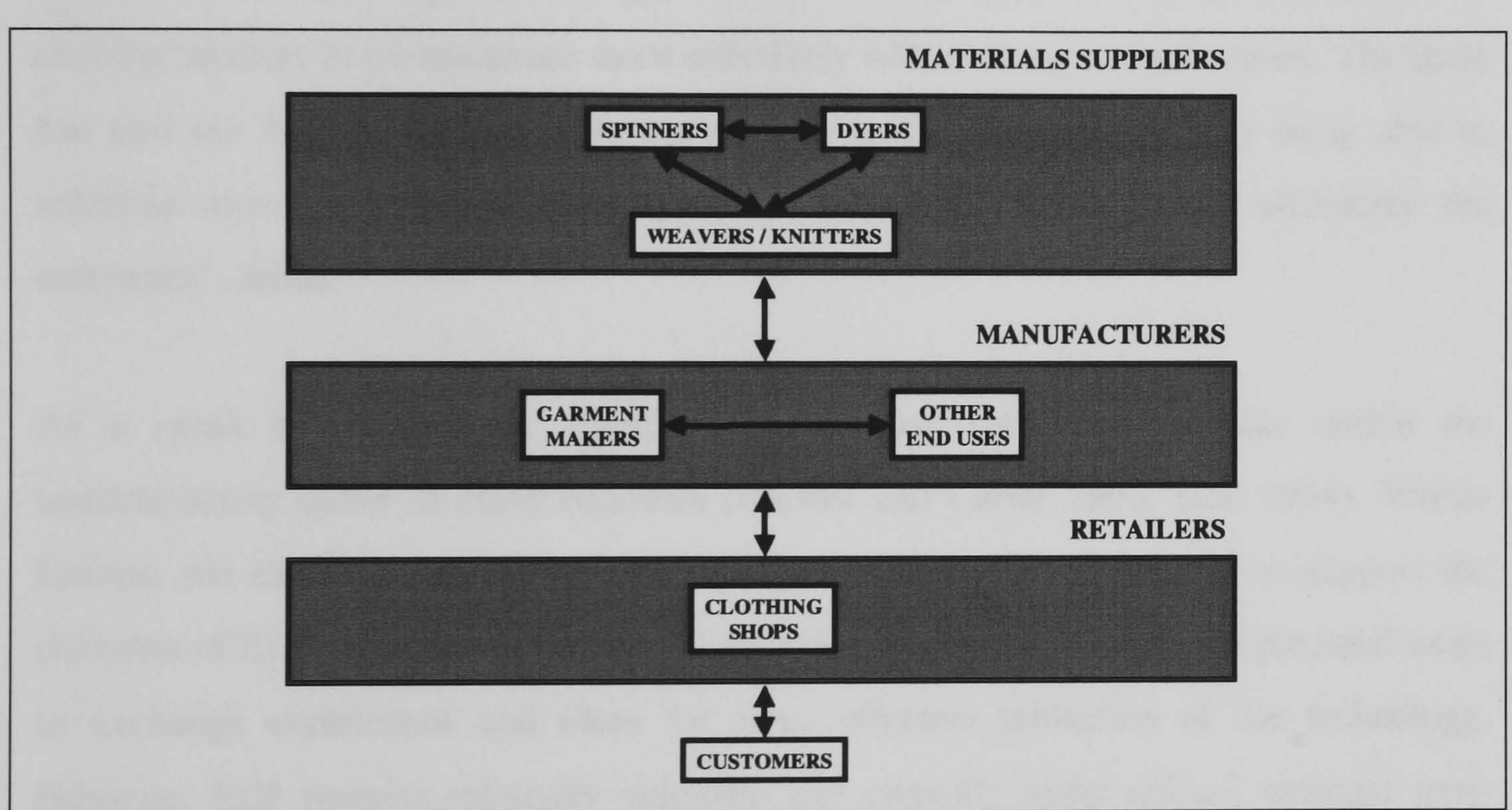


Figure 10. The Typical Textile/Clothing Sector Value Chain

The sector is also characterised by very high lead times for production (Hammond 1991, Skinner 1992), and a typically short life span of products (affected by seasonal and fashion trends). The combination of these factors has led most companies in the sector to an intense search for methods and tools that would deliver competitive advantage by shortening production times and/or enabling faster and more efficient exchange of information across the value chain (Rhodes and Carter 1993).

3.2.2. EDI in the Textile/Clothing Sector

It is theoretically predicted that EDI, if used effectively, can contribute to the competitiveness of an organisation (Jelassi and Figon 1994) as well as to the overall efficiency of an industrial sector (Cox and Ghoneim 1996). Organisational benefits from EDI include reduced costs (Emmelhainz 1993), improved communication with trading partners (Reekers and Smithson 1994), and even business scope redefinition (Venkatraman 1991). In the context of the textile/clothing sector, the use of EDI can support new, innovative business strategies such as Quick Response (QR) (Sullivan and Kang 1999). QR aims at reducing production lead times and enabling better response to demand fluctuations by fostering closer inter-relationships between companies in the industry value chain (Iyer and Bergen 1997). For example, the use of EDI can allow clothing retailers to communicate more effectively with clothing manufacturers. The latter can also use EDI to exchange information with textile suppliers, thereby being able to schedule more flexible production plans to meet the retailers', and ultimately the customers', needs.

As a result of its strategic significance, EDI has been very popular within the textile/clothing sector in many countries (Rhodes and Carter 1993, Hall 1994). Within Europe, the EDITEX user group (EDITEX 1993) has been established to support the diffusion of EDI within the sector and to provide a forum for existing and potential users to exchange experiences and ideas for more effective utilisation of the technology. However, EDI remains relatively unknown and certainly under-utilised amongst most Greek textile/clothing companies. This relates to the typical positioning of Greek companies in the early stages of IT maturity models (Doukidis et al 1994), where they have not yet identified the strategic importance of Information Systems. Especially in the textile/clothing sector, the small size of most companies, combined with the traditional style of family-based ownership and management, means that companies are in general ignorant of the potential of Information Systems, including EDI applications, to deliver competitive and strategic benefits. Moreover, such small companies are known to lack the resources and strategic vision to evaluate such investments in detail (Hoogeweegen and Wagenaar 1996). It was against this background that the overall project was initiated to raise EDI awareness amongst Greek textile/clothing firms, investigate the potential economic and business effects of EDI within the sector, and propose appropriate strategies for adoption.

3.3. Scope and Objectives of the Study

Within the wider project surrounding this case study, a survey of companies operating within the Greek textile/clothing sector was undertaken to identify the most prevalent concerns and problems that organisations faced in their day-to-day activities. For all stages of the value chain, it was found that high inventories and their associated costs ranked high in organisations' concerns (Doukidis et al 1995). Against this finding, it was decided to pursue a detailed investigation of the potential effects of EDI on inventories for companies operating at each individual stage of the textile/clothing value chain.

This coincided with our search for real-life situations that would allow for investigating the practical issues and problems of IS evaluation and hence enhance the understanding gained by the theoretical review discussed in the previous Chapter. The research ideas stemming from this review were presented to the project team and it was agreed to carry out a simulation exercise to provide quantitative estimates on the operational benefits that could be anticipated if EDI was used in the sector. The goal of the simulation exercise was consequently specified to provide a measure of the efficiency gains that can be achieved in inventory control within the textile/clothing value chain. It was further agreed that the simulation exercise would also attempt to examine how the existing business practices in the sector could be amended to leverage the EDI investment in order to achieve further benefits in inventory reduction. Thus, it became possible to inform the objective of studying the problem of IS evaluation within the context of business engineering or, in other words, within the context of aligning the design of IS applications with the design of business processes that these applications were intended to support.

A complementary literature review showed this to be a valid topic for investigation. Inventory reduction is reported to be one of the main factors influencing most companies' decision to adopt EDI (Anvari 1992, Reekers 1994). However, despite the theoretical claims, few and limited investigations of the conditions under which an EDI system is worth adopting have been reported. The few studies that exist have invariably taken different paths from the one discussed in this Chapter:

a) Mukhopadhyay et al (1995), for example, discuss the business value of EDI, albeit at the post-implementation level (i.e. by measuring already realised impacts) and at the level of a single company only.
b) Hoogeweegen and Wagenaar (1996) report on the development of a decision support tool to evaluate net benefits from EDI investments in the port community of Rotterdam. The system is however limited in its scope as it only addresses communication cost savings without any concern for other benefits or business process redesign issues. Furthermore, the system supports analyses at the single-organisation level only.
c) Other studies, for example Kekre and Mukhopadhyay (1992), Nygaard-Andersen and Bjorn-Andersen (1994), and Srinivasan et al (1994), have argued for the strategic business value of EDI, albeit based only on perceptual data, thus not addressing the issue of *a priori* quantification of EDI benefits.

Taken from another perspective, assessing inventory policy options can be considered as one of the 'typical' applications of discrete-event simulation to business decision making (for example, Bergmann 1990, Alstrom and Madsen 1992). Modelling the fluctuations of demand and lead time can aid in determining key decision points in inventory management (order times and order quantities). Inappropriate decisions in inventory control can result either in excessive stock-out costs or in excessive inventory holding costs. However, most studies to date have been confined to modelling and comparing inventory policies *per se* (i.e. isolating them from specific organisational contexts). The approach followed in this case study is different due to the following reasons:

a) The focus does not rely on the detailed workings of the inventory function, but rather on the *business processes* that affect and are being affected by the efficiency of inventory policies.
b) The objective is not to study alternative inventory policies as such, but rather to investigate how a given policy can be supported by Information Technology (EDI applications).
c) The concern is not on the internal workings of a single company, but on the dynamics and inter-relationships between companies across a whole industrial sector.

The case study addresses the *ordering*, *production planning*, *material requirements planning*, *demand forecasting*, and *inventory management* business processes of the organisations involved. These processes had been identified (Doukidis et al 1995) as related to the EDI applications and the inventory control strategies of the companies in the sector. Further explanation of the structure of these processes in the sector is provided in Appendix B of the dissertation.

Given the above scope and objectives, the case study was deemed as an excellent basis for gaining an additional empirical perspective against the theoretical findings of Chapter 2. In relation to the findings of that Chapter, the case study provided a forum for:

a) Studying the problem of IS evaluation in the context of *business engineering*. The goal of the study was to evaluate EDI, while considering opportunities for redesigning a number of business processes across the textile/clothing value chain.
b) Adopting the *process* as the fundamental unit of analysis in IS evaluation. The study did not focus on specific EDI *applications*, but rather on the impact of EDI on the *business processes* of the organisations involved at both the intra-organisational and the inter-organisational levels.
c) Incorporating only *high-level IS design* in business engineering, leaving technical options to be managed in the aftermath of IS evaluation. Indeed, the focus of the simulation was to evaluate EDI *in general*, without proceeding to consider alternative technical options for implementing EDI applications in the companies involved.
d) Concentrating on IS *benefit assessment*. The goal was to study the potential effects of EDI on inventory reduction, without considering issues of costs, other benefits, or risks involved. This allowed the researcher to 'isolate' a single variable to investigate, thus retaining a better, almost laboratory-like, degree of control than it is usually feasible within a real-life case study.
e) Supporting the *data generation* phase of IS evaluation. The goal of the simulation was not to perform an actual evaluation of the EDI investment, but rather to provide the quantitative data on inventory reduction which, combined with data regarding other benefits and costs of the investments, could support an actual evaluation exercise (for example, by means of a cost-benefit analysis).

3.4. Research Design

The first step in designing the simulation study was to identify a pertinent methodological framework to guide the researcher's effort and ensure that rigour and attention was maintained at all modelling steps. In the absence of a context-specific theoretical or methodological approach, as already discussed in Chapter 2, it was decided to follow a generic methodology for simulation modelling, namely the ten-step method advocated by Law and Kelton (1991) (illustrated in Figure 11). Using such an approach presented the additional benefit of educating the research effort further, by pinpointing potential limitations of generic simulation methods and informing the process of developing a *context-specific* simulation methodology as part of a design theory of IS evaluation by simulation.

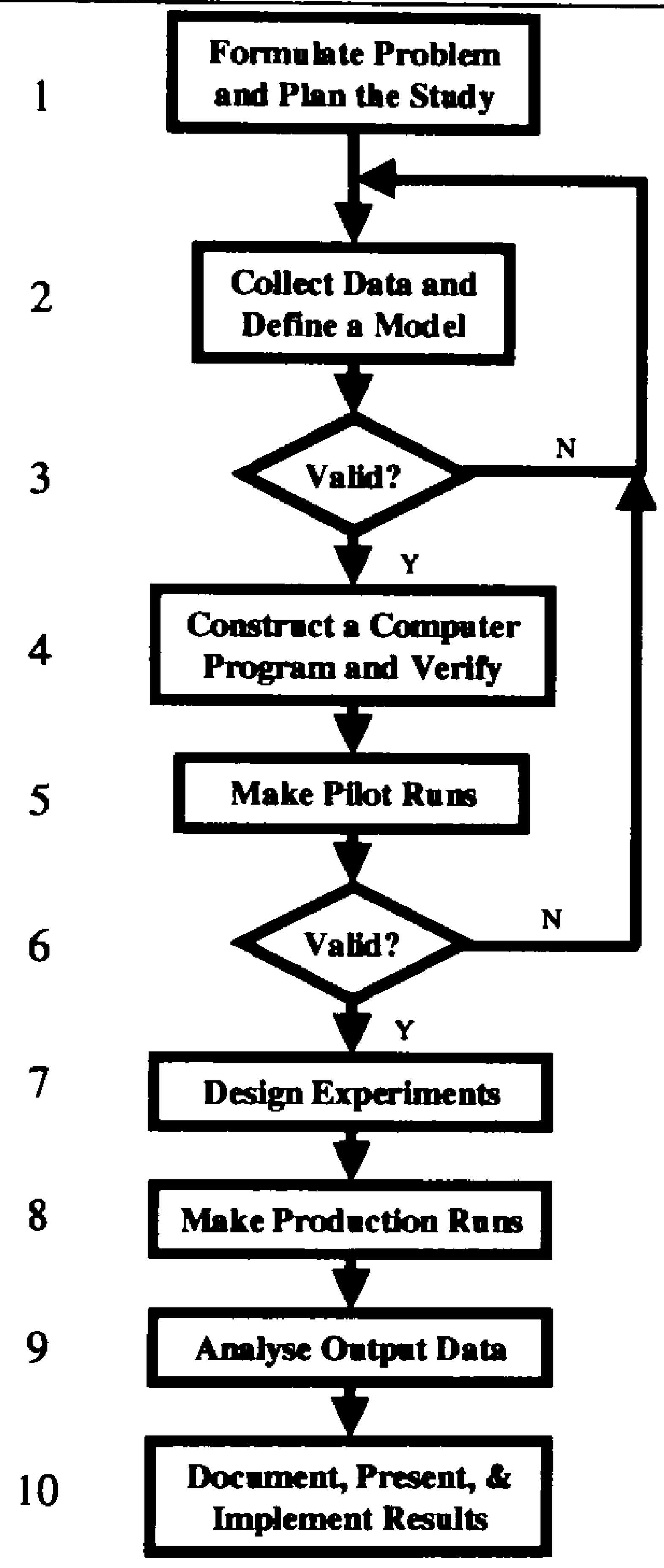


Figure 11. A Generic Simulation Study Methodology (Law and Kelton 1991)

Given the case study objectives and the research questions addressed within this dissertation, not all steps of the above methodology were pursued in detail. This is in line with the assertion of the methodology's developers who advocate that '*not all studies will necessarily contain all these steps and in the order stated*' (Law and Kelton 1991). Since the objective of this Chapter is not to document the simulation model development in detail, but rather to focus on the lessons learnt regarding simulation-supported IS evaluation, the steps of the case study will be only briefly discussed in the following sections. For a more detailed discussion, the interested reader is referred to Doukidis et al (1995), Mylonopoulos et al (1995a, 1995b), Giaglis (1996), and Appendix B of this dissertation, where various aspects of the model development are covered in greater depth.

3.5. The Steps of the Case Study

3.5.1. Problem Formulation

The scope and objectives of the case study (discussed earlier) were formulated under the co-operation between the project team and the researcher in a number of discussion and presentation sessions. In line with the above discussion, it was agreed that the case study would address the potential impact of EDI on inventory reduction at all three stages of the textile/clothing industry value chain. To keep the study's complexity within a manageable size, it was also agreed that the simulation models would be confined to establishing overall estimates of EDI impact for each value chain stage, without being concerned with effects on individual companies.

Law and Kelton (1991) advocate that within the first step of a simulation study '*the alternative system designs to be studied should be delineated*'. In accordance with this guideline, the project team engaged in rather time-consuming discussions regarding the alternative scenarios that should be modelled within the simulation. Finally, it was agreed to model only two extreme simulation scenarios. In the first scenario (henceforth referred to as the *AS-IS scenario*) no company in the value chain is using EDI, while in the second scenario (henceforth referred to as the *TO-BE scenario*) all companies at every stage are EDI users. The first scenario represents the actual situation in the sector and was included to provide a benchmark for comparison of EDI impacts, as well as for model validation purposes. The second scenario was included to provide an indication of an envisaged 'optimal' situation that could be demonstrated to the companies in the sector as part of the project's awareness activities. Other intermediate (and perhaps more realistic) scenarios were ruled out by the project team. It was deemed that such scenarios would inevitably lead to discussions about which companies would benefit most by EDI and which would achieve only marginal benefits (a situation known in EDI theory as '*unequal distribution of benefits*', discussed by Riggins and Mukhopadhyay 1994), an outcome that the project team wanted to avoid.

3.5.2. Data Collection and Initial Model Definition

It was decided to start with a moderately detailed model that would depict the overall value chain of the industry and the business processes outlined by the project team as influencing inventories. This decision was taken in accordance with the theoretical prescription that '*a model should contain only enough detail to capture the essence of the system for the purposes for which the model is intended*' (Law and Kelton 1991). The initial model depicted the archetypal structure of the sector, as well as a set of trading rules between the companies in each stage of the value chain. Figure 12 and Figure 13 depict the overall structure of the sector and the detailed sub-models used (greyed areas are out of scope).

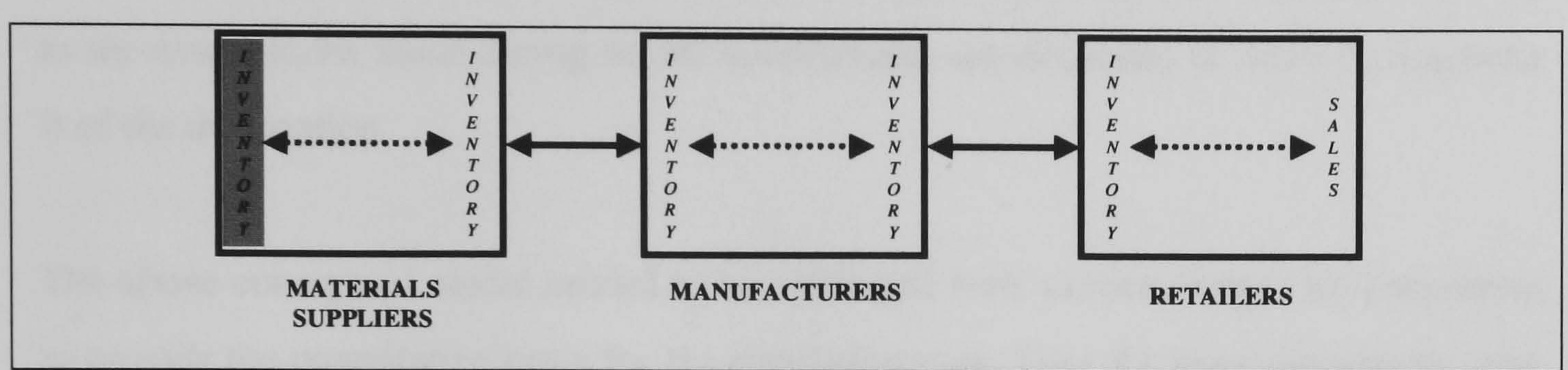


Figure 12. The Simulation Model Structure (Overview)

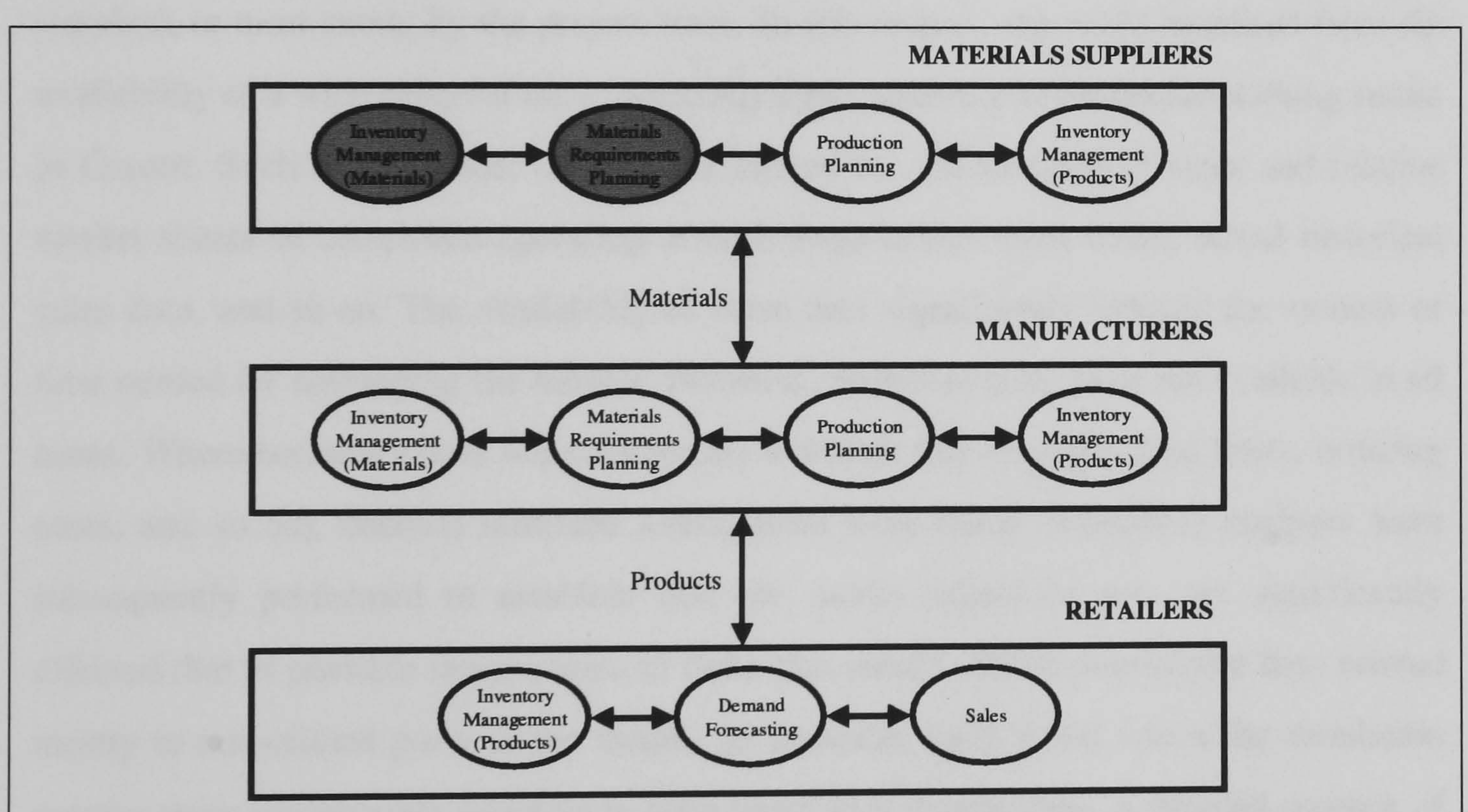


Figure 13. The Simulation Model Structure (Sub-Models)

In principle, the behaviour of the companies in the model is as follows: *Retailers* (clothing shops) satisfy customer demand for products from their existing product inventory. Inventory control is based on the processes of forecasting customer demand, order planning, and actual ordering of products to *Clothing Manufacturers*. The manufacturers also maintain product inventories to satisfy retailers' demand. Inventory control for manufacturers relies on the order plans and actual orders received by retailers, which determine the manufacturers' demand for production, and hence also the requirements for raw materials to support production. Based on their production planning, manufacturers maintain a materials inventory and communicate their needs for raw materials to *materials suppliers* in the same way as they have received the needs for products from retailers. The materials suppliers operate in a similar fashion to manufacturers, the main difference being that their own materials inventory management has been left outside the scope of the simulation model.

The detailed behaviour of the companies at each stage of the industry value chain, as well as the assumptions made during model development, are discussed in detail in Appendix B of the dissertation.

The above conceptual model needed to be calibrated with various exogenous parameters to provide the quantitative basis for the simulation runs. Data for these parameters were specified by the researcher throughout the process of initial model development and were supplied, in most cases, by the project team. In this respect, the study benefited from the availability of a wide range of data, especially those referring to the textile/clothing sector in Greece. Such data include, but are not limited to, distributions of sizes and relative market shares of companies operating at each stage of the value chain, actual historical sales data, and so on. The availability of these data significantly reduced the amount of time needed for developing the models. However, necessary data were not available in all cases. Where necessary data were not readily available (for example, lead times, ordering costs, and so on), detailed informed assumptions were made. Sensitivity analyses were subsequently performed to establish that the model behaviour was not significantly affected due to possible inaccuracies in these parameters. Since unavailable data related mostly to non-critical parts of the model, no instances were found where the simulation outputs were significantly sensitive to such input data fluctuations. A detailed account of the assumptions made during model development is provided in Appendix B.

3.5.3. Validation of Conceptual Model

Throughout the process of conceptual model development and data collection described above, the researcher remained in close contact with the project team, which was made aware of and agreed to all modelling assumptions made. The involvement of decision-makers and the interaction with the researcher was believed to contribute to higher face validity of the conceptual model developed, as well as to greater model credibility (perceived validity).

Regarding the validity of the data collected, most information was provided directly by the project team and was taken at face value since the researcher had no means of establishing the accuracy of the data from primary sources (direct data collection would be extremely costly and time-consuming). The sensitivity analyses that were performed, as outlined above, helped to ensure that the simulation results were not highly dependent on the assumptions made about unavailable data.

3.5.4. Program Development and Verification

The elements of the initial conceptual model, together with the quantitative data collected, were encapsulated into a simulation program written in Pascal (see Appendix B). A generic programming language was chosen for model development because of the nature of the study that necessitated that an adequate degree of flexibility was maintained. It was not felt that any of the existing data-driven simulators could accommodate the requirements of the particular study, especially the demand forecasting and inventory keeping rules employed (see Appendix B) and the inter-organisational nature of the study (Giaglis et al 1997). Furthermore, the model development team was already familiar with Pascal and benefited further from the existence of previously developed code that could be re-used to provide some of the 'standard' features needed for programming a discrete-event simulation model, for example next event handling.

Significant attention was paid to the verification of the simulation model or, in other words, to ensuring that the conceptual simulation model described above was correctly transformed into an executable simulation program. Both generic software engineering techniques and simulation-specific verification techniques (Sargent 1994) were used to test the computer model. These techniques included:

a) Gradual development of the code and testing of each program module as it was developed.
b) Re-use of previously developed and thoroughly tested program segments, especially for 'standard' discrete-event handling functionality.
c) Program walkthroughs and inspections by other programmers (i.e. not the model developers).

d) For all the complex modules, as well as for the final program itself, manual simulations were carried out to compare the expected system state, under deterministic conditions, with the program outputs (under the same conditions). An example of the manual simulation template and results is shown in Appendix B.

3.5.5. Pilot Runs

Pilot runs of the verified simulation program were carried out to provide the basis for model validation in the following step. The pilot runs were also used to determine other model parameters, such as the model run duration, the warm-up period, and so on. The values for these parameters were chosen after running the model repetitively with different input values and comparing the results. The final model was run for a simulated period of four years, the first of which is used as a warm-up period (i.e. no data are collected). Time is measured in days and, assuming that each month consists of 30 days, this gives a total of 1440 days run duration (of which 360 are warm-up period). The chosen run duration and warm-up period were deemed adequate for generating valid results after tests with alternative options were made.

The final deliverables of the program consist of large amounts of raw numerical data generated in text files. Daily demand and inventory levels for each company are recorded. These data are subsequently uploaded into an Excel spreadsheet for further processing and presentation. *Visual Basic* macros were developed in Excel to automate the process of uploading and aggregating the output data to the chosen level of analysis (value chain stage – see below), as well as for generating the graphical outputs used. It is worth mentioning that the simulation program itself includes no visual capabilities (graphics, animation, interaction, and so on) as they were not perceived to be necessary for the project (the system itself was not intended to be demonstrated to any organisation, just the results of the simulation study).

3.5.6. Validation of Computer Model

Simulation model validation deals with substantiating that a model, within its domain of applicability, behaves with satisfactory accuracy and is consistent with the study objectives (Carson 1986, Sargent 1994). The problem of simulation model validation is an inherently difficult one as '*it involves a host of practical, theoretical, statistical, and* *even philosophical complexities*' (Naylor 1979). In our case, since the model depicted the operation of an existing real-world system, the process of validation was made slightly easier. The modelling objectives, coupled with unavoidable project-imposed constraints, meant that model validation in the case study consisted mainly of 'comparing' the model's behaviour with the real-world system it is supposed to depict.

Based on the results of the pilot runs, output data regarding the average levels and fluctuations of product and material inventories were calculated for each stage of the sector value chain and were presented to the project team. The decision-makers agreed that the simulation output data resembled, at least in terms of trends, the actual situation in the sector. While no formal techniques were used for model validation, the above method was deemed to be sufficient for the purpose in hand.

Detailed validation of model behaviour and outputs would anyway be almost meaningless, since the generic nature of the business processes modelled meant that the processes could not be validated by comparing them to one or more real-life instances. Rather, the usefulness of the model relies on its ability to highlight process performance improvements due to EDI adoption, *regardless* of the internal workings of, say, the production planning mechanisms employed. Inasmuch as the model results are independent of these workings (due to the fact that all scenarios are run using the same input parameters), the model can be considered as valid for the purpose in hand. In other words, model validity does not refer to the *absolute* numbers produced by the simulation runs (which are very much dependent on the aforementioned process workings and input data), but rather on the *comparative* evaluation of results between the AS-IS and TO-BE models (which use the same inputs and differ only in the EDI adoption factor). A more detailed discussion and critique of the underlying validity of the simulation study as a whole is presented in section 3.6 below.

3.5.7. Experimental Design

As mentioned above, it was decided from the outset of the study that only two scenarios would be modelled. Consequently, no design of experiments was performed within the case study.

3.5.8. Production Runs

The results obtained by running the AS-IS scenario were intended to be used as a basis for analysing and comparing the results of the TO-BE scenario runs (where all companies use EDI). To this end, the AS-IS model needed to be modified to incorporate the expected effects of EDI adoption on the sector. However, when faced with the challenge of incorporating the role of EDI in the AS-IS simulation model, the researcher faced extreme difficulties.

The theoretical prediction is that EDI, at the operational level, facilitates increased speed of transactions, labour savings (Emmelhainz 1993), greater accuracy (Hoogeweegen and Wagenaar 1996), and reduced costs (Reekers and Smithson 1994). However, when put against the simulation model, these theoretical propositions proved to be rather abstract and impractical, as none of them could be directly integrated into the simulation model:

a) Speed of transactions was not an issue, as the lead time for all information exchange between the companies was assumed to be zero and therefore could not be reduced via EDI.
b) Resource constraints had not been taken into account, therefore labour savings could not be modelled either.
c) Similarly, possible data inaccuracies in the pre-EDI era had not been modelled, so EDI could not be hypothesised to reduce any such errors.
d) Finally, there was no provision in the model for measuring inventory costs *per se*, as the stated aim of the model was to provide quantitative data on benefits only (inventory reduction).

It could perhaps be argued that a solution to the aforementioned problems might have been to modify the model to include factors such as the above. However, none of the aforementioned parameters (speed of transactions, labour savings, error and cost reductions) was expected to significantly affect the model's key performance indicator, namely inventory *levels*. The problem seemed to be of a wider nature, which was not due to some inadequacy of the simulation model. Rather, it could be traced back to the need for incorporating the expected IS impact on business performance in the simulation model in an explicit manner. Such incorporation could support the generation of reliable, quantitative data for the *specific* problem of IS evaluation under investigation.

To this end, after it became apparent that it would be significantly difficult to incorporate the impact of EDI within the simulation model based on the above parameters, we set out to investigate other, easier to operationalise, impacts of EDI. Anvari (1992), in one of the few published works dealing explicitly with inventory management facilitated by EDI applications, claims that the use of EDI can result in reduced uncertainty during lead time, reduced lead time and reduced ordering cost. The former of these factors provided a starting point for translating the theoretical impacts of EDI into practical simulation model modifications to support the process of IS evaluation in our case.

Disentangling our focus of analysis from the EDI applications, and instead emphasising the business processes that EDI was called to support, proved to be useful. In line with the theoretical prescriptions outlined in the previous Chapter, we assumed that the introduction of EDI could perhaps be beneficial for cost or error reduction, but was expected to provide only marginal benefits in terms of inventory reduction if applied in itself. In order to be able to model such effects, it was necessary to make additional assumptions regarding the *business processes* that companies would need to change to take advantage of the increased communication/co-ordination capabilities brought by EDI. Since EDI is supposed to support '*better demand forecasting*' (Srinivasan et al 1994) by '*making it less expensive to frequently transmit demand information up the supply chain*' (Bourland et al 1996), it was decided to recommend a business change scenario where companies take advantage of EDI to exchange information about expected future demand in more frequent intervals across the value chain. According to Anvari (1992), '*this effect is present not only in placing the actual order, but in all data communication that takes place [via EDI]*'.

As a consequence, the difference between the AS-IS and TO-BE simulation models has basically to do with order plan submission. In the model, a retail shop without EDI (AS-IS scenario) makes only one demand forecast in the beginning of each season and sends only one order plan to its suppliers. This forecast is based on the previous season's sales. This mechanism is consistent with the actual operating policy of most companies in the sector, which indeed send one (or even no) such plan per season to assist clothing manufacturers in better scheduling production. Conversely, retailers with EDI (TO-BE scenario) re-estimate the expected total demand for the whole season at regular intervals (based on the actual demand realised in the market) and update their order plans sent to manufacturers. The simulation model implements a simple forecasting method using the cumulative distribution of historical sales data. For example, if it is known from past data that up to a given time during the year 15% of total yearly sales are realised, the total expected sales for the current year can then be calculated using the current sales figure. The past sales database is updated with the realised sales for each period during the course of the simulation. The same approach is followed by EDI-enabled manufacturing companies regarding the submission of their own materials order plans to materials suppliers.

This method effectively implements the prescriptions of the theory for better demand forecasting (Srinivasan et al 1994), reduced information transmission cost (Bourland et al 1996), and reduced uncertainty in the value chain (Anvari 1992). More frequent and better informed demand forecasts in the case of EDI are expected to result in better adaptation of the whole value chain to the realised demand. If the theoretical predictions are valid, this improvement in demand forecasting can be hypothesised to be able to 'tune' inventories along the value chain to the realised customer demand. This change is also easy to incorporate in the AS-IS simulation model by changing the time interval between order plan submissions by retailers and clothing manufacturers. It only remained to see whether this change would be in line with the above hypothesis or, in other words, whether it would indeed result in lower inventory levels for all companies.

3.5.9. Output Data Analysis

The basic measurements taken during the course of the simulation are the daily demand faced by retail companies (customer demand) and the daily inventory levels of each one of the companies in all stages of the value chain. Since most of the input data of the simulation are aggregated parameters for each stage of the sector, rather than detailed measurements for individual companies, the results produced by the simulation runs were also aggregated to the level of the value chain stages. It was perceived that data for individual companies, although generated by the simulation runs, could not be considered as valid estimations.

AS-IS Scenario Results

Figure 14 illustrates an example of the daily demand faced by retail companies. Customer demand is an input parameter to the model and is calculated pseudo-randomly from a normal distribution to which actual historical sales data from the sector have been fit (taking into account the smaller market size in the model). Conversely, the daily demand faced by clothing manufacturers and textile companies are dependent on the orders they receive from their customers (i.e. no input data are used).

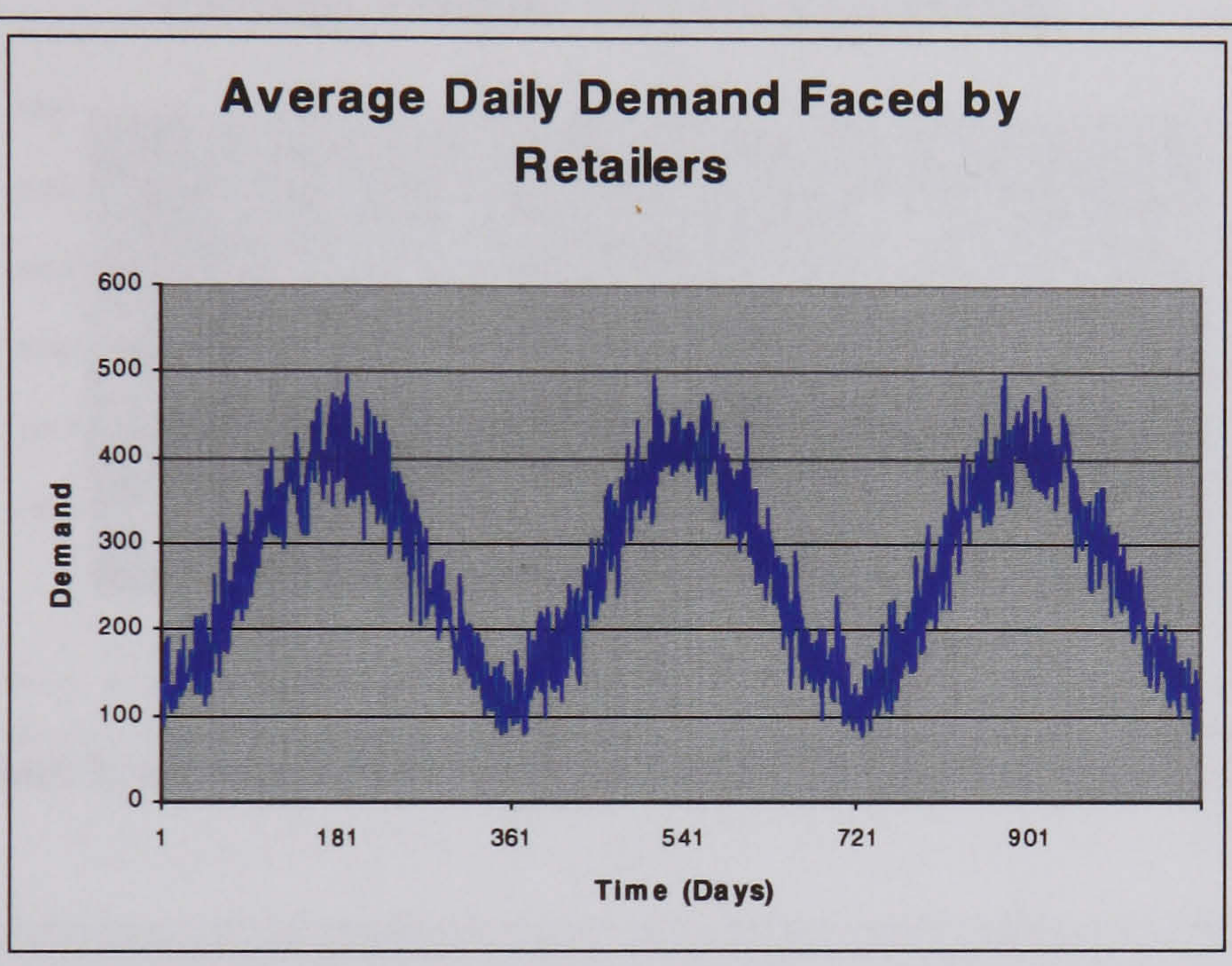


Figure 14. Customer Demand Faced by Retail Companies (example)

Figure 15 illustrates average daily product inventory levels faced by retail and clothing companies in the AS-IS model. Product inventories for textile companies were not calculated since the production planning and procurement mechanism for textile companies had been left outside the model's scope. Finally, Figure 16 depicts the average daily materials inventory level for clothing companies.

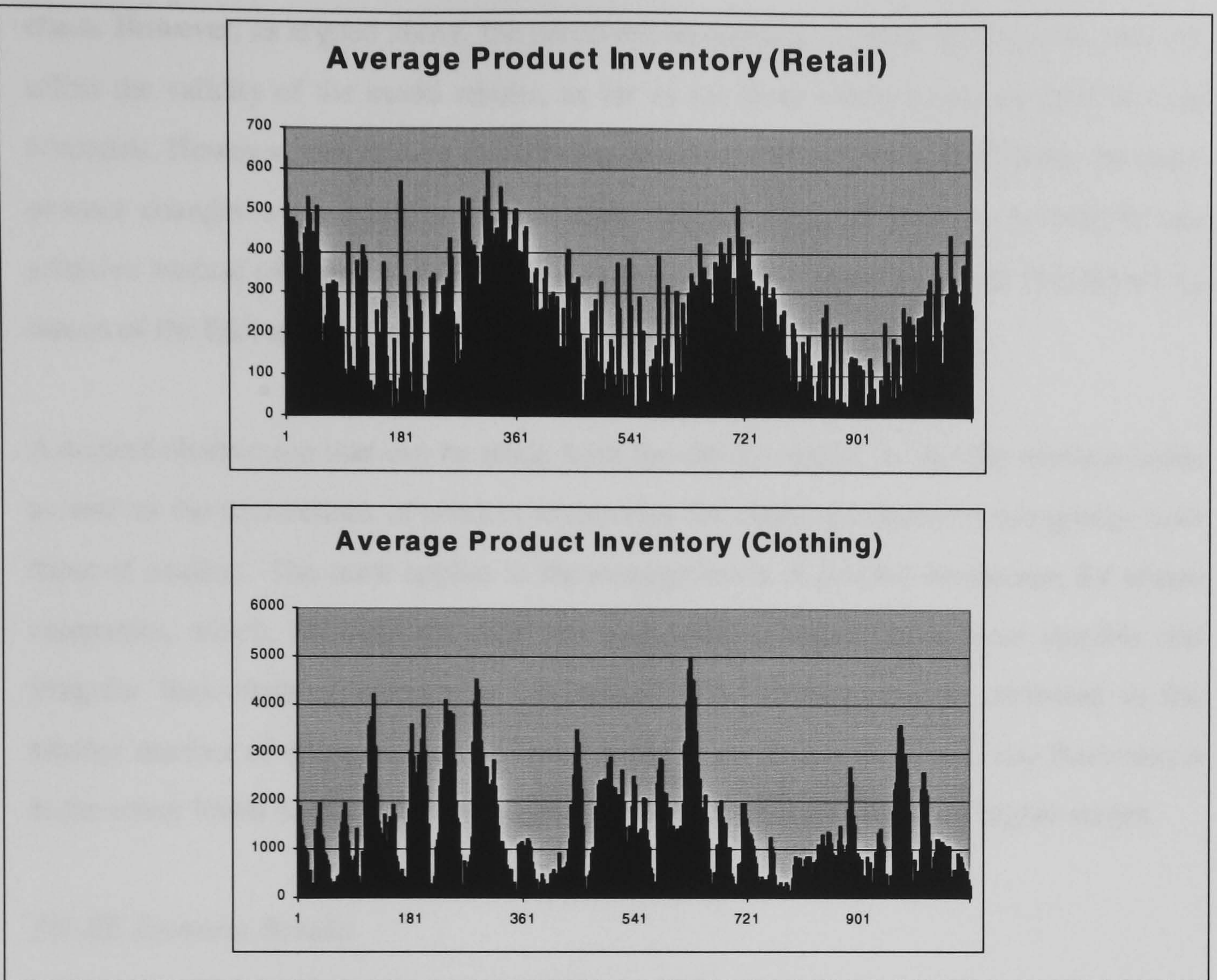


Figure 15. Product Inventory Levels for Retail and Clothing Companies: AS-IS Scenario

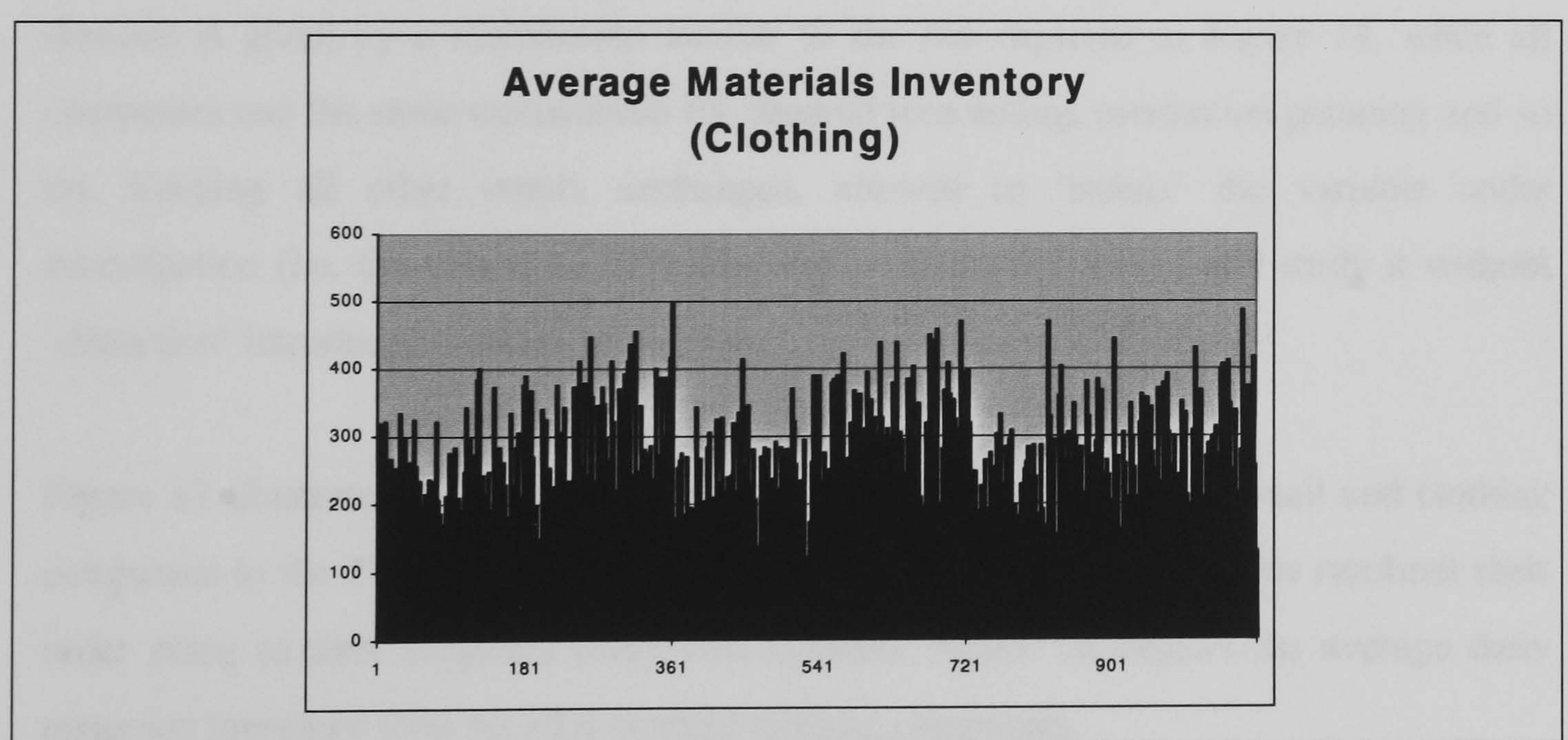


Figure 16. Materials Inventory Levels for Clothing Companies: AS-IS Scenario

The first observation that can be made is that inventory levels (especially for products) are highly irregular. This high deviation can be partly attributed to the relatively simplistic and static nature of the mechanisms used for production scheduling, inventory management, and order planning. The heuristic algorithms used were not always sufficient to facilitate an effective co-ordination between companies across the value chain. However, as argued above, the perceived inadequacy of these mechanisms does not affect the validity of the model results, as far as the same mechanisms are used in both scenarios. However, this finding can serve as an additional indication that further business process changes are needed to address areas beyond the need for a more flexible and adaptive method of communication between the companies (which is to be introduced by means of the EDI applications in the TO-BE scenario).

A second observation that can be made from the AS-IS results, is that the average levels as well as the fluctuations of product inventories for clothing companies are greater than those of retailers. The same applies to the average levels of product inventories for textile companies, which, although not valid for comparisons, appear to be more sizeable and irregular than clothing companies' inventories. This finding can be attributed to the smaller number of outlets at higher levels of the value chain. Therefore, any fluctuations at the lower levels of the chain are naturally magnified as we move up to higher stages.

TO-BE Scenario Results

The input data for the TO-BE scenario were the same as above. Thus, the customer demand is given by a distribution similar to the one depicted in Figure 14, while all companies use the same mechanisms for demand forecasting, production planning and so on. Keeping all other inputs unchanged, allowed to 'isolate' the variable under investigation (i.e. the effects of EDI adoption on inventory levels) and study it without 'distortion' introduced by other changes.

Figure 17 illustrates daily average product inventory levels faced by retail and clothing companies in the TO-BE scenario (assuming that EDI-enabled companies resubmit their order plans to their suppliers every two months). Figure 18 depicts the average daily materials inventory level for EDI-enabled clothing companies.

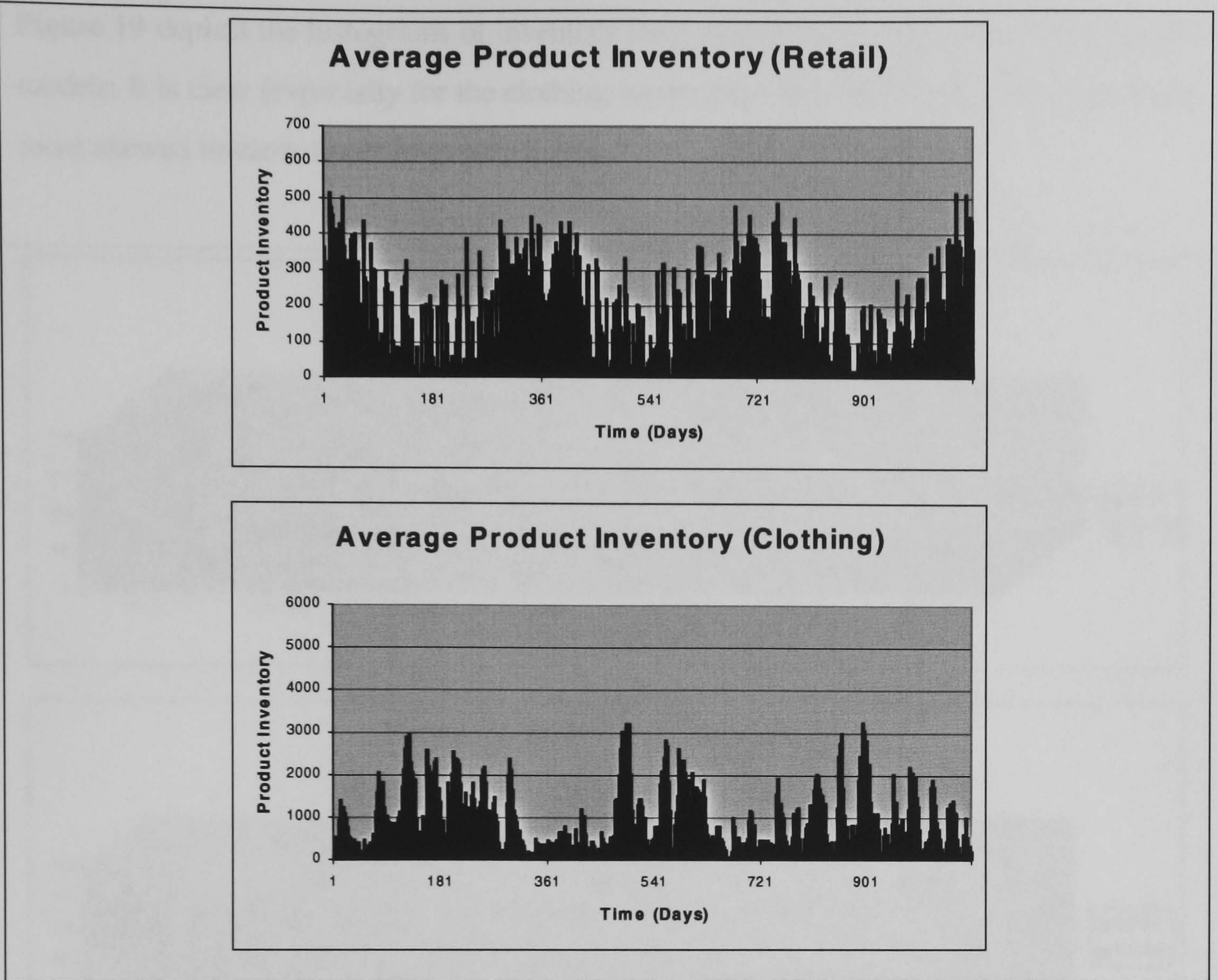


Figure 17. Product Inventory Levels for Retail and Clothing Companies: TO-BE Scenario

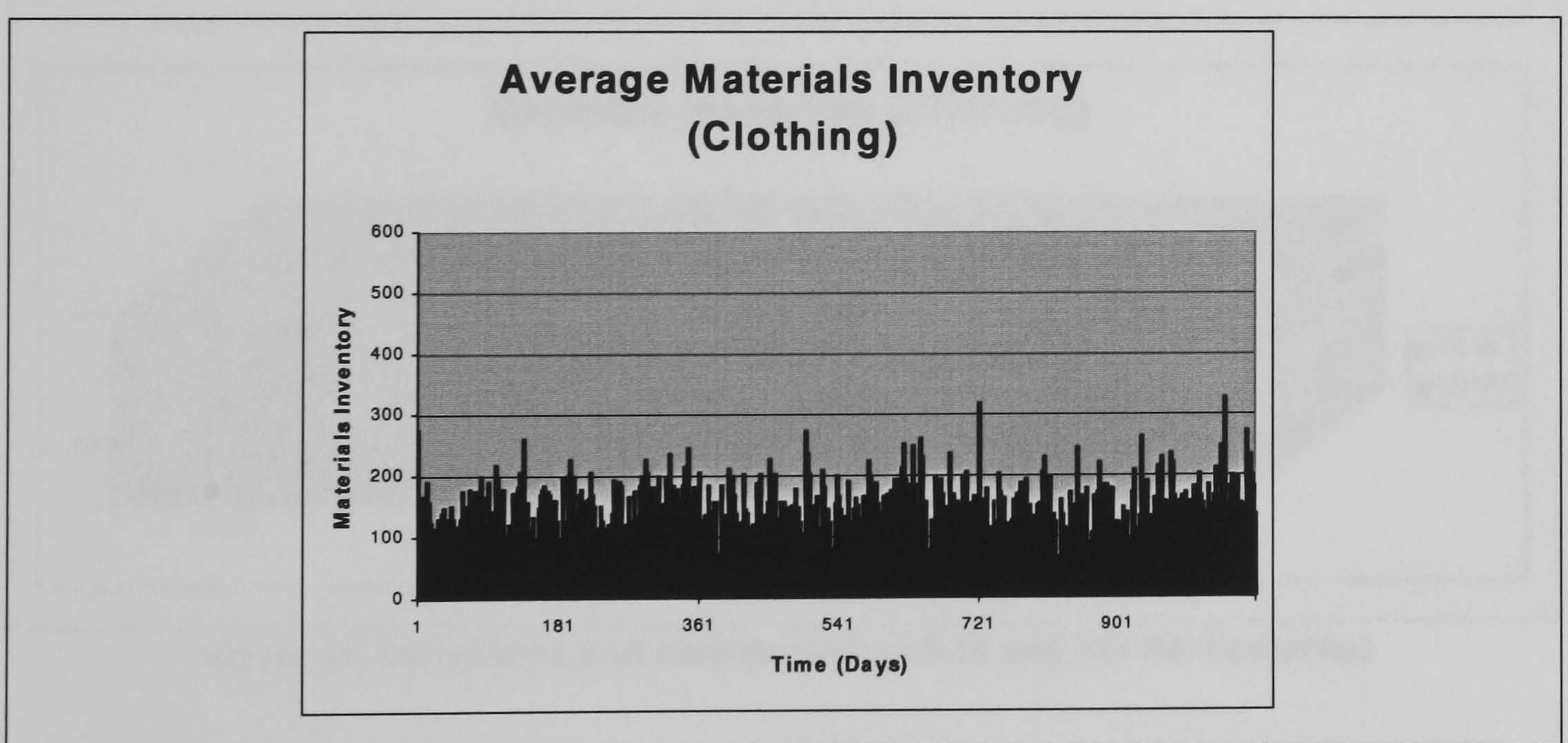


Figure 18. Materials Inventory Levels for Clothing Companies: TO-BE Scenario

Since the same mechanisms were used for all other business processes apart from order planning and inter-company communication, it is not surprising that the output from the TO-BE scenario generally follow the same pattern as their AS-IS counterparts. However, even without resorting to statistical calculations, it is evident that all inventory levels are significantly reduced in terms of average levels, if not in terms of fluctuations as well.

Figure 19 depicts the histograms of inventory level distributions in the AS-IS and TO-BE models. It is clear (especially for the clothing companies) that the TO-BE distributions are more skewed towards lower inventory levels.

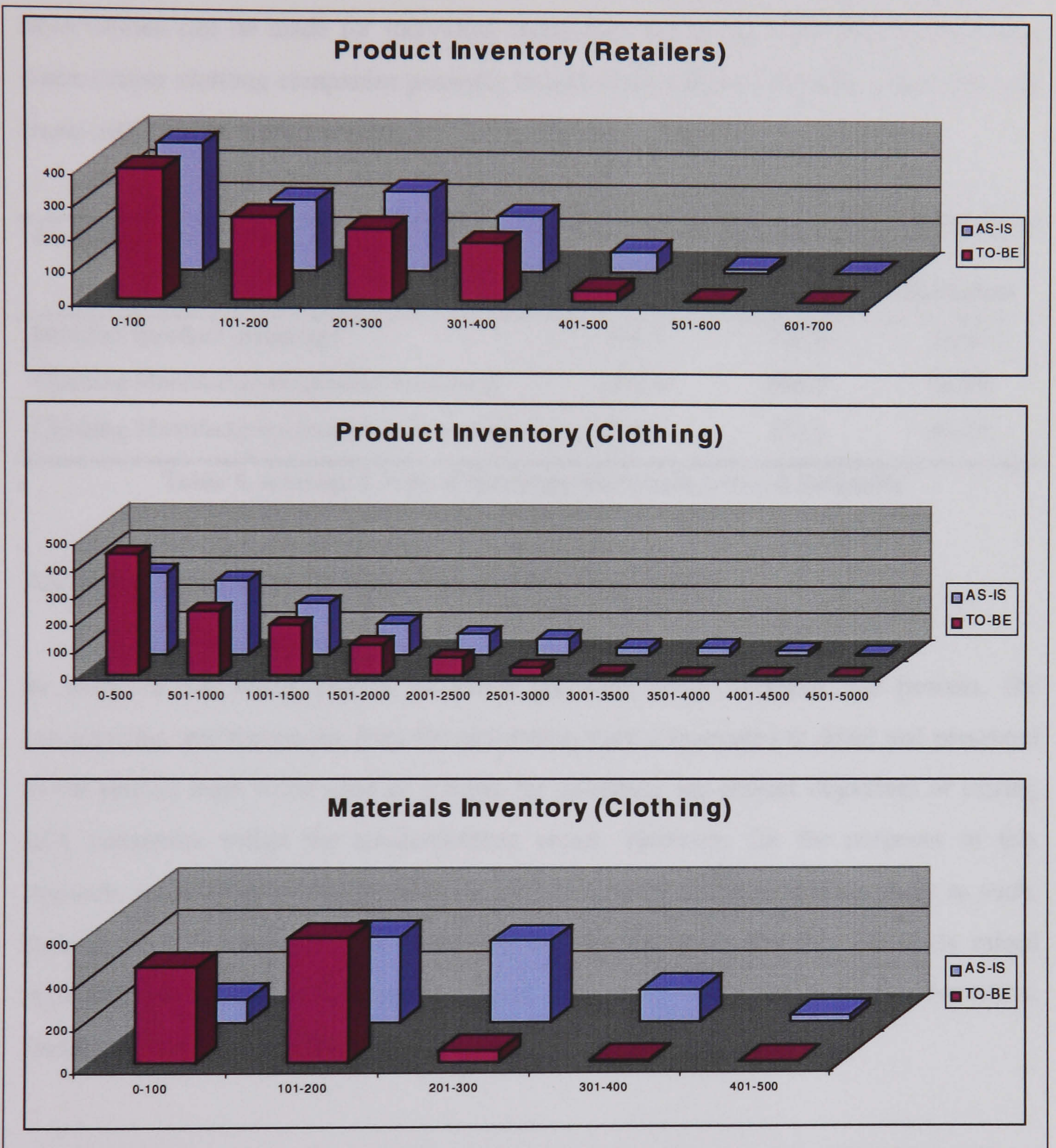


Figure 19. Inventory Level Distributions (AS-IS and TO-BE Scenarios)

Looking at the means of inventory levels in more detail, Table 8 summarises the results in terms of the reductions of inventory levels after the introduction of EDI. Apart from the inventory reductions for the industry as a whole as a result of EDI adoption, the numbers also provide empirical support for another theoretical prediction. Indeed, as Riggins and Mukhopadhyay (1994) predict, EDI benefits seem to be distributed unevenly amongst the participants. Larger companies and companies at higher levels of the value chain seem to enjoy significantly greater reductions in inventory levels. For example, while retailers achieve a 7% reduction on average, clothing companies achieve reductions between 27% (for products) and 42% (for materials), thus making the EDI investment much more attractive for them. Although, as stated above, results for individual companies are not considered to be statistically significant due to the aggregation level of the model, similar observations can be made for individual companies within the same level of the value chain (larger clothing companies generally benefit from greater inventory reductions than those with smaller market shares).

Category	Average Inventory Levels		
	Before EDI	After EDI	Reduction
Retailers (product inventory)	184.1	171.6	6.8%
Clothing Manufacturers (product inventory)	1212.0	886.5	26.9%
Clothing Manufacturers (materials inventory)	211.9	113.9	46.2%

Table 8. Average Levels of Inventory Reduction between Scenarios

3.5.10. Documentation, Presentation, and Implementation

In terms of the wider project to which the case study belonged, the process, the assumptions, and the results from the simulation were documented in detail and presented to the project team to be used as a basis for informing the project objectives of raising EDI awareness within the textile/clothing sector. However, for the purposes of this research, we will not be interested in the detailed results of the simulation study as such. Instead, we will concentrate on addressing the specific issues that the case study raised regarding IS evaluation by simulation and how these issues relate to the theoretical findings of the previous Chapter.

3.6. A Critique of the Case Study Process and Results

The quantitative results presented above are clearly insightful but questions may be raised regarding their accuracy and reliability as predictions for the sector. Although a detailed theoretical discussion of model validity and usefulness falls outside the scope of this dissertation, we will briefly reflect on the process and results of the simulation study in this section.

Inasmuch as a simulation model is a simplified version of reality, it is of paramount importance to substantiate that the assumptions and beliefs built within the model are subject to careful scrutiny before using the model as a learning and decision-making tool (Pidd 1992). The 'philosophical' question that may then arise is whether a simplified version of reality can be sufficiently adequate to study reality itself. Essentially, the notion of simulation model validation refers to comparing two sets of observations (data from the model and data from the 'real world'), none of which can be regarded as 'true' (i.e. as a basis for assessing the validity of the other). Indeed, according to Popper (1959), what we mean by 'real world' is nothing more than a set of human-made observations that cannot be unbiased because they are subject to a number of influencing factors, most importantly the mere fact that they are made having a specific objective in mind: validating the model.

For that reason (as well as many others that are not covered here), *absolute* model validation is essentially an unattainable objective (Horn 1971). However, even in relative terms, models cannot be universally valid (Law and Kelton 1991). Instead, we can increase our confidence in them if we carefully define their field of applicability. It is therefore important to examine issues such as model scope and intended use before we define what 'validity' means.

Regarding the utility of the simulation results as decision-aiding tools in our study, it is worth re-emphasising that the results obtained are not suggested as autonomous and unique answers. Rather, they are complemented by a set of clearly stated conditions and assumptions against which they should be evaluated. Two kinds of assumptions are built in the simulation models: those related to the current modes of operation of the companies in each sector and those concerning the future impact of EDI. Regarding assumptions of the first kind, it is true that in practice companies would probably employ variations of a more experience-based and intuitive kind to substitute the relatively simple mechanisms used in the simulation. However, as discussed above, the exact choices regarding modes of company operation are not expected to influence the results regarding the effects of EDI adoption, provided all choices are kept constant throughout the study. As for the assumptions of the second kind, they follow the expectations of the potential adopters as well as the relevant literature. Coupled with the fact that simulation results are not intended to be used as absolute numbers, but rather have value only as comparative estimates, we can deduce that the model possesses adequate validity for its intended use.

Regarding the choice of the simulation scenarios, it could be argued that, apart from the two scenarios modelled, other intermediate cases with varying proportions of companies with and without EDI should also be analysed. This sort of information would be interesting but marginally useful given the purposes of the research presented in this dissertation. Indeed, for the purposes of our analysis, the actual scenarios run do not play a particularly important role. Keeping in mind that the research objective was to study the ways in which IS evaluation can be supported by Business Process Simulation (BPS), one could argue that even the simulation results themselves are not important. What is important though, is to reflect on the case study and assess the lessons learnt regarding *IS evaluation by simulation* in practice. Therefore, in the following section we will discuss how the empirical insights gained by the case study relate to the theoretical findings of Chapter 2 in order to advance the process of theory development in the following Chapter.

3.7. Conclusions: Towards a Design Theory of IS Evaluation

3.7.1. Empirical vs. Theoretical Findings: Lessons from the Case Study

Probably the first and most important observation that could be made from the case study is that the direct incorporation of IS impacts in BPS models can be a problematic task. However, it is also an extremely important one if we want to generate the quantitative data that could drive a formal investment appraisal of a proposed system. To this end, the study provided empirical support to the argument of using the *business process* as the mediating factor between IS adoption and business returns. Indeed, in our study, it became clear that the expected theoretical impacts of EDI, if studied in isolation, are only tentative, in the sense that they cannot be realised (or at least they cannot be exploited to their full extent) just by implementing the technology. However, if the Information Systems are accompanied by specific changes in business processes, then organisations could perhaps more easily take full advantage of the capabilities offered by the systems. What is even more important, is that simulation at this level (of the business process change) seems to be easier and more intuitive than attempting to model the IS itself as an independent and standalone entity, isolated from its organisational context.

Further to supporting the theoretical findings of the previous Chapter, the case study played an additional, perhaps even more important, role. The detailed execution of a real-life simulation model development for IS evaluation pointed to additional issues that would have been more difficult to capture in a purely theoretical study. One of these issues related to the usefulness of employing simulation as a supporting technique for business engineering. It was observed that the process of developing and using the simulation models necessitated a level of thinking that enabled us to identify business changes that were needed to leverage the IS investment. In other words, the study showed that the process of developing, validating and using simulation models for IS evaluation can in itself be a very useful learning exercise, as it generates greater awareness of both the specifications of the proposed system and the conditions of the business operations under which the system can produce the desired results.

As far as IS development is concerned, an additional benefit of the approach is that IS designs do not need to be specified in any substantial depth. Indeed, in the case study, we were able to model the impact of EDI without being concerned about issues of applications integration, network and telecommunications support, or any other 'technical' implementation detail. Using such an approach, we can avoid the pitfall of reductionism identified in the previous Chapter as a drawback of most extant development approaches. Furthermore, we can also avoid the cost of specifying in detail the operational details of systems that may never be developed in practice because they will not pass through the initial, business-focused, evaluation phase supported by the simulation model development. Having said that, however, the models *were* able to point towards high-level IS design issues that could feed the process of IS development. For example, in the case study, knowing that the EDI applications will have to be integrated with the forecasting and order plan submission mechanisms of the companies involved, provided IS specialists with valuable knowledge for a more detailed specification of the EDI applications requirements.

Summarising, we can conclude that the study provided further support to the claims about the efficacy of *business engineering* in organisations. Indeed, simulation can provide support to all three 'reference disciplines' of business engineering:

a) It can support a better 'fit' between business processes and Information Systems, thus satisfying the main requirement of *process-based organisational design*.
b) It can point to high-level IS design issues, thus providing valuable feedback to the process of *IS development*.
c) It can support the benefit assessment and data generation phases of *IS evaluation*.

3.7.2. Additional Insights: Simulation Methodology

The case study also proved invaluable in highlighting additional points of caution that should been taken into account in simulation-assisted IS evaluation. One such issue deals with the methodological approach used. Generic business process change methods, extant IS development methodologies, and IS evaluation techniques, were all criticised in the previous Chapter as not adequately addressing the requirements of business engineering. The simulation-oriented methodology followed in the case study pointed to similar conclusions regarding the efficacy of generic simulation methods for our purpose. Although the methodology followed in the case study was adequate for reaching a successful completion to the project, we feel that a context-specific method needs to be developed to overcome some of the limitations found. It must be noted here that these limitations are not criticisms of the specific methodology used, but apply equally to any generic simulation method.

Firstly, simulation methodologies cannot be reasonably expected to provide any explicit guidance for IS evaluation, as they are not developed with this purpose in mind. However, given the complexities of the IS evaluation problem, generic approaches may fail to flag the modellers' attention to the complexities that can be anticipated when IS impacts have to be incorporated in the business process simulation model. The significant problems encountered when trying to model the impact of EDI adoption on inventory levels in the case study, which we believe are not atypical of similar evaluation situations, suggest that specific attention should be paid to this issue by a context-specific methodology. For example, IS impacts should be thought of, and at least outlined, at the very outset of model development, to avoid problems such as those encountered in the case study.

Secondly, we felt that the methodology followed in the case study (and indeed, any generic simulation methodology) focused too heavily on simulation-specific issues, without addressing in enough detail relevant organisational or systems concerns pertinent to the problems of business engineering and IS evaluation. To the extent that simulation is not an end in our case, but rather a means of supporting a wider project, it is natural to expect the emphasis to shift from simulation-focused to organisational-focused and IS-focused issues. This means that any context-specific simulation methodology should be easy to integrate with (in the sense of allowing the simulation project to be performed within) a wider business or IS project, which would itself be expected to be based on a business process change or IS development method, like the ones presented in Chapter 2.

3.7.3. Requirements for Simulation-Supported IS Evaluation

The aforementioned issues have certain implications regarding the requirements that should be met by an effective and efficient approach to IS evaluation by simulation. Although this issue will be covered in more detail in the following Chapter, we will attempt to sketch some of these requirements based on the insights gained by the case study in this section.

The case study emphasised the impacts of EDI on inventory management. However, in certain circumstances (for example if other performance indicators need to be modelled to support IS evaluation), it may be necessary to broaden the scope of the simulation. This, in our case, could involve modelling other operational and strategic effects of EDI, such as customer related factors, communication related factors, production related factors and cost related factors (Reekers 1994). Taking a step further, even a simulation of the *strategic* effects of EDI would be interesting, incorporating such issues as the competition amongst participants in the value chain, dynamic EDI adoption decisions by companies, and market interactions over time.

However, if modelling the impact of EDI on inventories was problematic, attempting to incorporate the above effects as well is surely expected to be a daunting task, one that needs to be supported by specific theoretical and methodological guidelines if it is to be carried out effectively. It can be suggested that a gradual approach to model development and incorporation of IS effects may be necessary in such cases. A sound understanding and an efficient implementation of the *operational* IS effects can, for example, be considered as a prerequisite of modelling the *strategic* ones. Thus, one can start from a simpler model used to study the immediate effects of the system under evaluation and enhance this model as needed to study effects at higher levels of complexity. To keep the model at a manageable size, it can also be argued that all effects need *not* be studied in all cases. Indeed, if the data generated by the initial model versions are adequate in arriving at a positive evaluation of the proposed system (i.e. if the benefits surpass the respective costs), then the investment can be considered as justifiable and the remaining benefits may well come as additional rewards after system implementation. This approach can contribute to more manageable and cost-effective IS evaluations by simulation.

Furthermore, in order to be a useful and accessible decision aid, simulation models for IS evaluation should provide friendly interfaces to the users, as well as a certain degree of flexibility in using and interacting with the models. Given that the models will probably be used in the business domain by users who will not necessarily be modelling and simulation experts, issues such as ease-of-use, visual and interactive capabilities (Bell et al 1999), and so on, become even more important. Such capabilities would enable decision-makers to experiment with different scenarios and rapidly identify the expected effects through advanced graphic displays (Hurrion 1986). No such capabilities were included in the models developed in our case study, thus we were unable to investigate user-related issues in detail.

This observation relates also to the platform used for model development. Although a generic programming language was used in the case study presented in this Chapter, this route is neither the only, nor necessarily the best, to follow. A number of data-driven business process simulators have appeared on the market, as discussed in Chapter 2, claiming to assist users in developing and using business process simulation models more effectively and efficiently. Although these claims may well be true regarding business models in general, it remains to be tested whether these simulators possess the necessary functionality to be used as tools for IS evaluation as well. The choice of platform that was made for the particular case study did not allow for addressing this issue, but the need for software support for simulation-assisted IS evaluation remains nevertheless undiminished. A discussion of the nature of the facilities that such software should provide will be (amongst others) the concern of the following Chapter.

3.7.4. A Concluding Note

It is evident that the case study provided valuable additional insight to the knowledge accumulated through the background material review, but at the same time generated more questions and issues that will require further exploration and testing. In the following Chapter, we will synthesise the findings we have obtained through the background material review of Chapter 2 and the case study presented here into a design theory for IS evaluation by simulation. Some of the issues that will still remain open for discussion and further research will then be further addressed by a second case study that will be used to test and enhance the theory. In the meantime, Table 9 summarises the findings discussed in this Chapter as pertaining to the use of discrete-event simulation for business engineering and IS evaluation.

Finding	**Justification**
Process Orientation	The value chain perspective followed in the case study is directly analogous to the process-based perspective of organisational design and differs significantly from approaches taken in previously published studies. Process Orientation can be an efficient and cost-effective approach, as it can address all the reference disciplines of business engineering.
IS Impact Modelling	Cannot and should not generally be performed in isolation. *Informational* changes do not happen in vacuum, but are usually triggered by *structural* changes. Adopting the business process as the analytical lens may be useful. Specific attention to the issue should be paid at the outset of any study.
Model Development	The modelling process can itself be a valuable experience for learning, understanding, and integrating business process and Information Systems issues. However, it may be extremely difficult to incorporate all IS impacts to the simulation model at once. An approach where more intangible IS benefits are gradually added to an already well documented and understood model of the immediate IS effects, may be desirable.
Methodology	Generic methods for business process change, IS development, IS evaluation, or simulation modelling, may prove inadequate in bringing together the complete spectrum of issues that need to be addressed. A context-specific methodology may be required, providing however clear interfaces to the above 'encompassing' methods. In such a method, specific attention should be given to the IS impact modelling step.
Development Platform	Generic programming languages offer flexibility but may result in complex, time-consuming modelling efforts. More work is needed towards the articulation of specific requirements for business process simulation software, capable of handling IS evaluation problems. Some initial requirements may include explicit IS impact modelling, ease-of-use to appeal to targeted audiences, animation/interaction capabilities, and so on.

Table 9. Summary of Case Study Findings

Before closing this Chapter, it is worth mentioning that, since the case study was performed, at least three other independent studies have followed very similar approaches in modelling the effects of EDI (albeit not using simulation as the supporting technique):

a) Bourland et al (1996) follow a strikingly similar path to model (via mathematical modelling techniques) the relationships between a single supplier and a single customer in an imaginary value chain. The authors investigate how the participants could exploit the advantages of more timely demand information exchange enabled by EDI to reduce inventories or improve the reliability of deliveries.

b) Barua and Lee (1997) also use formal models to analyse the introduction of an EDI system in a vertical market involving one manufacturer and two suppliers. However, the scope of their analysis is quite different, as they concentrate on modelling the expected impacts of subsidising or penalising decisions introduced by the manufacturer to 'pull' the suppliers towards entering EDI partnerships.

c) Even in the more specific case of the apparel sector, Iyer and Bergen (1997) use formal models to study choices of production and marketing variables in a single manufacturer-retailer channel before and after the adoption of Quick Response. The major assumption that the authors used is that under Quick Response, the retailer '*has the ability to adjust orders based on better demand information*'.

The aforementioned studies, which were not published until after the case study had been completed, provide additional support to the arguments discussed above. However, the simulation analysis followed in our case study provides an additional benefit. Because it is not confined by the inherent complexities of mathematical modelling, it is possible by the use of discrete-event simulation to study (albeit in a less rigorous fashion) more complex real-life problems of IS evaluation.

3.8. Summary

In this Chapter, we have discussed an empirical study that was used to complement and enhance the findings of the theoretical review presented in Chapter 2. Drawing on the findings of this study, we were able to gain additional insight on how some of the theoretical considerations identified earlier may materialise in real-life organisational situations. Furthermore, we were able to outline an initial set of requirements for effectively utilising simulation in the context of business engineering and IS evaluation.

However, the findings of both Chapter 2 and Chapter 3 are still somewhat 'isolated', at least in the sense of not being united under the 'umbrella' of a robust theoretical framework that would foster a more targeted approach to the problems under consideration. To this end, in the following Chapter, we will use such a foundational framework, namely the concept of an Information System Design Theory (ISDT), to synthesise our findings into a blueprint of a *design theory* of IS evaluation by simulation.

CHAPTER 4. A DESIGN THEORY FOR IS EVALUATION BY SIMULATION

If you can't replicate something because you don't understand it, then it really hasn't been invented; it's only been done

Drucker (1987)

In the previous Chapters we identified a lack of specific theoretical work to explicitly guide the design and use of simulation models for IS evaluation in the context of business engineering. In this Chapter, we will draw on the knowledge obtained so far to articulate such a theoretical approach. Because we are concerned with both the *design process* that can lead to IS evaluation simulation models, as well as the *design products* of this process (i.e. the models themselves), we contend that the underlying theoretical basis of our research can be addressed through a *design theory* of IS evaluation by simulation. Such a theory can contribute towards the development of '*a body of intellectually tough, analytic [...] doctrine about the design process*' (Simon 1981).

The concept of Information System Design Theories (ISDT) (Walls et al 1992) will be employed as a vehicle for guiding and structuring the development of our theoretical propositions. We will begin by presenting the nature and structure of ISDTs in general, and we will then use these principles to develop a design theory in our particular context. The theoretical propositions set forth in this Chapter will then be further tested and expanded through a second empirical case study to be discussed in Chapter 5.

4.1. The Information Systems Design Theory (ISDT)

The concept of ISDT was first articulated by Walls et al (1992). According to the authors, a design theory for Information Systems is '*a prescriptive theory which integrates normative and descriptive theories into design paths intended to produce more effective information systems*'. It must be noted that an ISDT aims at the *design of classes of Information Systems*, rather than the *development of specific IS instances*. This renders ISDTs particularly suitable for driving the design of simulation environments that would provide useful assistance to IS evaluation in general, as opposed to the evaluation of a particular IS investment in a given organisational context. It was due to this, more than any other characteristic, that ISDT was chosen as the theoretical foundation of the work to be presented in this Chapter.

Before proceeding with applying the principles of ISDT for the development of our design theory, it is worthwhile examining the thinking behind the development as well as the components of ISDTs in general.

4.1.1. The Nature of Design Theories

The primary difference between design theories and other scientific theories of the natural or social sciences is how they deal with purposeful behaviour or goals (Walls et al 1992). Goals are meaningless in the natural sciences and typically constitute only a secondary element of the social sciences inquiry (for example, to explain why specific goals exist). Conversely, the purpose of a design theory is to support the *achievement* of a particular goal or set of goals. To this end, design theories are *prescriptive*, in the sense that they provide constructs and guidelines for the achievement of stated goals, rather than explaining phenomena (explanatory theories) or predicting outcomes (predictive theories). Furthermore, design theories are *composite*, as they encompass and integrate kernel theories from their reference disciplines. Finally, design theories are theories of *procedural rationality* (Simon 1981), as their objective is to prescribe both the *properties* that an artefact should have if it is to achieve certain goals, and the *methods* of artefact construction.

4.1.2. The Components of ISDT

Since 'design' is both a noun and a verb, design is both a product and a process. Therefore, according to Walls et al (1992), design theories must have two aspects, one dealing with the *product of design* (i.e. the artefact that will form the outcome of applying the design theory) and one dealing with the *process of design* (i.e. the method by which the design product can be realised). We will use this distinction to describe the components that form an ISDT. These components are summarised in Table 10.

DESIGN PRODUCT	
Kernel Theories	Theories from reference disciplines that govern design requirements
Meta-Requirements	The class of goals to which the theory applies
Meta-Design	A class of artefacts hypothesised to meet the meta-requirements
Design Product Hypotheses	Used to test whether the meta-design satisfies the meta-requirements
DESIGN PROCESS	
Kernel Theories	Theories from reference disciplines that govern the design process
Design Method	Description of procedures for artefact construction
Design Process Hypotheses	Used to test whether the design method results in an artefact consistent with the meta-design

Table 10. Components of an ISDT (Walls et al 1992)

It must be noted that the terms 'meta-requirements' and 'meta-design' are used instead of simply 'requirements' and 'design' because a design theory does not address a single problem (for example, the simulation-supported evaluation of a specific Information System) but a class of problems (for example, IS evaluation by simulation in general). Therefore, specific sets of requirements and specific design structures are expected to be derived from the generic meta-requirements and meta-design depending on the nature of specific projects. Due to this, Nissen (1996) argues that ISDTs are analogous to object-oriented design, in that they provide a method to generate a common set of meta-requirements and a meta-design at the *IS class* level, which can then be inherited by many specific *IS instances*.

4.1.3. The Applicability of ISDT for IS Evaluation

ISDTs have been used as the foundational element of many specific IS design theories. The developers of ISDT, Walls et al (1992), have used it to develop a theory to guide the design of Executive Information Systems (EIS). Other authors have also used the underlying principle of ISDTs to develop design theories for, amongst others, Decision Support Systems (Kasper 1996), Group Decision Support Systems (Limayem 1996), and Organisational Memory Information Systems (Stein and Zwass 1995).

In a context more closely related to the research presented in this dissertation, ISDT has been used by Nissen (1996) to develop a design theory for the use of qualitative simulation[4] in the context of business change. The use of ISDT proved to be an effective means for deriving and testing detailed design requirements for the theoretical propositions made by the author. Nissen concludes his work by presenting a number of directions for further research, which include, amongst others, the extension of ISDT to address *integrated* IS and business process design.

Drawing on this proposition, we focus our attention on the potential of ISDT to drive the development of a theory that supports the design of discrete-event simulation models for IS evaluation in the context of business engineering. Having presented the underlying foundations of ISDTs in general, the remainder of the Chapter will be concerned with using these foundations for building a design theory for evaluating investments in Information Systems through the use of simulation models that depict both organisational processes and the effects that IS have on them.

4.2. Towards a Design Theory for IS Evaluation by Simulation

The theory will be developed taking into account the conclusions reached in Chapter 2 by studying the reference disciplines of business engineering, namely Process-based Organisational Design (POD), Information Systems Development (ISD), and Information Systems Evaluation (ISE). Moreover, the additional findings of the case study presented in Chapter 3 will also be used to enhance the practical applicability and usefulness of the theory's propositions.

The aim of the theory can be summarised as follows:

> *To provide a systematic approach to the problem of benefits assessment within the context of pre-implementation IS evaluation and business engineering, and to form the basis for the development of methods and tools for simulating organisational structures and the anticipated impacts that Information Systems will have on them.*

---

[4] Qualitative Simulation (QS) is a symbolic technique associated with the common-sense reasoning branch of Artificial Intelligence. Despite its name, QS bears little resemblance to the principles and techniques associated with numerical, discrete-event simulation. A more detailed discussion on QS can be found in Appendix A (under Knowledge-Based Techniques).

In the remainder of the Chapter, we will use the ISDT structure illustrated in Table 10 above, to articulate the components of our theory. We will start by briefly reviewing the kernel theories, which we will take to include the reference disciplines of business engineering already reviewed in Chapter 2 (process-based organisational design, IS development, and IS evaluation). Next, we will discuss a set of meta-requirements, a meta-design, and a design method that form the 'core' of the theory. Finally, we will outline a number of hypotheses for testing the theory's validity and completeness. These hypotheses will form the basis for analysing the findings of a second (explanatory) case study that will be discussed in Chapter 5.

4.3. Kernel Theories

The reference disciplines of business engineering present an obvious starting point for identifying appropriate kernel theories that would drive the design theory's development. Since these disciplines have been the subject of detailed scrutiny in Chapters 1 and 2, here we will only include a brief reminder of the main findings presented there.

Process-based Organisational Design (POD)

The development of novel approaches to viewing and analysing organisations based on the processes they perform has presented researchers and practitioners with a whole new set of opportunities for change management. Process change can be viewed primarily as a design problem (see Chapter 2) and therefore an opportunity exists for incorporating the elements of this problem in the design theory to be articulated here. Furthermore, it should be evident from the analysis presented in Chapter 2 that the role of Information Technology as an enabler of process change is central to the success of process improvement programmes. Therefore, the theories and techniques of business process change should be an inseparable part of the design theory.

Information Systems Development (ISD)

We have already seen how the extant approaches to IS development fail in principle to address the issue of pre-implementation IS evaluation, if not in technical terms, at least in terms of its anticipated effect on business performance. We have also addressed the problem of reductionism and assessed its potential consequences as far as business engineering is concerned. It is important that these observations are taken into account during the theory articulation to ensure that the design theory is suitable for use within the context of IS development and, at the same time, remains alert towards the potential limitations of existing approaches.

Information Systems Evaluation (ISE)

Finally, we have argued that the process of IS evaluation itself is of an inherently problematic nature and no definite theory for addressing its problems has to date been developed. We have also argued in favour of adopting a different perspective from the one implicitly advocated in most extant techniques. More specifically, we have chosen to focus evaluation efforts at the level of the business process, instead of the IS project. Within this perspective, we have chosen to concentrate on two issues that were identified as sources of potential IS evaluation problems. These issues relate to *IS benefits assessment* and *data generation* to support quantitative evaluation techniques (see Chapter 2).

4.4. Meta-Requirements

The meta-requirements of the design theory should follow naturally from the findings of the kernel theories review, discussed in Chapter 2. Figure 20 summarises the findings from each kernel theory and synthesises them into a set of four generic meta-requirements that the design products (i.e. simulation models) of the theory should satisfy. The arrows in the Figure point to common requirements found in more than one kernel theories. In the following paragraphs, these meta-requirements will be discussed in more detail. This discussion will allow for complementing the lessons from the kernel theories with the additional conclusions derived by the case study. It is worth emphasising that the meta-requirements in ISDT relate to the *design products* (i.e. the simulation models). Other lessons relating primarily to the method for arriving at these products will be addressed in a later section, when the theory's *design method* will be developed.

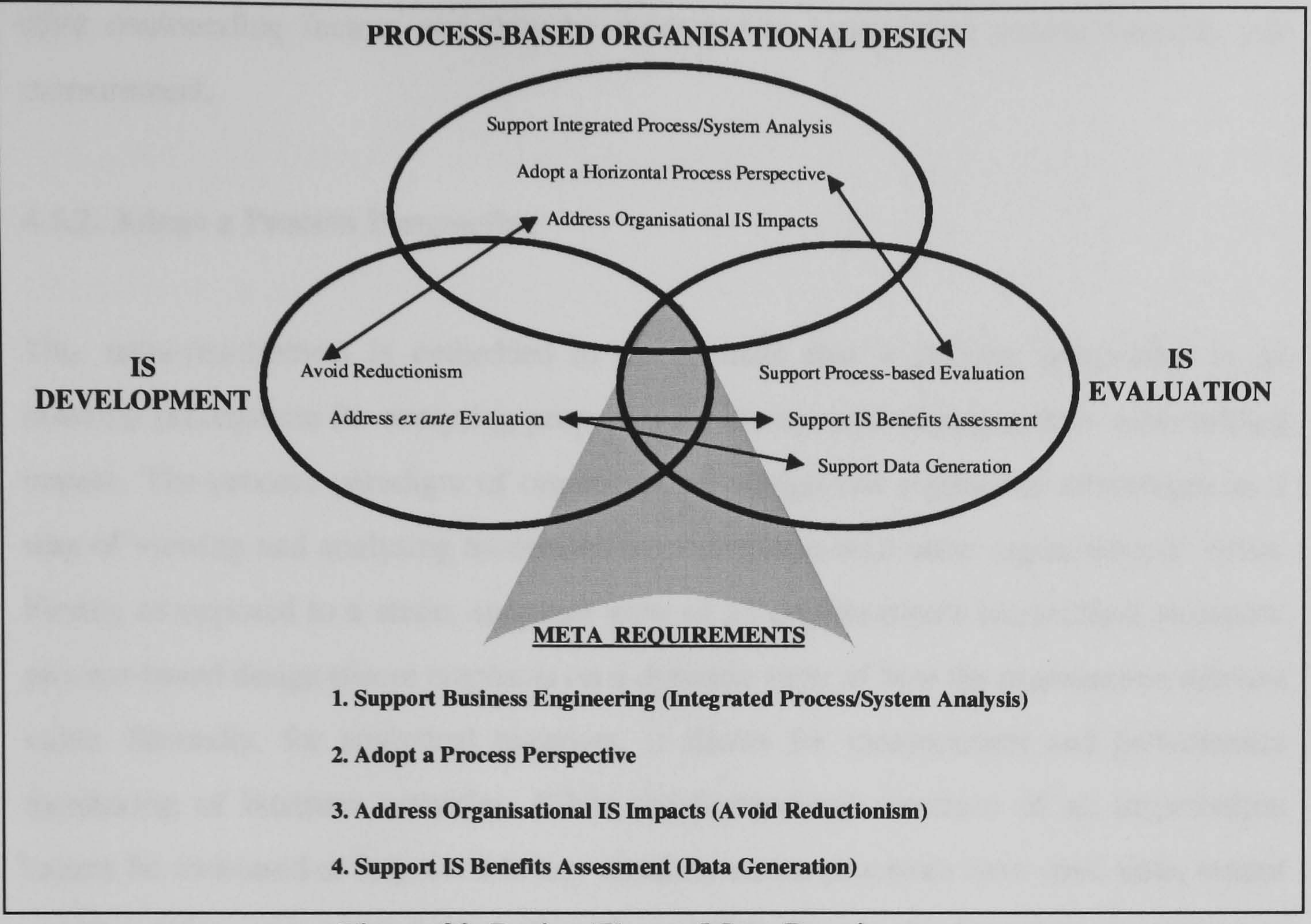


Figure 20. Design Theory Meta-Requirements

4.4.1. Support Business Engineering

A fundamental meta-requirement, based on the objectives of the design theory itself, is the ability of the simulation models to address the principles of business engineering. Since the objective is not just to represent business processes and evaluate generic proposals for change, but rather to concentrate on evaluating the impact of Information Systems on business performance, it naturally follows that the simulation models should be capable of explicitly addressing the anticipated effect of *informational* (IS-induced) changes.

However, it should also be kept in mind that the use of an Information System is not the only way of addressing a business problem. Information Technology is only one of the enablers of process change and business performance improvements may come as a result of other, *structural*, changes as well. Therefore, the design theory should also be able to put the IS against alternative proposals for change and compare the effects of each on business performance. This ability will support the assessment of the likely impacts of both types of change in an integrated manner, thus allowing for evaluating heterogeneous investments that compete for organisational resources. This facility should contribute towards the generation of a laboratory-like experimentation facility on which benefits from proposed IS specifications and/or structural process changes can be isolated from other confounding factors and thus be subjected to independent experimentation and measurement.

4.4.2. Adopt a Process Perspective

This meta-requirement is embedded in the premise that a process perspective is an essential prerequisite for analysing proposals for change and assessing their value-adding impact. The process paradigm of organisational design has significant advantages as a way of viewing and analysing businesses in comparison with other organisational views. Firstly, as opposed to a static, snapshot view of an organisation's hierarchical structure, process-based design places emphasis on a dynamic view of how the organisation delivers value. Secondly, for analytical purposes, it allows for measurement and performance monitoring of business activities. While the hierarchical structure of an organisation cannot be measured or improved in any absolute sense, processes have cost, time, output quality, and customer satisfaction (Davenport 1993). Due to this, the process perspective also fits more 'easily' to the simulation paradigm, and hence emerges as a natural candidate for the design theory.

Although the process perspective may in itself contribute to increased user acceptance of simulation models (as it offers an 'intuitive' way of representing work activities), the importance of a user-friendly front-end to the simulation models should not be underestimated. The case study of Chapter 3 highlighted the need for easy-to-use simulation models, given the likely audience of non-expert model users in the organisational domain. There should therefore be provisions in the meta-design for visual interfaces and other facilities that would satisfy this need.

Adding to this, the familiarity of business managers with other modelling perspectives (for example, functional or organisational, see Appendix A) may mean that the process-based representation of simulation models may need to be complemented by other 'worldviews' to provide a comprehensive and easy to understand picture to model users. This need for *multi-perspective* modelling will be discussed in more detail in the following section (meta-design).

4.4.3. Address Organisational IS Impacts

In Chapter 2 we identified *reductionism* as one of the main sources of difficulties in evaluating proposals for Information Systems at the pre-implementation stage and at the organisational level. We have also argued for the need of evaluation approaches to remain at a relatively high level of abstraction in order to be able to effectively address the business benefits of an IS-induced change. In other words, we advocate that the simulation does not need to be concerned with the detailed specifications of an Information System to be used for IS evaluation. In fact, the Information System itself does not need to have been specified in great detail for the IS evaluation by simulation to take place.

Such an assertion reinforces the point that the design theory can be used in the early stages of the IS development process, and even when no formal IS development has begun. Furthermore, it also means that the simulation models should not be so detailed as to become data models. Instead, they should constantly remain at their intended organisational process level.

Having said that, it should also be acknowledged that the complexity of the IS evaluation problem, as well as the different needs of model users, may require modelling at different levels of aggregation. For example, a top executive need not (some may say should not) be concerned with process details, hence a need for 'communicating' the model at a high level of abstraction. However, these details may be of paramount importance for a middle manager or an end-user to understand and use the simulation effectively. Hence, the meta-design should support hierarchical model development and decomposition at different levels of abstraction, albeit always keeping in mind the need to remain at the organisational level of evaluation, as discussed above.

The case study discussed in Chapter 3 also pointed to the need for explicitly addressing IS impact modelling as early as possible in the simulation exercise. However, since this need is concerned primarily with the *design method*, it will be revisited later in this Chapter.

4.4.4. Support IS Benefits Assessment

One of the major problems of IS evaluation, as argued in Chapter 2, is the problem of *measurement*. Hence, the design theory (and therefore the simulation models) should aim at addressing this problem by providing decision-makers with quantitative information regarding the expected benefits associated with the introduction of a proposed Information System, along with any associated process changes that may also be implemented. Such information can then be used in a formal appraisal to evaluate the justifiability of the investment.

To address this need, the simulation models should explicitly incorporate the *bottom-line* effects of structural and informational changes on business performance. To achieve this, we need an explicit statement of the *Key Performance Indicators (KPIs)* to be monitored by the simulation and the ways in which these indicators are expected to be influenced by business and/or IS changes. Such an approach will assist towards maintaining focus on the business-critical parameters and will also provide explicit guidance for the output analysis step of the simulation study. Due to the above, this meta-requirement has certain implications for the simulation methodology to be followed and will therefore be revisited during the development of the design method.

Furthermore, reflecting on the findings of the case study discussed in Chapter 3, IS benefits assessment may not always be possible to perform in one step. A gradual model development approach may be necessary to allow for modelling the immediate IS impacts first and then, if needed, expand the models to include more intangible IS effects. Hence, both the meta-design and the design method should provide facilities that allow for such a gradual approach of model development and enhancement. Regarding the meta-design, this may necessitate a modular approach to model development. Design modularity has already been advocated (MacArthur et al 1994) as a desirable feature of business process simulation models as it can support component reuse and gradual model development and testing.

4.4.5. Implications for the Meta-Design and the Design Method

Table 11 summarises the implications of the meta-requirements discussed above for both the *meta-design* and the *design method* components of the design theory. These implications will be further explored in the following sections.

META-REQUIREMENTS		META-DESIGN		DESIGN METHOD	
MR1.	Support Business Engineering	**MD1.**	Model Structural and Informational Changes	**DM1.**	Integrate to POD Methods
MR2.	Adopt a Process Perspective	**MD2.**	Support Multi-Perspective Modelling		
		MD3.	Use Familiar Front-end Interfaces		
MR3.	Address Organisational IS Impacts	**MD4.**	Support Hierarchical Decomposition of Models	**DM2.**	Explicitly Address IS Impact Modelling (at an early stage)
				DM3.	Integrate to ISD Methods
MR4.	Support IS Benefits Assessment	**MD5.**	Address Key Performance Indicators	**DM4.**	Address Key Performance Indicators (at an early stage)
		MD6.	Support Design Modularity	**DM5.**	Support Gradual Model Development

Table 11. Meta-Design and Design Method Implications of the Meta-Requirements

4.5. Meta-Design

Before developing the elements of the meta-design, it must be noted that the purpose of this section is not to articulate a comprehensive design structure for IS evaluation simulation models. Such a design may be useful, and indeed necessary, for the *development* of simulation software products for IS evaluation, however such a goal lies beyond the scope of this dissertation. The work presented so far has not even demonstrated a clear need for such products, by pointing to potential inadequacies of already available business process simulators. Instead, our goal in this section is to support the *assessment* of such simulation software products. To this end, the meta-design to be articulated consists only of those design facilities that need to be present in such software, if the meta-requirements discussed above are to be satisfied. Consequently, many aspects of simulation software design will not be discussed, as they are not of interest in the context of our research. The following paragraphs will discuss the meta-design propositions illustrated in Table 11 above.

4.5.1. Model Structural and Informational Changes

As discussed above, to address business engineering requirements, the meta-design should provide guidelines for modelling two distinct types of changes: *structural* and *informational*. Initiating a *structural* change means that specific tasks that constitute a business process will be added, modified, or omitted from the model. Such changes can be considered typical in simulation experimentation and they result in modifying the structure of the simulation model. For that reason, they do not present specific difficulties for the modeller and are well embedded into the use of simulation for business modelling. Therefore, we will concentrate our discussion on the second type of changes.

Informational changes are concerned with the effects of Information Systems on business performance and have not been explicitly dealt with in the literature. As a result, the kernel theories provide little insight for dealing with this problem. Therefore, our main point of reference will be the ideas derived from the case study discussed in Chapter 3. As argued there, informational changes do not happen in a vacuum, but are triggered by structural changes. One could say that the effects on business performance are due to the synergistic effects from the combination of IS adoption with business process change. For example, in the case study, the reduction of inventory levels was achieved due to the combination of reduced communication costs (enabled by EDI) and the change in the order plan submission mechanism employed by the companies (which itself can be considered as an EDI-independent, structural change).

Taking this argument further, we contend that *all* changes in the system, and hence in the simulation model, can be tracked down to structural ones. This in turn means that in order to capture these changes, an explicit representation of the Information System in the simulation model may ultimately not be needed at all (an approach that was, unintentionally, followed in the case study). What is however needed is the ability to capture the *Key Performance Indicators (KPIs)* that are expected to be influenced by the IS adoption and assess how these KPIs will be affected in the simulation model. KPIs are defined as those business parameters that determine the justifiability of changes depending on the business objectives of a given situation. KPIs may involve cost, time, throughput, resource utilisation, or other parameters that should be defined by the decision-makers in the beginning of the simulation study (indeed in the beginning of the process change or the IS evaluation project) as the critical determinants of the acceptance of change proposals.

The KPIs then become the critical parameters against which the IS effects and the simulation output results should be evaluated. Indeed, the KPIs become the parameters that should guide, more than anything else, the direction of the simulation model development as a whole. Furthermore, KPIs are important as they also relate to other meta-design issues as well, as will be discussed in the following paragraphs.

A question that remains however is how can this meta-design component be supported in practice in IS evaluation simulations. The route to answering this question has to start with an investigation of the exact nature in which Information Systems can influence business performance in operational terms (using a different terminology, in *KPI* terms). The research presented so far has not addressed this issue in detail. This will therefore form part of the work to be presented in the remaining Chapters of this dissertation.

4.5.2. Support Multi-Perspective Modelling

The second meta-design component relates to the need for simulation models to support process-based organisational analyses and at the same time offer intuitive interfaces to the non-expert business users. A detailed discussion of *modelling perspectives* is presented in Appendix A of the dissertation, in the context of comparatively evaluating a number of business and IS modelling techniques. To summarise the arguments presented there, a business/IS model can be thought of as representing one or more of the following 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.

Business and IS modelling techniques differ significantly in the extent to which they provide the ability to model the aforementioned perspectives. Some techniques focus primarily on functions, some others on organisational roles, and yet some others on data. Some may argue that we need to develop a single, 'holistic' technique that could effectively represent all perspectives in a rigorous and concise fashion, and hence be applicable in all modelling situations. However, the multiplicity of possible modelling goals and objectives and the diversity of uses to which a model may be put, possibly render the development of such a modelling technique impossible, or at least impractical. Such a technique, if it existed, would probably generate complex models, thus reducing the ease of their use for any single modelling need. To deal with this problem of complexity, most techniques choose to concentrate on addressing specific parts of organisational design and therefore address only specific modelling perspectives. By providing constructs and concepts that allow for modelling only specific views of an organisation, a technique can maintain its appropriateness and usability for its intended use, but cannot be effectively utilised across organisational projects of a different nature and focus.

In Appendix A, a number of modelling techniques are comparatively evaluated to assess their ability to represent the aforementioned perspectives. Discrete-event simulation is found to be an effective supporter of the *functional*, *organisational*, and *behavioural* perspectives, while the analysis shows that it provides only limited support for addressing the *informational* perspective. The research presented in this dissertation can be argued to address this gap, at least as far as IS evaluation is concerned. To this end, the earlier discussion regarding the ability to translate *informational changes* into *structural ones* based on the *KPIs* of a particular study is a significant step towards addressing this perceived limitation of simulation for multi-perspective representations as well.

4.5.3. Use Familiar Front-end Interfaces

This meta-design component relates to the need for easy-to-use simulation models that are intended for non-expert business audiences. We chose to concentrate on a specific aspect of ease-of-use, namely the front-end interfaces of simulation models because of the widely acknowledged importance of visual interfaces for user involvement and confidence in simulation models (Bell et al 1999).

Indeed, the familiarity of most business managers and decision-makers with many of the static modelling techniques discussed in Appendix A (for example, flowcharting) perhaps makes it important to develop simulation models having such front-ends. Many authors have resorted to similar approaches to overcome the limitations of business process simulators. For example, Bruno et al (1995) combined MODSIM and SIMOBJECT models with data flow diagrams to provide a familiar interface to users. Similarly, Harrel and Field (1996) discuss the integration of static IDEF0 and flowcharting models with dynamic simulation models. The authors argue that '*one of the reasons for the lag in application of simulation technology [in the BPR domain] is that it has not been effectively integrated with more general purpose process mapping tools*'.

Since the case study discussed in Chapter 3 provided no front-end interfaces that would allow us to present the simulation models themselves to the decision-makers, no definite conclusions can be made at this stage regarding the efficacy of the above arguments. Further research will be needed to address this meta-design component in practice. A starting point for such research will be addressed in the second case study to be discussed in Chapter 5.

4.5.4. Support Hierarchical Decomposition of Models

Hierarchical decomposition is a well-known requirement for business simulation models (MacArthur et al 1994). However, the need for remaining at an organisational level without being concerned with the technical implementation details of the Information System to be evaluated, may have certain implications for the hierarchical modelling process.

Although it is naturally expected that a model may need to be developed at different levels of abstraction so that modelling complexity is managed and details can be 'hidden' or 'exposed' depending on the user audience, modellers must remain alert to the level of depth they should allow the simulation models to possess. The natural tendency to decompose a complex problem into more specific and manageable parts (already discussed in the context of IS development) has to be controlled so that the problem of reductionism does not re-appear, even unintentionally. In operational terms, this meta-design component means that model decomposition into more detailed sub-models has to be exercised with great care so that the simulation exercise always remains at the organisational level of abstraction, unless of course the detailed representation of IS designs has been defined within the scope of modelling.

The hierarchical decomposition mechanism may also mean that simulation output data may be possible to analyse at different levels of aggregation. Such a facility is important in business engineering as it allows for evaluating 'local' changes (by analysing data at the sub-model level), while at the same time remaining alert to potential side-effects of local changes on global performance (by analysing data at the model level).

4.5.5. Address Key Performance Indicators

The importance of KPIs has already been discussed. It should however be noted that this importance is reinforced due to the meta-requirement related to benefit assessment and data generation. To support the generation of such data, the detailed operational elements (KPIs) that will contribute to the determination of whether the investment is justifiable or not have to be explicitly articulated in the very beginning of the simulation study.

In design terms, this need translates to providing modellers with explicit articulation and representation of KPIs during model development. It also means that simulation output analyses should be targeted, more than anything else, to the KPIs and how they are affected by the simulated changes. As far as IS evaluation is concerned, this points to a need for more research on the nature of IS impacts on business performance and the classification of these impacts in KPI terms, as already mentioned above.

4.5.6. Support Design Modularity

As discussed earlier, evaluating all expected IS benefits at once may be neither cost-effective nor desirable in many practical situations. Therefore, this meta-design component addresses the need for a modular approach to IS evaluation by simulation, allowing the incorporation of additional IS benefits to existing models, as the evaluation exercise progresses. Since this meta-design element relates more than anything else to the methodological approach used, it will be discussed in detail in the following section during the development of the theory's design method. In strict design terms, this element relates to the issue of component-based model development and reuse of sub-models, which however lie outside the scope of this research.

4.6. Design Method

Having established the meta-requirements and meta-design attributes of the design theory artefacts, we will now turn our attention to articulating a method for ensuring that these meta-requirements and meta-design structures can be met when the design theory is applied in practice. The need for such a context-specific method was demonstrated in the case study discussed in Chapter 3. The key elements of the method, derived directly from the design theory's previously discussed components, are summarised in Table 11 above. In the following paragraphs, these elements will be discussed in more detail, before the design method itself is presented.

4.6.1. IS Impact Modelling

Ways to address IS impact modelling in an explicit manner to support IS evaluation by simulation were discussed earlier in the meta-design component of the theory. For the purpose of the design method development, what is important is to re-emphasise the need for addressing the issue of IS impact modelling *as early as possible* in the simulation study. Therefore, it naturally follows that the design method should include provisions to address this requirement in order to avoid costly delays or inefficient outcomes of the simulation-supported IS evaluation. Early consideration of how the IS impact will be incorporated in the simulation models will also benefit the process of model development itself, as it will enable the modellers to better focus their attention on the important elements of the model.

4.6.2. Key Performance Indicators

This element was also discussed in detail earlier. Regarding its implications for the design method, it again points to the need for addressing KPIs *as early as possible* in the simulation study in order to focus the efforts on the important parameters that will ultimately support the IS evaluation process.

4.6.3. Gradual Model Development

We have suggested that benefits assessment should start with those benefits that are realised as a direct outcome of the system under examination and are readily quantifiable. Once these benefits are studied, understood and measured, more indirect and intangible benefits can gradually be brought into perspective. In other words, we contend that the benefits at higher levels of aggregation and complexity can be studied and measured more easily and accurately after a well understood model of the direct and quantifiable benefits is established. Knowledge gained at each step of this incremental process is expected to facilitate easier incorporation and quantification of more complex effects.

Figure 21 (Giaglis et al 1999a) builds on the IS benefits taxonomy proposed by Brown (1994) to illustrate this argument. Brown has suggested that IS benefits may generally be classified into four categories: hard, intangible, indirect, and strategic. *Hard* benefits are usually related to cost reduction or revenue generation and are generally easy to quantify and express in monetary terms. *Intangible* benefits can be attributed to particular applications but they cannot be easily expressed in quantitative terms. *Indirect* benefits are potentially easy to measure but cannot be wholly attributable to the proposed IS investment and can only be realised as a result of further IS-related or business-related investments, enabled by the new system. Finally, *strategic* benefits refer to positive impacts that are realised in the long run and usually come as a result of the synergistic interaction among a number of contributing factors. Such benefits are notoriously difficult to quantify in advance due to their very nature and to the risk associated with their realisation.

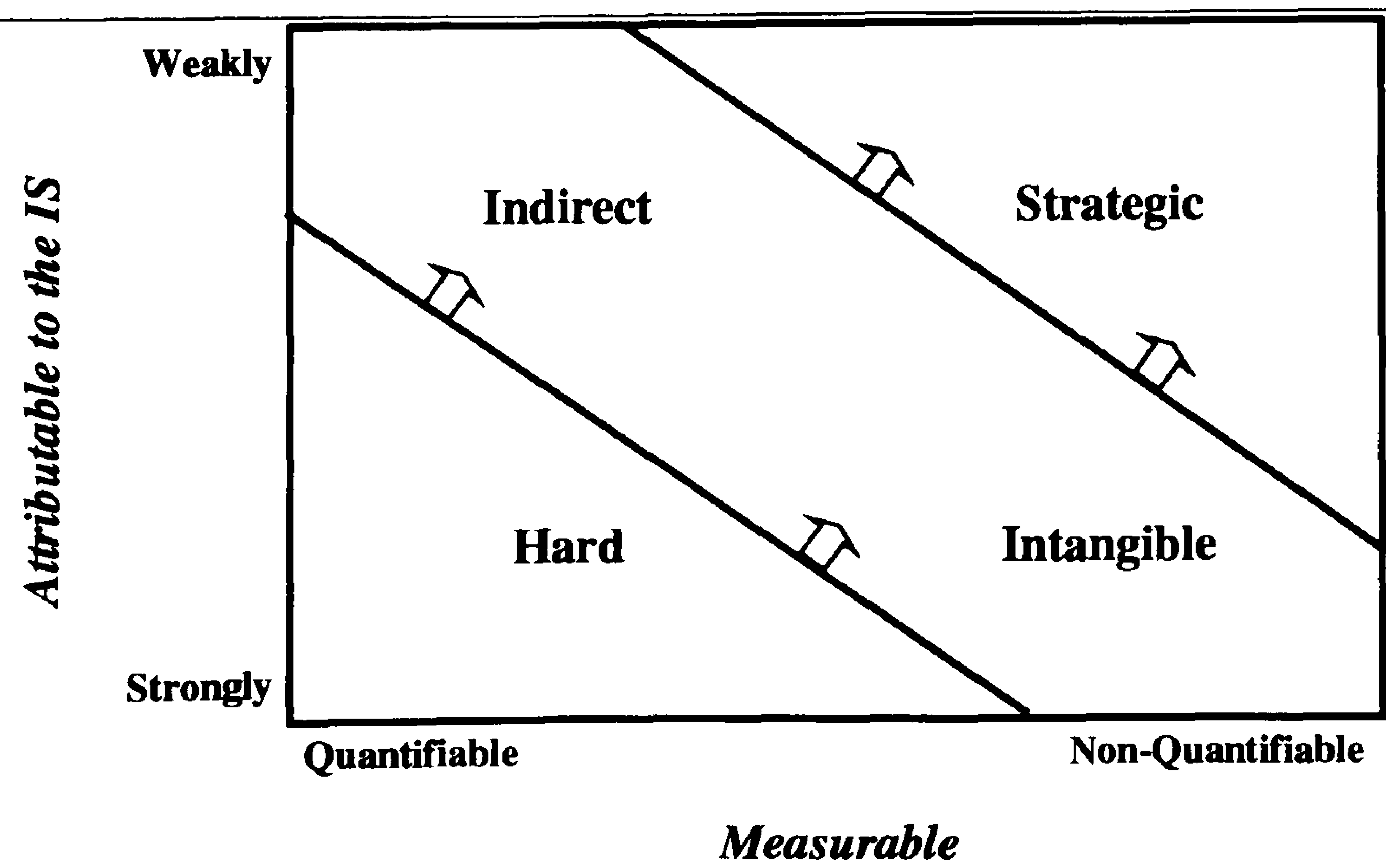


Figure 21. Incremental measurement of IS benefits

Figure 21 builds on this classification to expose the degree of '*quantifiability*' and '*attributability*' of different IS benefit types. At the same time, the Figure illustrates our argument for incremental IS evaluation and, therefore, gradual simulation model development. The arrows present the proposed route to IS benefits measurement: climbing the ladder from quantifiable benefits directly attributable to the IS, to more indirect, intangible and/or strategic ones.

4.6.4. Integration to POD and ISD Methods

The case study presented in Chapter 3 showed that the IS evaluation by simulation exercise would probably be carried out within the context of a wider project, which could be either a process change project or an IS development/evaluation project. To this end, the design method should fit smoothly within an overall method that might be employed in the wider project to ensure trouble-free project execution.

Furthermore, the IS evaluation exercise should sufficiently address the requirements deriving from the technique used or, in other words, should be a conceptually and practically 'valid' discrete-event simulation project. Therefore, the design method should also be 'compatible' with generic approaches to simulation modelling to benefit from their tested legitimacy and applicability.

To this end, the design method to be presented in the following section has been developed based on an inductive process of pattern identification (also followed by Kettigner et al 1997 for the development of the S-A framework) using the following methods as inputs:

a) Davenport's (1993) and Kettinger et al's (1997) frameworks for business process change.
b) The SDLC method of IS development.
c) Law and Kelton's (1991) generic methodology for simulation modelling used in the case study discussed in Chapter 3.

To develop the design method, each of the aforementioned methods was analysed in terms of the stages and activities they advocate. Based on this analysis, a set of five core stages for simulation-assisted IS evaluation was developed (see next section). This mapping process was tested in a laboratory-based reliability test, using Rust and Cooil's (1994) reliability measure for qualitative judgements. The process and results of this test are documented in Appendix C. The results of the tests showed an extremely reliable mapping process with reliability ranging between 95% and 99% for all the aforementioned methods (the minimum accepted standard according to the test is 70%). Details of the test results and their interpretation are discussed in Appendix C. For the purpose of our analysis however, these results provided empirical evidence to the reliable and comprehensive treatment of the stages of all wider project methodologies within the design method to be articulated in the following section.

4.6.5. The ISSUE Method

The result of the above process was the development of the *ISSUE* method for simulation-supported IS evaluation. The method consists of five specific stages supporting the management of the evaluation process in the context of business engineering. The stages of the method are illustrated in Figure 22. The name of the method is derived from the initials of these stages, namely *Initiation*, *Simulation*, *Substantiation*, *Utilisation*, and *Estimation*. Each of these stages will now be explained in more detail.

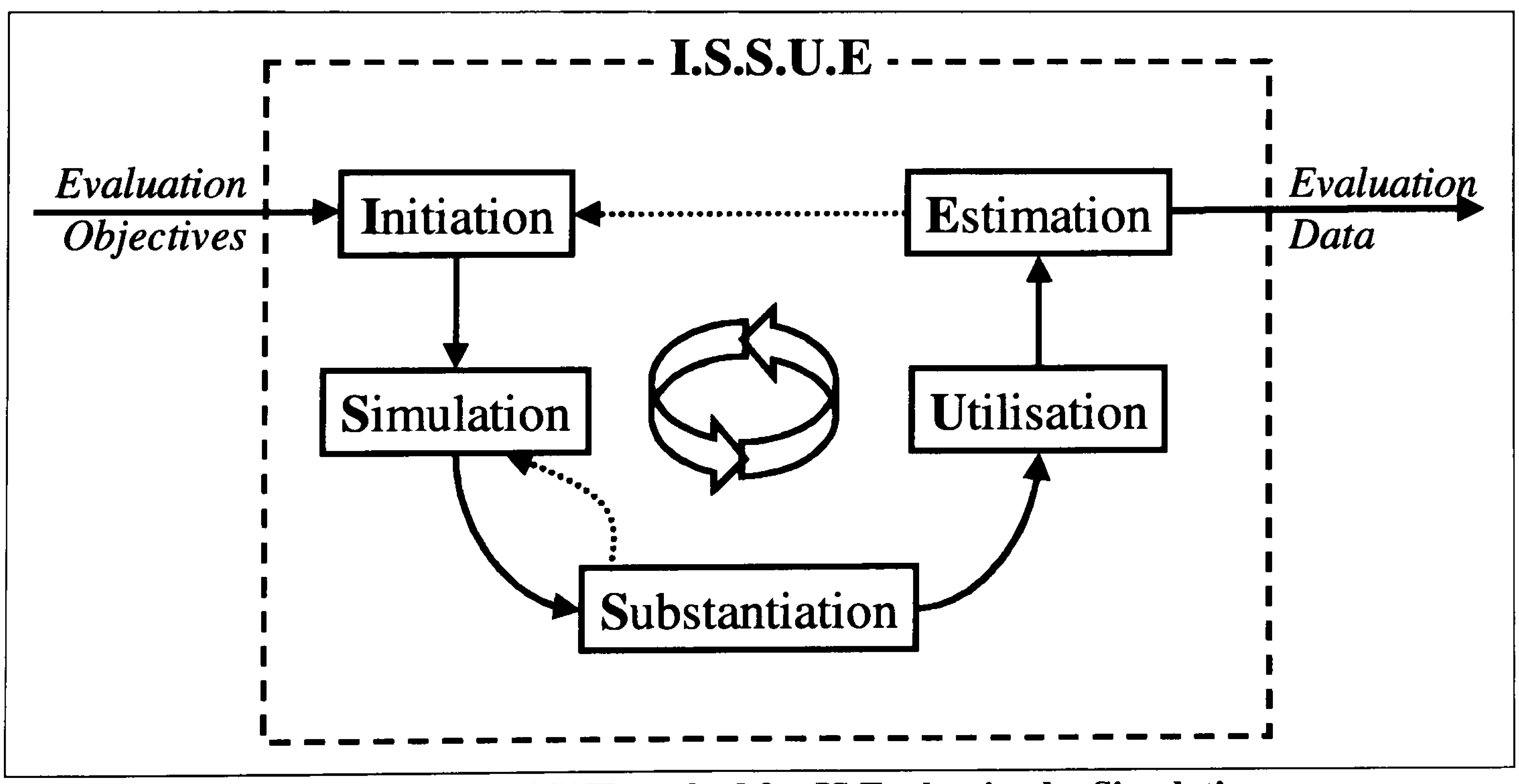


Figure 22. The ISSUE method for IS Evaluation by Simulation

Initiation

The first stage is concerned with the identification of the business goals that the Information System to be evaluated is supposed to support. These goals constitute the *Key Performance Indicators (KPIs)* that will drive the rest of the simulation exercise.

After the KPIs have been identified, the expected effects of the IS introduction on the KPIs should be delineated. These effects should be classified according to their immediacy (i.e. the degree to which they are attributable to the system) and their quantifiability. Essentially, this process means classifying the expected IS impacts into hard, intangible, indirect, and strategic ones. This classification will then form the basis of the gradual model development and enhancement at subsequent stages. Further to articulating the *informational* changes, this step should also be concerned with translating them into respective *structural* changes and KPI implications, as argued earlier.

Finally, the business processes that are going to be affected by the Information System should also be identified and demarcated at this stage. This means drawing the boundaries of the system to be modelled according to the KPIs and the expected effects of the IS on business processes.

The above process satisfies two of the basic needs identified in the preceding sections: addressing KPIs and IS impact modelling as early as possible in the simulation project. By alerting the modellers' attention to these issues, the methodology is expected to result in more efficient IS evaluations than those supported by a generic simulation method.

Simulation

The second stage of the method involves the actual construction of the simulation model(s) that will support the evaluation process. The model(s) should represent the current mode of operation of the organisation (AS-IS modelling), i.e. without incorporating the changes that the investment under evaluation is expected to deliver. The development of the AS-IS model(s) is important for two reasons. Firstly for validity checking (see next stage of the method) and secondly to provide a basis for comparison with any future changes (structural and/or informational) introduced by the proposed investment.

The platform used for simulation model development, whether it is a data-driven simulator, a simulation language or a generic programming language, should be capable of satisfying the meta-requirements and the components of the meta-design identified above. These components of the theory can then additionally serve as criteria for simulation platform selection. Such criteria may include, for example, the ability to support multi-perspective modelling, user-friendly front-ends, hierarchical decomposition of models, output analysis at different aggregation levels, design modularity, and so on.

Substantiation

The substantiation stage is concerned with providing the analysts and the decision-makers enough confidence that the simulation model is an adequate representation of reality and can therefore be used as a basis for experimentation and decision making. Depending on the complexity of the model, validating the simulation model could involve the deployment of specifically designed techniques (Balci 1994).

Since the issue of model validation is well covered in the existing literature and lies outside the immediate scope of our research, the substantiation stage *per se* will not be the subject of further research in this dissertation. It is however included as a major stage in ISSUE method to flag its importance for simulation model development and to ensure that it is not neglected when the method is applied in practice.

Utilisation

After the model has been validated, it can then be used for experimentation with and analysis of the proposed IS investment. This involves the design of simulation experiments to be run and the development of the TO-BE model(s) representing the business processes under the planned structural or informational changes. The new models could be updated versions of the AS-IS model (in cases where the planned changes are mainly targeted to supporting existing business structures) or they can be significantly different models (where the changes are expected to be radical, resulting in business process transformations).

Estimation

After quantitative estimates of business performance (based on the KPIs) have been obtained for both the AS-IS and TO-BE models, an analysis of the simulation output should be performed to decide the extent of improvements introduced by the proposed changes. The complexity of this analysis depends on model size and on the number of variables that will influence the final decision. For the purposes of this research, simulation output analysis will not be considered in further detail, for reasons similar to the ones discussed above (in the substantiation stage).

Re-ISSUE?

We have argued earlier that an incremental approach to model development offers a promising avenue for cost-effective and efficient evaluations. To this end, ISSUE is not a sequential process. Rather, it must be viewed as an iterative, spiral framework whereby stages may need to be revisited until modellers are able to prove (or disprove) the justifiability of the proposed investments. The incremental approach to benefits measurement advocated earlier dictates that, for example, if the users are not satisfied with performance improvement based on hard benefits alone, they may wish to go back and initiate a new ISSUE cycle in order to include (and measure) more complex benefits. Each step of the iteration builds upon the previous models to analyse and incorporate additional effects.

Furthermore, iteration does not relate only to full ISSUE cycles, but is also applicable to revisiting individual stages within the method. For example, revisiting the *Simulation* stage repetitively until the validation performed in the *Substantiation* stage yields satisfactory results, is one of the well-known iterative steps of simulation model development in general. In order to avoid 'overloading' the discussion, such well-known issues have not been explicitly addressed in the method presentation, without this implying that they should not be taken into account when applying ISSUE in practice.

4.6.6. A Critique of the Method

ISSUE focuses on benefit assessment as one of the most important practical problems of IS evaluation. In other words, the method is not intended to be a generic investment appraisal technique. There is no reason however to suggest why the principle of the method cannot be extended to take account of cost measurement as well. This however goes beyond the scope of this dissertation.

The incremental, iterative approach to benefits measurement that the methodology advocates is also expected to promote learning, feedback and modular model development in a cost-effective fashion with clear exit criteria. The case study presented in Chapter 3 showed that the process of simulation model development itself is a valuable process, contributing to improved learning and deeper understanding of the situation in hand. It should therefore come as no surprise if, in practical situations, the method serves its purpose even before one full ISSUE cycle has been completed. Indeed, we anticipate that the level of thinking required in the initial stages of the method regarding articulation of the KPIs and the exact ways in which a proposed IS will influence business performance, will in some instances be so beneficial for decision-making that no simulation model development may need to take place. This should still be viewed as a valid outcome of the method deployment, as long as the whole spectrum of IS-induced impacts has been taken into account and the evaluation process is effectively supported.

It can perhaps be argued that the unanticipated effects of an Information System may prove to be more important than the intended goals, so that they must also be sought and measured. Side effects can be attributed to pure chance, to improper analysis and design, to poor implementation, or to inadequate management of change. Such sources of uncertainty generate risks for IS investment decisions that can rarely be avoided. Risk analysis thus becomes another important part of IS evaluation (Willcocks and Griffiths 1994). However, risk analysis is also outside the scope of this dissertation. Nonetheless, ISSUE involves considerable analysis and experimentation, additional to the system's analysis and design, which can identify other areas of the business which affect or are affected by the success or failure of the system. Hence, the method can be argued to provide some support for risk analysis as well.

Finally, it could be argued that the method constitutes a complex and laborious endeavour that may prove ineffective in practice. Indeed, sceptics may argue that the whole idea of simulation model development for IS evaluation may result in more costs for the organisation than the benefits it can provide. We will however postpone the discussion of these arguments until later in the dissertation, when both the validity of the arguments, as well as ways for addressing their concerns, will be discussed in more detail.

4.7. Testing Hypotheses

Walls et al (1992) distinguish between two kinds of tests for a design theory. Phase I testing refers to testing the design method, while Phase II testing refers to testing the design products. The objective of Phase I testing is to assess whether the design method (the ISSUE methodology in our case) results in an artefact that is consistent with the meta-design. The purpose of Phase II testing is to substantiate that the products prescribed by the meta-design can efficiently serve their purposes (in other words, satisfy the meta-requirements). Since in our case the meta-design has been developed *based on* the meta-requirements (i.e. it is not an independent construct), Phase II testing for our theory is reduced to logical argumentation (an approach also followed by Nissen 1996). Therefore, Phase II testing has already been addressed when the meta-design was developed earlier in the Chapter.

However, the practical usefulness of the design method (Phase I testing) still needs to be substantiated. The value of ISSUE can be assessed by comparing the value of using it with the value of using an alternative method (Walls et al 1992). To this end, in the following Chapter we will discuss a second case study that was carried out to validate and enhance the design theory. The empirical work to be presented in Chapter 5 will be comparatively evaluated to the case study discussed in Chapter 3 (which was carried using an alternative generic method). This comparison will form the basis of assessing ISSUE and, more generally, the design theory as a whole. The criteria for this assessment will be discussed in more detail during the comparison of the two case studies in Chapter 6.

4.8. Reflections on the Design Theory

In the preceding sections, we outlined the components of a design theory of IS evaluation by simulation. The theory consists of kernel theories, a set of meta-requirements, a meta-design, a design method, as well as testing hypotheses for assessing the validity of the theory's assertions. The problem of IS evaluation is a complex one and in order to manage the complexity of the theory development, the theory components had to be decomposed into the above elements. However, the careful reader may have already contemplated that this decomposition process, although necessary, may induce a side-effect that has been criticised earlier (albeit in a different context): reductionism. Therefore, before closing this Chapter, we will attempt in this section to 'reconstruct' the wider problem that the theory was initially supposed to address and we will reflect on the theory's ability to do so.

Essentially, the underlying proposition of this Chapter, and indeed of the whole research discussed in this dissertation, is that IS evaluation can be effectively facilitated by computer simulation models that depict the business processes which form the surrounding environment of a proposed Information System. Such simulation models can be used to assess the expected effects of the IS on business performance, by explicitly modelling the changes on the business processes that the system is expected to induce. Once implemented, the simulation can be used as a tool in planning sessions, during which decision-makers can experiment with alternative future scenarios and obtain measurements of the various expected impacts of the proposed changes on business performance. As MacArthur et al (1994) contend, such an approach to change management can even result in a cultural shift in the organisation towards more measurement-oriented evaluation practices in general.

The simulation approach advocated by the theory effects a 'virtual' implementation of the proposed system. By measuring the performance of the relevant business operations with and without the Information System, one can collect the necessary quantitative information needed to conduct further investment appraisal using established financial or other methods. Moreover, the simulation modelling process itself and the subsequent experimentation with alternative system and business configurations, constitute additional learning processes which can support a feedback mechanism adjusting the whole decision making process.

Despite its potential complexity, the theory includes provisions for supporting cost-effectiveness and economic efficiency. Measurement need only continue until the benefits exceed the estimated costs to an acceptable degree, thus making the investment justifiable in financial terms. This incremental approach means that difficult to capture and analyse benefits may not actually need to be assessed, thus saving time and effort. In cases where such benefits will *need* to be assessed, this can be taken as an indication of a high-risk investment, thus making the extra effort required for simulation-supported IS evaluation worthwhile. Moreover, the incremental and analytic nature of the process can generate substantial awareness and knowledge amongst participants. This knowledge can provide valuable feedback to the process of IS development, thus contributing to further cost and time savings during the IS development project.

Despite the perceived utility of the design theory, the road to successfully complete its development still remains unpaved. Firstly, as discussed above, it remains to test the theory's applicability and efficacy in a practical context, something that will be addressed by the case study discussed in the following Chapter. Secondly, and perhaps even more importantly, the theory development has generated as many new questions as the answers it has possibly provided. Perhaps the major issue that deserves further exploration and research, according to the discussions presented earlier, is to articulate the exact ways in which Information Systems influence business performance and to transform these ways into operational elements (KPIs) that could be used in simulation models. This issue will be addressed in the case study discussed in the following Chapter and, in more detail, in the evaluation and expansion of the design theory to be presented in Chapter 6. Other issues for further research include the need for multi-perspective modelling, the efficacy of front-end interfaces to support more easily accepted simulation models, issues of design modularity, and so on. Some of these issues will be addressed, in varying degrees of detail, in the remainder of this dissertation. However, they will remain, as a whole, as open issues for further research work.

4.9. Summary

In this Chapter we have articulated the components of a design theory of IS evaluation by simulation. The concept of ISDT was used as a basis of developing the theory components in a systematic and structured fashion that ensures rigour and conceptual legitimacy. The approach advocated by the design theory constructs can be thought of as creating a 'virtual reality' of the organisation and the proposed Information System. This virtual implementation can be used to study the impact of alternative business process specifications and IS configurations on an organisation in an integrated and laboratory-like setting. Such an approach ensures that the major aim of IS evaluation in the context of business engineering is achieved, inasmuch as business process design and IS design remain aligned.

Although the design theory represents a distinct theoretical contribution to the fields of business engineering and IS evaluation, it cannot be considered as complete until it is tested and validated in an empirical manner. To this end, in the following Chapter we will discuss a detailed case study of IS evaluation that was carried out using the design theory as a guiding aid. The findings of this case study will then be compared to the exploratory case study of Chapter 3 to assess whether the theory results, as hypothesised, in more effective and efficient IS evaluations.

CHAPTER 5. CASE STUDY II: INTER-COMPANY EDI EVALUATION

In the previous Chapter we outlined the components of a design theory of IS evaluation by simulation. Drawing on this theory, this Chapter will document the process and findings of an empirical study that was pursued to test the validity of the theoretical propositions set forth earlier. The *case study* method, coupled with an *action research* perspective, was followed within this empirical study. Therefore, as in Chapter 3, we will begin with a brief discussion of the role and significance of the research methodology employed in this study. This will complement and conclude the discussion of the methodological issues underpinning this research, which were also addressed in Chapters 1 and 3.

5.1. The Action Research Method: Role and Significance

The overall research methodology followed in this dissertation was outlined in Chapter 1, where an argument was made in favour of adopting a pluralistic methodology, comprising both case study and action research methods for the empirical parts of our work. The rationale for adopting the case study method for the first study was further discussed in Chapter 3. In this section we will outline the reasons for combining this method with an action research perspective for the empirical work to be discussed in this Chapter.

The *action research* method allows the researcher, instead of taking the observer point of view, to be an active participant in the research process, seeking practical results while at the same time evaluating the intervention technique used within the research process (Wood-Harper 1992). A combination of case study/action research methods is especially suited for acquiring an in-depth, first-hand understanding of organisational phenomena in cases where previous detailed studies and elaborate theoretical understanding are missing (Bensabat et al 1987). The findings of the literature review presented in Chapter 2 (that indeed revealed a lack of a detailed, cumulative previous research in the area of this study) further reinforced our initial choice of these research methods. Since, however, such an inductive research strategy does not release the researcher from formulating a conceptual theoretical framework before starting a research project (Galliers 1992b), the design theory discussed in the previous Chapter was used to guide the implementation and interpretation of the empirical work presented here. The objective was to use the study as a mechanism for testing the efficacy of the design theory in a real-life setting and gain further insight into its contribution and potential weaknesses.

Moreover, the study to be discussed in this Chapter is both comparative to, and at the same time more detailed than, the study presented in Chapter 3. The Information System to be evaluated in this study also involves (as in the first case) EDI applications. However, this time the setting of the study is far 'richer', thus allowing us to consider a wider spectrum of IS evaluation-related issues than in the first case study. Furthermore, compared to the 'loose', exploratory character of the first case study, the work to be presented here benefits from the availability of a context-specific theoretical framework and from a set of specific research questions and issues to be addressed.

The action research method followed was believed to contribute further to the usefulness of the study, as it brought the researcher much closer to the practical problems addressed, thus allowing for studying the *process* as well as the *products* of simulation-assisted IS evaluation.

5.2. Study Background

The study refers to a business process improvement effort jointly undertaken by two collaborating organisations in Greece: a major pharmaceuticals company (Johnson & Johnson Hellas S.A., henceforth referred to as 'J&J') and one of the regional distributors of its products (a small sized company called Ramma Ltd.). The project aimed at assessing the potential of redesigning the extant communications scheme between J&J and Ramma and evaluating the possibility of introducing Information Technology to support the redesigned processes between the two firms.

Johnson & Johnson Hellas S.A is the Greek subsidiary of Johnson & Johnson, a well-known multinational family of companies. Johnson & Johnson, with $21.6 billion in sales and 89,300 employees, is the world's larger manufacturer of health care products serving the consumer, pharmaceuticals, diagnostics, and professional markets. The company manufactures and markets a wide range of products ranging from baby care, first aid, and hospital products to prescription pharmaceuticals and medical devices. The Johnson &

Johnson family consists of 170 operating companies in 50 countries around the world, selling products in more than 175 countries.

Johnson & Johnson Hellas was founded in 1974 with an initial aim to market the parent company's products in Greece. However, two years later, J&J also started a production facility aiming to manufacture and market products for South Europe and Middle East. Today the company employs more than 300 people in three sites. The headquarters are in *Athens*, while the plant and the warehouse are located on the outskirts of the city, in *Mandra*. Furthermore, the company operates a smaller office in *Thessaloniki* (the second largest city in Greece, some 300 miles north of Athens). This office is responsible for managing J&J sales for northern Greece.

J&J is divided into two separate business units (*Medical* and *Commercial*) that operate quite independently from each other, in line with the overall structure of the parent company. The case study presented herein was carried out within the Medical unit. This business unit trades hospital consumables (for example, surgical dressings, disposable surgical packs and gowns) and medical devices (for example, blood glucose monitoring systems). It deals primarily with relatively large corporate customers, mostly in the public sector. These customers include hospitals, health care organisations, networks of physicians, and the government. Smaller corporate customers (for example, chemists and supermarkets that subsequently sell products to individual consumers) are dealt with by the Commercial business unit.

The Medical unit (unlike the Commercial one) is not involved in producing the products it markets. Instead, products are imported from other J&J production sites in Europe (mainly Italy, Great Britain, and Ireland) and are stored in the Mandra warehouse. In other words, the warehouse operates as a central departing point for all products, which are then distributed to the company's customers via a network of collaborating distributors. One of these distributors is Ramma Ltd.

Ramma is a small company (employing at the time of the case study nine people, five of which are the company's drivers) and is based in Thessaloniki. Ramma has signed, since 1993, an agreement to act as J&J's exclusive distributor of Medical unit products for northern Greece. According to this agreement, Ramma can also distribute products manufactured by other companies, provided that they are not competitive to those of J&J.

However, Ramma has not taken advantage of this provision in practice. Therefore, for the moment, the company is totally dependent on the collaboration with J&J to stay in business. The agreement signed between J&J and Ramma states that the latter is responsible for:

a) Receiving orders from J&J customers.
b) Maintaining an adequate inventory of products in order to be able to fulfil these orders.
c) Distributing the ordered products to customer premises.

As mentioned above, J&J also maintain their own site in Thessaloniki. However, this site is no more than a small office responsible for sales and marketing of Medical unit products in northern Greece. The office consists only of a small team of salesmen and clerical staff. The salesmen travel across the region, visit customer premises, and are responsible for informing customers about J&J's range of products, acquiring and maintaining the company's customer base, and signing sales contracts.

5.3. Scope and Objectives of the Study

Due to the special nature of the health care market and the subsequent urgency of most customer demands (especially those initiated by hospitals), Ramma has to operate within strict deadlines regarding deliveries. Indeed, the targets set by the two companies specify that each order has to be fulfilled with 24 hours, if the products are to be delivered within the city of Thessaloniki, or within 48 hours for the rest of northern Greece.

However, since the beginning of the collaboration between the two companies in 1993, it has been noted by J&J management that the aforementioned targets are virtually never met in practice. Preliminary discussions between J&J and Ramma did not result in any definite proposals for change. However, the two companies agreed that the problems seemed to be arising from inefficiencies in the ordering process as well as due to the inability of Ramma to maintain an optimal level of product inventory to support order fulfilment. Furthermore, the extant communication and information exchange scheme between the two companies was deemed to be cumbersome and inflexible. Since these inefficiencies represented a major source of customer dissatisfaction it was decided that a more in-depth study of the problem should be pursued.

In this context, the management of the two companies sought external help in addressing the aforementioned problems. It was felt that the people within the two companies were too close to the existing way of doing things, so that their ability to identify innovative opportunities for process redesign might be inhibited. This coincided with the period when the *IS evaluation by simulation* design theory was formulated. The ideas of this theory were presented to the management of the two companies and it was agreed to use these ideas as a basis of an action research project addressing the aforementioned issues.

At this point, it is worth mentioning that the two companies had initiated the project with a pre-conceived solution based around the implementation of an EDI application. Such solution-driven business process change projects are not uncommon in the literature (Hammer and Champy 1993). However, they may present dangers for process change due to implementing solutions not serving the business needs (Davenport 1993). In our case, both companies wanted to start the project directly with simulating the current processes and analysing the impact of the proposed EDI-based solutions. Considerable effort was therefore applied to convincing the two companies for the need to take a step back and start by developing clear goals, objectives, and business visions before actually starting with simulation analysis and business process redesign.

Against this background, the study discussed in this Chapter was conducted. For the purposes of the *project* against which the action research was carried out, the objective of the study was threefold:

a) To examine in detail the existing business processes that may contribute to high order fulfilment lead times.
b) To identify the sources of problems and propose alternative business process layouts by which these problems could be alleviated.
c) To evaluate the potential of introducing an appropriate IT infrastructure (EDI-based or otherwise) to facilitate the communication between the two companies in a more efficient manner.

Introducing an EDI system (along with any corresponding business process changes), would necessarily involve significant expenditure on behalf of both firms: hardware, software, telecommunications, training, and business re-organisation, to name but a few sources of such expenditure. The main problem facing the management was then to evaluate the magnitude of benefits that could be achieved by the proposed change in order to assess whether it would surpass the associated investment costs. Thus, the overall problem clearly fitted our objective of studying the problem of IS evaluation in the context of business engineering, as it involved the co-ordinated design of new processes along with the evaluation of IS structures that could help these processes deliver organisational value.

As a result, for the purposes of our *research*, the aim of the work presented herein was to apply the theoretical postulates set forth in Chapter 4 in a detailed practical application of IS evaluation. By placing the design theory under careful scrutiny, we wanted to test the hypotheses of the previous Chapter regarding the practical usefulness and efficacy of the ISSUE method and the design theory as a whole. Furthermore, it was expected that the additional knowledge gained during the empirical work would also contribute towards identifying gaps and weaknesses in the theory, and hence improving it further.

It was also appreciated that the nature of the Information System under evaluation in this case study is the same as the one examined in the case discussed in Chapter 3, namely EDI applications. This similarity was believed to contribute to developing as much a 'controlled' environment for inter-case comparison as possible within case study research. In other words, because the two case studies are similar in almost every factor but the methodological approach used, it can be expected that the findings derived from case comparison are valid, at least in terms of keeping potential side-effects introduced by other confounding factors at a minimum level.

In the remainder of this Chapter, we will discuss in detail the case study, using the structure of the ISSUE method on which the study was based. In the following Chapter, we will then compare the findings obtained here with those discussed in the previous case study (Chapter 3).

5.4. Initiation

5.4.1. Problem Identification

According to the theoretical prescriptions of the design theory, the study should begin with a process of identifying the business goals that would drive the development of the KPIs and the articulation of the expected IS-induced impacts on them. However, we quickly realised that for *goals* to be articulated, the *problems* of the existing situation had first to be examined in more detail. To this end, a number of preliminary interviews were held with J&J and Ramma representatives to address these problems in informal, unstructured discussion sessions.

The major problems identified during these discussions can be summarised as follows:

a) ***Excessive Order Lead Times***. Customer orders are usually fulfilled much slower than the stated targets (24 or 48 hours, see above). This problem is further exacerbated when Ramma does not hold in stock some of the products ordered by the customers. In this case, a backorder has to be placed to J&J, thus contributing to further delays and even higher total lead times for order fulfilment.

b) ***Out of balance inventory and excessive stock levels***. In order to ensure that orders could be fulfilled without need for backordering, the J&J warehouse managers had historically followed a policy of generous replenishments of Ramma's warehouse. However, this has caused considerable inventory holding costs for Ramma, as well as further problems due to sensitive medical products exceeding their expiry date. Furthermore, it is questionable whether this policy has managed to achieve much more than camouflaging the internal process inefficiencies.

c) ***Poor customer service***. Unacceptably high lead times result in customer dissatisfaction that is expressed through a growing number of complaints about delivery delays.

d) ***Excessive Invoice Lead Times***. Further to the order delays, the time it takes for invoices to reach customers is unnecessarily long, resulting in poor cash-to-cash cycle for both J&J and Ramma.

e) ***Duplication of work and errors***. Ramma use a warehouse management software package to monitor their stock. The J&J warehouse managers also need to know the level of Ramma inventory in order to be able to schedule replenishment shipments. J&J use their own warehouse management software to monitor Ramma's stock data.

Apart from duplicating work (double key-in of the same information), the stocks reported by the two systems do not always match.

f) ***Information Sharing***. Because of incompatibilities between the J&J and Ramma information infrastructures, the companies have been relying on paper forms for exchange of information. Apart from duplication of effort and slow processing times, this has resulted in building a culture of limited information sharing between the two partners.

Poor, incompatible, sometimes even non-existent, IT infrastructure was identified as one major contributor to the problems faced by J&J and Ramma. It was in this context that the management of the two companies decided to examine the potential of adopting electronic messaging applications to facilitate the exchange of information between J&J and Ramma. The initial vision was to examine the potential of introducing Electronic Data Interchange (EDI) to support faster and more reliable exchange of data between the firms. It was believed that EDI could address the majority of the aforementioned problems by contributing to more efficient inventory management (and hence to fewer backorders), by eliminating work duplication and data errors, and by addressing the problem of incompatible IT infrastructures and limited information sharing. Order and invoice lead times were also expected to be reduced due to the elimination of unnecessary delays during information exchange between the two companies.

It was also believed that an EDI system could be the starting point for building a wider Inter-Organisational Information System (IOS) (Cash and Konsynski 1985, Meier and Sprague 1991) that would strengthen the links between J&J and Ramma and effectively make them work as a single virtual enterprise. J&J also wanted to use this project as a pilot for introducing similar systems to foster closer relationships with their other distributors across Greece. This notion is similar to the idea of 'organisational prototyping' (Leonard-Barton 1987), i.e. building and testing prototypes of business processes on a limited scale before extending them to full implementation.

5.4.2. Business Goals

The list of problems presented above served as the starting point for identifying and agreeing upon the *business goals* that would drive the overall process change and evaluation project. This consensus was reached during a group meeting between the researcher and the team of decision-makers, where the aforementioned problems were summarised, classified, and translated into business goals. These goals were defined to include:

a) *Customer Satisfaction*, which can be fostered by reducing the order and backorder lead times, as well as reducing the need for backorders in general.
b) *Cost Reduction and Revenue Generation*, which can be facilitated by reduced inventory holding costs for Ramma and reduced invoice lead times for J&J. Cost savings for both companies can also be realised by reducing or eliminating the amount of work duplication identified earlier.
c) *Closer Inter-Company Relationships*, which can be facilitated by building a 'culture' of information sharing across the two companies.

The articulation of these goals, although extremely useful in the context of a business process change project in general, provide little specific guidance for simulation-assisted evaluation, as predicted by the design theory. In other words, these goals are not necessarily easy and straightforward to translate into simulation modelling requirements. To address this issue, according to the design theory prescriptions, we needed to translate the business goals into operational *Key Performance Indicators (KPIs)*. These indicators can then provide valuable input to the process of simulation model development in the next ISSUE stage.

However, to articulate KPIs effectively, a more detailed knowledge of the internal workings of the business processes to be affected by whatever structural and/or informational changes are introduced needed to be established. In other words, before articulating the KPIs, we need to analyse business processes in detail and decide on the boundaries of the system to be simulated and evaluated. The knowledge elicited by the business process analysis can then be used to translate generic business goals into detailed operational statements for improvement (KPIs). This finding constitutes a minor improvement to the design theory prescriptions, which, although advocating the analysis and demarcation of business process boundaries, address them only as the concluding activity of the *Initiation* stage (i.e. *after* the identification of the KPIs).

5.4.3. Business Process Analysis

To support knowledge elicitation regarding the detailed existing modes of operation, a wide variety of both qualitative and quantitative data needed to be collected. Qualitative data are typically collected in process change projects to develop conceptual models of business processes (Davenport 1993). However, the simulation modelling approach underlying the design theory, means that a significantly greater amount of quantitative data will also need to be collected to drive simulation model development. Such data include duration of activities, decision paths, work schedules, resource levels and allocations, and other parameters not normally expected to be addressed in generic business engineering projects.

The issue of data collection has not however been explicitly taken into account in the design theory discussed in the previous Chapter. We therefore contend that data collection should be designed and performed *within* business process analysis and that it should include not only the data needed for process representation, but also data that will be required later for simulation model construction. Of course, it is acknowledged that at this stage the model layout is not yet developed and therefore a definite data collection exercise cannot be performed. This issue will therefore be revisited later (see *Simulation* stage). For the purposes of our research however, this finding constitutes a further elaboration of the design method based on the case study insight.

Returning to the case analysis, data were collected in a number of ways. A number of *personal interviews* were held with managers and employees from both companies in Athens and Thessaloniki. The purpose of the interviews was to elicit expert knowledge regarding the process structure, the activities that constitute the process and their current arrangement, as well as the problems of the existing situation as these were perceived by each individual interviewee. On the one hand, *process managers* were interviewed to ensure that the entire breadth of the processes under investigation could be analysed (top-down approach to process change, advocated by Hammer 1990). On the other hand, *process users* were also interviewed to ensure that the detailed knowledge of those actually performing the process was taken into account (bottom-up or participative work design, advocated by Drucker 1987). Furthermore, involving users in the redesign process is acknowledged as one of the most critical factors for increasing the likelihood of user acceptance of changes (Davenport and Stoddard 1994).

The data collected during the interviews were used to capture the business process essence and decompose it into its constituent activities. The knowledge elicited by these interviews was also used to define the scope and boundaries of our analysis. In the following paragraphs we will document the details of the business processes. This documentation is necessary for the discussion and analysis of subsequent project steps. A more detailed description of the business processes is presented in Appendix D of the dissertation.

The Order Fulfilment Process (OFP)

The overall business process to be considered in the case study is the Order Fulfilment Process (OFP). This can be thought of as the collection of activities that occur from the time a customer places an order until the time this order is fulfilled (the customer has received the products) and an invoice has been issued and has also been delivered to the customer. The Order Fulfilment Process is amongst the most critical business processes in every organisation (Davenport 1993) and has been the subject of many process change projects (Hammer and Champy 1993, Stoddard et al 1996, Earl 1994). Because of the process's applicability in a wide variety of business settings, the study was deemed to be well suited for arriving at conclusions that can be generalised outside the narrow limits of the particular case, hence contributing to greater validity and applicability of our findings.

Further to ordering and invoicing, the OFP encapsulates the warehouse management operations that may affect the order lead time. Figure 23 depicts the parties involved in the OFP as well as the existing communication between the participants (both physical and informational exchanges). The OFP consists of three inter-related, but more or less independent of each other, sub-processes:

a) The **Order Taking Process (OTP)**. This process is triggered every time a customer places an order and ends when the order has been authorised and is ready for further processing by Ramma.
b) The **Warehouse Management Process (WMP)**. This process refers to Ramma's task to maintain an appropriate level of inventory in its warehouse to be able to efficiently fulfil customer orders. This can be thought of as a typical inventory management problem, as Ramma has to find a balance between keeping an adequate level of inventory that allows orders to be fulfilled without delays and keeping the inventory

costs as low as possible. However, in the context of this study, this problem will be viewed through the prism of the OFP rather than as an autonomous question.

c) The **Invoicing Process (IP)**. This process is triggered for every customer order (and therefore can be thought to start when a customer places an order) and ends when the customer receives an invoice corresponding to that order.

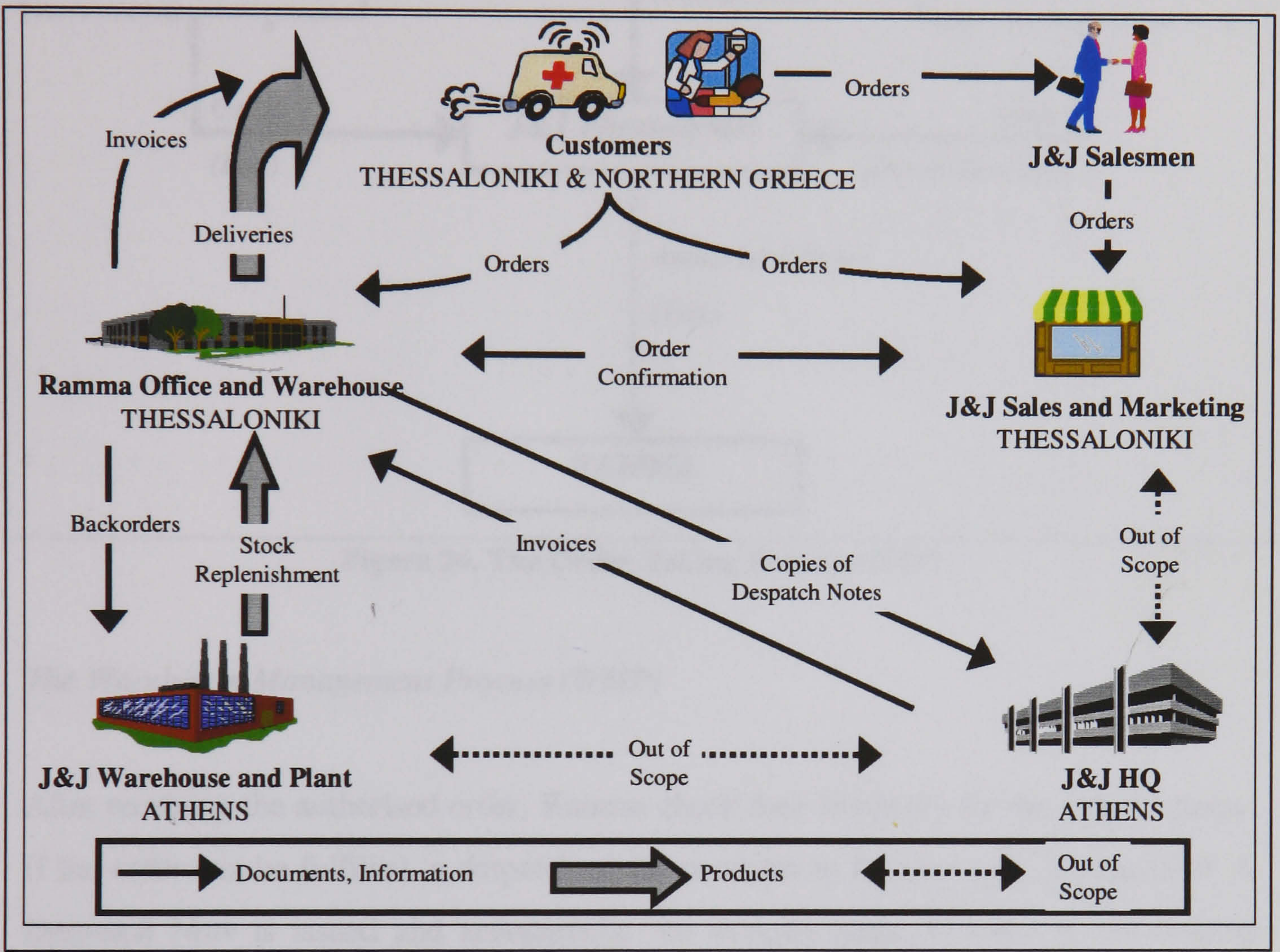


Figure 23. The Order Fulfilment Process (OFP)

In the following paragraphs, these sub-processes will be described in more detail.

The Order Taking Process (OTP)

The process is triggered when a customer places an order. Customers can place their orders either to Ramma or to the office of J&J in Thessaloniki or directly to a salesman. Orders are given by phone, fax, or directly to a salesman who visits the customer premises and then delivers the order to J&J Thessaloniki. In any case, only J&J Thessaloniki can authorise, modify, or reject a customer order. This is because orders have to be checked against the customer contracts to which they refer. Therefore, Ramma forwards all orders they receive to J&J Thessaloniki by fax. Figure 24 illustrates the OTP scenario.

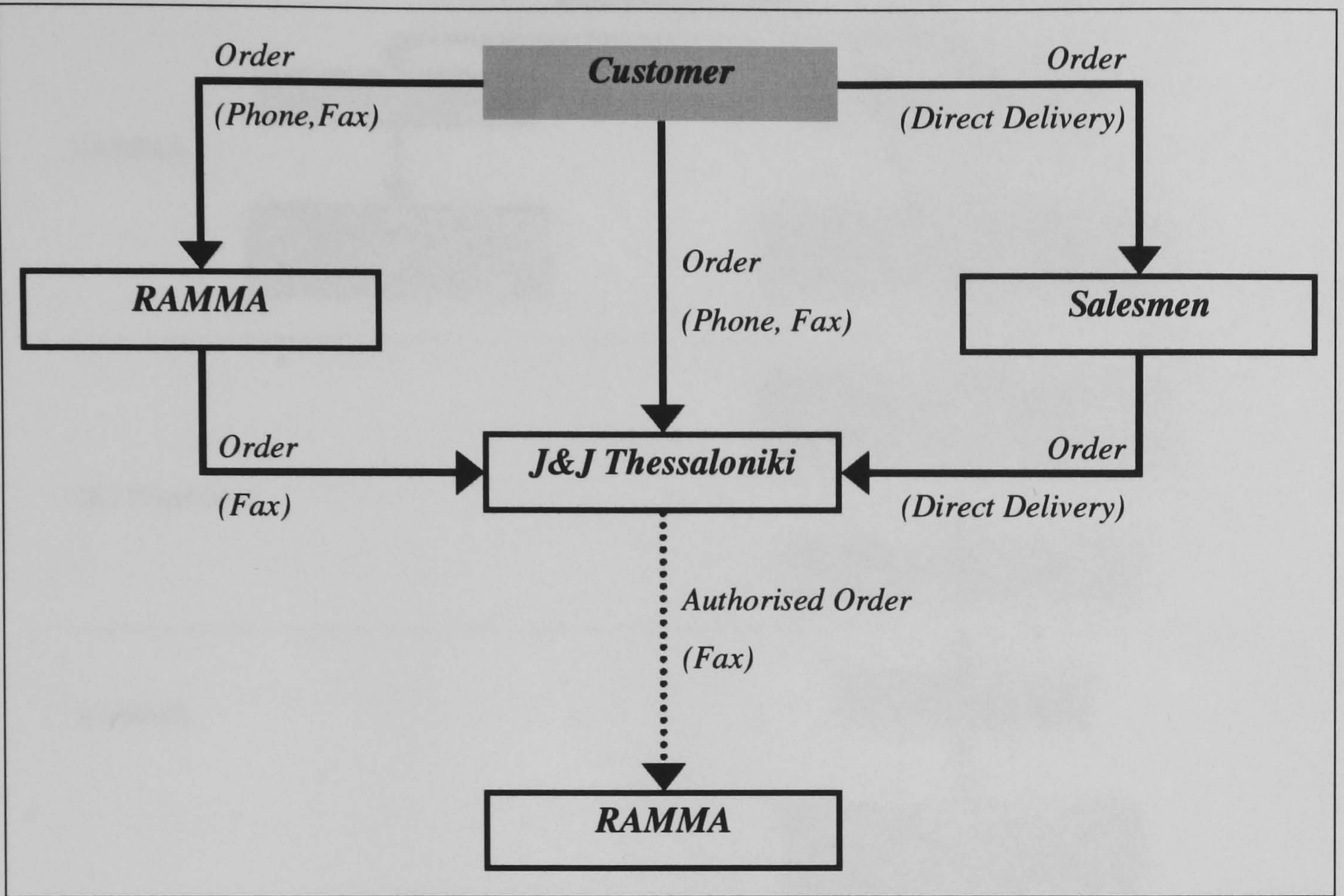


Figure 24. The Order Taking Process (OTP)

The Warehouse Management Process (WMP)

After receiving the authorised order, Ramma check their inventory for the ordered items. If the order can be fulfilled, a despatch of the products to the customer is scheduled. A *Despatch Note* is issued and accompanies the shipped items. If some of the ordered products are not in stock, the order is fulfilled only partially (if this is possible) and a *Backorder* is created for the remaining items.

At regular intervals, Ramma sends a *Backorder List* to the J&J warehouse. The backorder list contains all the products that have been ordered by customers but could not be delivered due to shortages in Ramma's warehouse. Upon receipt of the Backorder List, the J&J warehouse employees schedule a shipment of products to Ramma. Products are sent so that all backorders can be fulfilled and a regular replenishment of Ramma's warehouse is also performed (historical sales data and current inventory levels are used to decide on regular, non-backorder, replenishment). Figure 25 depicts the Warehouse Management process.

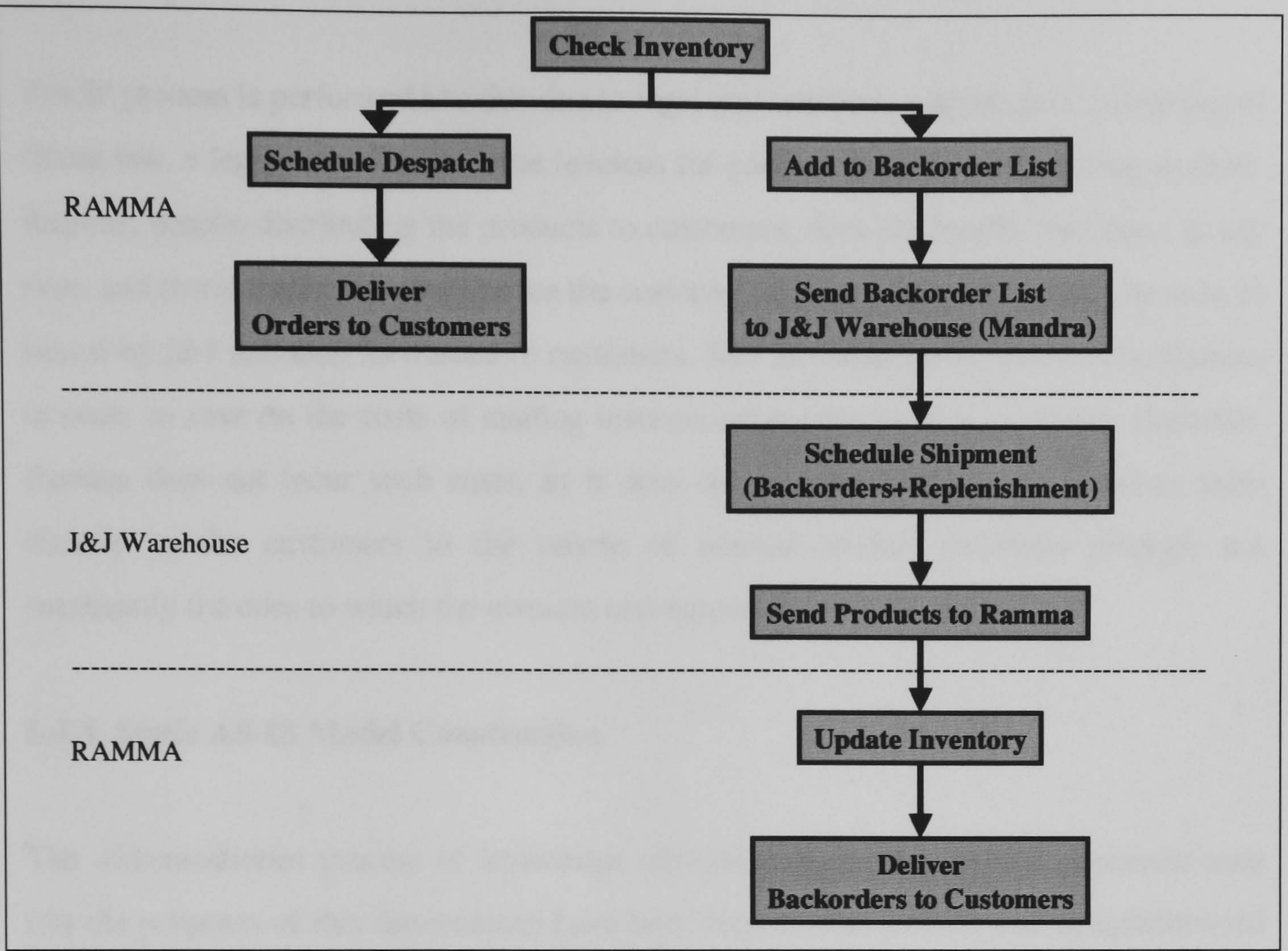


Figure 25. The Warehouse Management Process (WMP)

The Invoicing Process (IP)

At regular intervals, Ramma collects and sends to J&J headquarters in Athens copies of all the Despatch Notes issued during the previous days. J&J use these Despatch Notes to issue invoices that are sent back to Ramma. Ramma then schedules the delivery of invoices to customers along with the normal delivery of products (although naturally not the same products that the invoices refer to). Figure 26 depicts the invoicing process.

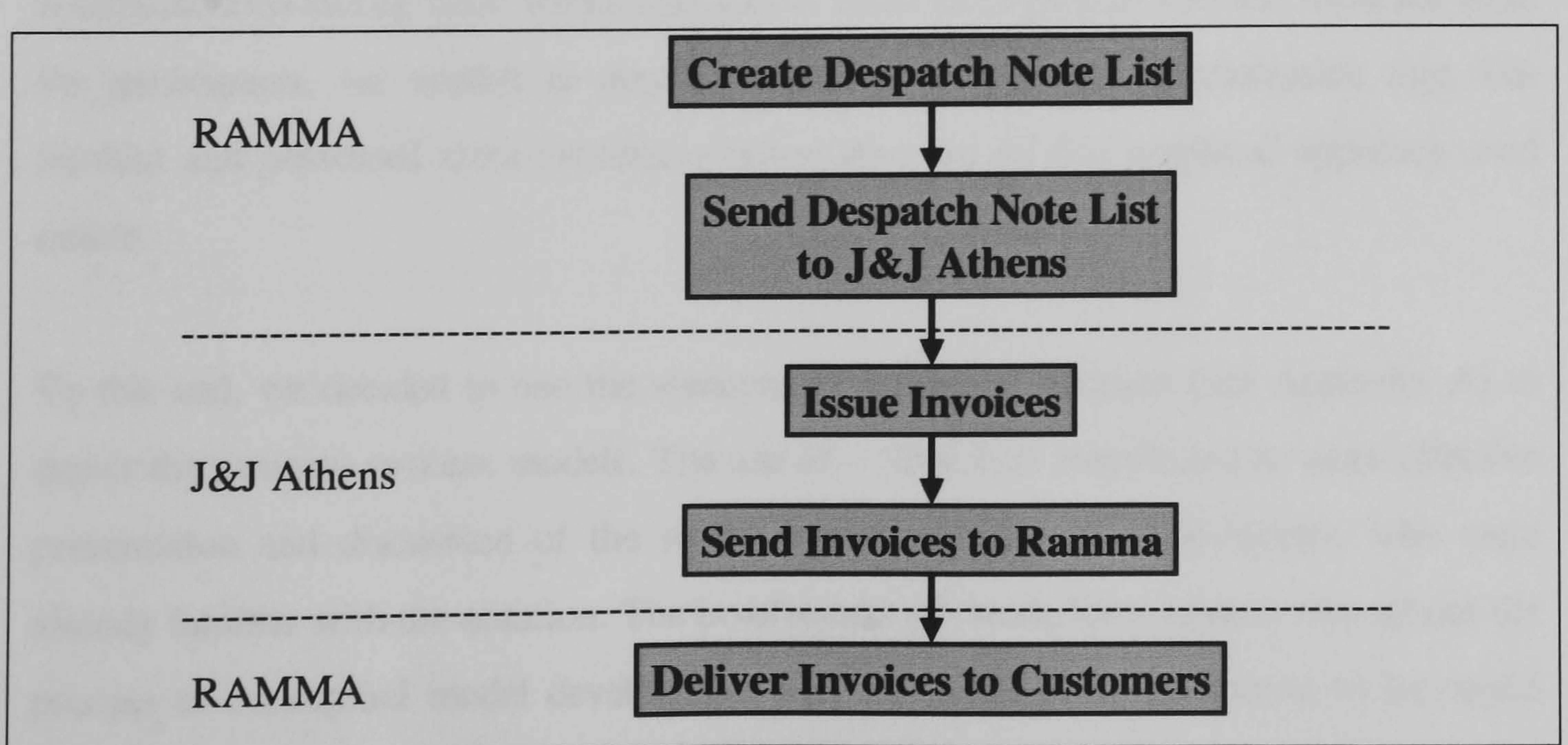


Figure 26. The Invoicing Process (IP)

The IP process is performed like this due to legal and taxation requirements. According to Greek law, a legal entity cannot issue invoices for goods unless the goods belong to them. Ramma, despite distributing the products to customers, does not legally own them at any time, and therefore they cannot invoice the customers directly. Instead, invoices have to be issued by J&J and then forwarded to customers. J&J forwards all the invoices to Ramma in order to save on the costs of mailing invoices separately to each individual customer. Ramma does not incur such costs, as it does not post the invoices, but delivers them directly to the customers in the course of normal product deliveries (though not necessarily the ones to which the invoices correspond to).

5.4.4. Static AS-IS Model Construction

The aforementioned process of knowledge elicitation regarding business processes may (for the purposes of this dissertation) have been described as a direct and straightforward task, but in reality was far from being so. The interviews held during data collection enabled us to sketch initial versions of the AS-IS business processes (using the *ad hoc* representational notation of Figure 23 to Figure 26 above). However, to validate these conceptual models and communicate the progress of the business analysis task to the interviewees and the decision-makers, we realised that a more 'formal' notation of conceptual model development needed to be employed. For example, we decided to organise a small number of *facilitated workshops* where decision-makers and end-users would gather to work towards arriving at a common understanding of the business processes and a consensus regarding their layout. To provide an effective means of communication during these workshops and to assist us in getting valuable feedback from the participants, we needed to employ a method of process representation that was familiar and possessed more expressive power than the *ad hoc* graphical approach used earlier.

To this end, we decided to use the standard flowcharting notation (see Appendix A) to depict the business process models. The use of a flowchart contributed to more effective presentation and discussion of the model layout with the decision-makers, who were already familiar with the notation. The involvement of the decision-makers throughout the process of conceptual model development was also believed to contribute to increased acceptance of the simulation models later. Figure 27 illustrates the flowchart that depicts the business process structure that was used for simulation model development later.

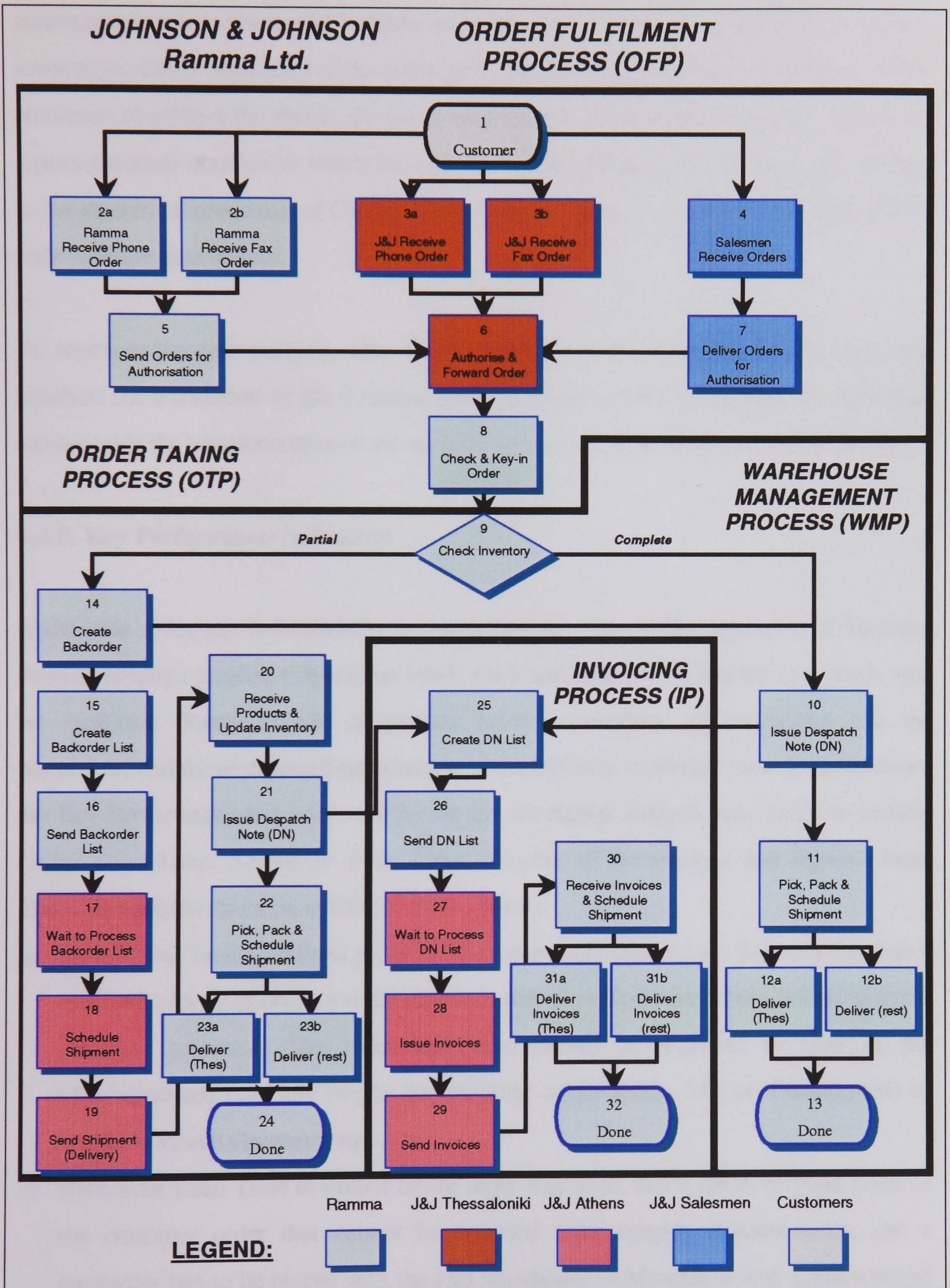


Figure 27. The AS-IS Static Process Model (Flowchart)

The activities in the flowchart depict the business process structure outlined earlier. For the purposes of our analysis, what is important is to reflect on the above process and note the lessons we can derive. The first lesson relates to the need for developing a static AS-IS conceptual model as early as possible in the study. 'Static' means that there is no need for quantitative data to be included at this stage. Such a model will assist towards communication between model builders and users and can also be expected to contribute towards increased credibility of the subsequent simulation model (Law and Kelton 1991). However, to achieve the above, the static model needs to be developed using a 'standard' representational notation to which the users can easily relate. This finding is also related to the theoretical prediction of Chapter 4 regarding the need to employ user-friendly front-ends to simulation models.

To return to the case analysis, after the conceptual model was developed, the next step involved the translation of the business goals outlined earlier into operational KPIs that would guide the transformation of the static flowchart into a dynamic simulation model.

5.4.5. Key Performance Indicators

Cycle time reduction is frequently cited amongst the most likely objectives of business process redesign projects (Davenport 1993, Stalk and Hout 1990) and the case study was no exception. Based on the discussions between company representatives and the researcher, and the aforementioned analysis of the business processes under consideration, the Key Performance Indicators (KPIs) for the simulation analysis were taken to include *Order Lead Time*, *Backorder Lead Time*, *Number of Backorders*, and *Invoice Lead Time*. The definitions of these KPIs were as follows:

a) Order Lead Time is defined as the total average time that elapses between the time a customer places an order and the time the ordered products have been delivered to the customer premises. The order lead time should be assessed in view of the aforementioned company targets for fulfilling orders within 24 (for Thessaloniki) or 48 (for northern Greece) hours.

b) Backorder Lead Time is similar to the order lead time, but it refers to those parts of the customer order that cannot be satisfied from existing Ramma stock and a backorder has to be placed with the J&J warehouse in Mandra. It was acknowledged by the decision-makers that, due to the unavoidable delays incurred in backordering, backorders could not be fulfilled within the same time limits set for normal orders. However, it was of paramount importance for the backorder lead time to be reduced as much as possible.

c) Related to the above, the target was also set to reducing the Number of Backorders being generated in the first place, perhaps by better management of the warehouse replenishment process.

d) Finally, Invoice Lead Time is the total time that elapses between the time a customer places an order and the time an invoice for that order has been delivered to the customer. J&J wanted to reduce the invoice lead time as much as possible because this will result in quicker payments, and hence to improved cash flow for J&J.

These KPIs were agreed to be used as a basis for guiding the process of simulation model development, as well as for analysing the results obtained by the simulation runs. Further, these KPIs were agreed to form the main criteria for assessing the desirability of each proposed *structural* or *informational* change in subsequent stages of the study.

Relating to the business goals outlined earlier, the above KPIs can be considered as operational statements of the abstract goals related to benefits assessment. Cost reductions, although part of the business goals, were deliberately left outside the KPI set because the cost of the current processes in general was not deemed to be excessive. Furthermore, as Davenport and Short (1990) point out, '*excessive attention to cost reduction results in tradeoffs that are usually unacceptable to process stakeholders*'. This was clearly the case in our project. The majority of decision-makers (especially those in the customer service function) were primarily concerned with reducing the overall lead time of the order fulfilment process. For the decision-makers, the high order lead time was more than anything else the main source for customer dissatisfaction and complaints. It was felt that the reduction of the time within which orders are fulfilled would provide the companies with significant competitive advantage in the marketplace, even if it meant that the overall cost of order fulfilment would have to increase. This view is in line with the design theory emphasis, which is placed predominantly on benefits assessment rather than on cost or risk analysis (see Chapter 4).

Another business goal, namely the one related to closer inter-company relationships, was also deliberately left outside the KPI set. This goal can be very broadly defined and hence its translation into an operational statement would necessarily have to rely on some surrogate measure that could be modelled within the simulation (for example, the level of inter-company communication before and after the introduction of the EDI applications). The management of both companies felt that such surrogate quantitative indicators do not necessarily imply a closer inter-company collaboration. For the purpose of our research, this finding points to a potential limitation of the approach advocated by the design theory. Simulation-assisted IS evaluation is expected to be better positioned to address quantitative performance indicators, which however will not always address the whole spectrum of IS-induced benefits. This in turn points to two alternative further research directions, either towards the articulation of the *exact* ways in which IS impacts can be translated into quantitative benefits (already identified in Chapter 4) or towards complementing simulation with some qualitative approach to IS evaluation to provide a holistic approach to investment appraisal. Both these issues will be discussed in more detail in the following Chapter.

5.4.6. IS Impact Modelling

The last step in the *Initiation* stage of ISSUE is the delineation of how the IS under evaluation is expected to affect the KPIs. Given the depth of the above analysis, we found this step to be much easier in practice than anticipated in theory. The detailed knowledge regarding the business processes, combined with the above list of KPIs, meant that the expected impacts of a future EDI adoption could be defined in a direct and straightforward manner. Firstly, EDI was expected to contribute to a reduction of all lead times (orders, backorders, and invoices) by enabling faster and more reliable inter-company communications throughout the Order Fulfilment Process. Secondly, EDI was also expected to contribute to reducing the number of backorders by enabling a more efficient inventory management policy to be followed (as shown in the case study of Chapter 3).

In terms of the IS benefits classification framework developed in Chapter 4, the first impact (lead time reduction) can be classified as a *hard* one, in the sense that it is directly attributable to EDI and naturally expressed in quantitative terms. The second impact (more efficient inventory management) can be considered as an *indirect* one since, although it is easy to quantify (reduction in number of backorders), it cannot be directly attributable to EDI. Rather, it is also dependent on further structural changes that will leverage the EDI investment, as shown in Chapter 3.

Two important conclusions can be drawn from the above analysis. Firstly, the design method involves considerable depth of analysis during the early stages of IS evaluation.

The knowledge gained through this analysis can significantly reduce the complexity of the IS impact modelling step (which in the previous case study was identified as the major impediment in model development). Secondly, contrary to what is predicted by the theory, the translation of informational changes into structural ones can still be a complex task, which may be difficult to perform effectively at this stage. In our study, we were fortunate to deal with one *hard* benefit (which is easily translated in operational terms) and one *indirect* benefit that was again easy to address due to the knowledge gained through the previous case study. However, there is no indication that this task will be equally easy to perform in general. Indeed, even in our case, the *exact* nature of EDI impact on inventory management is still difficult to express at this stage. The reason for this is that, while the aforementioned analysis has generated a detailed understanding of the AS-IS situation, the same does not apply to the TO-BE scenario. Indeed, while we know in general terms that we want to introduce EDI applications to support the Order Fulfilment Process, we have yet to address the exact nature and specifications of these applications. For this reason, we believe that the case study points to the need for revisiting this step later in the project, perhaps during the *Utilisation* stage, when the simulation output analysis of the AS-IS scenario is expected to have provided a more detail understanding of how the IS-induced changes will assist in alleviating the problems identified.

Before proceeding further, there is still one issue to address, namely the classification of IS impacts that will guide the *gradual model development* advocated by the design theory. Since in our case we had to model one *hard* and one *indirect* IS impact, we decided to include only the hard benefit in the first ISSUE cycle. Therefore, the initial working set of KPIs in our case will consist only of the order, backorder, and invoice lead times, while the number of backorders will be addressed at a later stage, if needed. As will be discussed later, this decision proved to have very significant consequences for the simulation models to be developed, as well as for the entire process of simulation-assisted IS evaluation.

5.4.7. Level of Modelling Abstraction

Probably one of the most important decisions taken during the *Initiation* stage (and yet one that can be easily overlooked, as it is 'transparent' to the model users) was to adopt the '*business document*' as the fundamental unit of analysis in the simulation model. The careful reader might have already noticed from Figure 27 that the flow of information between nodes in the flowchart is modelled at the level of *documents* (for example, orders, backorders, invoices, and despatch notes) rather than the more detailed level of the *products* specified in these documents. This decision was not taken arbitrarily but is directly related to the classification of IS impacts discussed above. The decision to concentrate in modelling *hard* IS benefits only during the first ISSUE cycle, leaving *indirect* benefits to a potential second cycle, meant that the KPIs of the first cycle were confined to lead times, leaving the number of backorders outside the first set of performance indicators.

This decision, although not particularly important at first glance, has very significant consequences for the simulation models to be developed. If we are concerned *only* with lead times for document exchange, a high level of modelling abstraction (at the level of these business documents) will suffice for our analysis, thereby contributing to maintaining a low complexity and cost to the entire modelling exercise. However, this level of abstraction would have been unacceptable if the number of backorders was also to be considered in the first cycle. Indeed, at the level of analysis chosen, the number of backorders has to be an *input* parameter to the simulation rather than a KPI output indicator. At the level of the business document, the question of whether an order produces a backorder or not is all that is relevant, as this generates the need for backorder processing. However, if we wanted to identify to what extent the *number of backorders* can be reduced by EDI adoption, we would need to acquire information about how EDI would affect the discrepancies between stocks reported by the inventory management systems of the two companies before and after the introduction of EDI. The more efficient inventory management enabled by EDI is theoretically expected to reduce the discrepancies, thereby enabling more efficient warehouse replenishments, which in turn will reduce the number of backorders generated (see earlier discussion). However, to address this, the simulation would have to address inventory levels kept by the two systems or, in other words, we would need to model entities at the level of the individual products rather than the level of the business documents.

For the purposes of our research, two conclusions can be reached from the above discussion. Firstly, since the KPIs addressed in the first ISSUE cycle refer to document exchange rather than product exchange, it seems reasonable to concentrate on this level of analysis without introducing unnecessary complexity to the model. The reason for this choice is mainly economic: if a high-level model is sufficient to address the problems of the existing ways of working and the benefits of any subsequent change proposals, then there is no need to complicate the study by introducing unnecessary details in the model. The argument in favour of high-level information analyses for business process change is also supported by Davenport (1993) who argues:

> *'Although the individual data element is the building block of a [...] model, higher-level and more understandable information units may be more appropriate for designing process-oriented information architectures. Because the flow of documents often defines the flow of a business process, we have experimented with the use of the document as the primary unit of information analysis'*

However, a second conclusion can also be drawn. If the evaluation exercise supported by the first ISSUE cycle is not deemed sufficient for a thorough investment appraisal, and a second initiation of the method is needed to address the remaining KPI as well, the simulation model would have to be significantly modified. This provides empirical support for a requirement that has already been identified in the theoretical argumentation of Chapter 4: the platform used for simulation model development has to support *hierarchical decomposition* and *design modularity* to allow for further levels of detail to be introduced in the models as needed.

Finally, the above discussion also supports the arguments in favour of *gradual model development* as a means of reducing the complexity of IS evaluation by simulation. If only hard benefits need to be measured to conclude the evaluation, then simulation models can be developed at higher levels of abstraction and hence at a lower total cost. If however, the systems under evaluation are expected to produce more intangible, indirect, and strategic benefits, then the level of complexity required in the simulation model is expected to be proportionate to the level of complexity of the IS. In other words, the IS evaluation by simulation design theory supports variable rather than fixed set-up costs, indicating greater cost-effectiveness than perhaps was initially expected.

5.5. Simulation

5.5.1. Platform Selection

Drawing on the conclusions of Chapters 3 and 4, it was decided that a data-driven business process simulator would be used as the platform for developing the simulation models in the case study. The reason for this choice related primarily to the need for assessing the constructs of such packages and their efficacy for IS evaluation simulations. Further, we wanted to compare the process of using a software package where little or no programming would be required with the general-purpose programming language approach followed in Chapter 3. It should however be noted that this comparison was not intended to be a formal evaluation based on a set of predetermined criteria, as such a task lies outside the scope of our research. Rather, this choice was targeted mainly at gaining additional insight as far as the design theory propositions are concerned.

To this end, an evaluation exercise of business process simulators was carried out and *Process Charter* (Scitor Corporation 1995, Essex 1995) was selected for modelling. The main reason for selecting Process Charter was the facility provided by the package to construct simulation models using a standard flowchart front-end. Since such a flowchart had already been developed, the use of the software was expected to contribute to less total model development time and greater user confidence in the simulation models. Process Charter also possessed a number of other useful facilities, as well as a number of limitations, which are discussed in more detail in Appendix D of the dissertation.

5.5.2. Data Collection

For the purposes of simulation model development, significant amounts of quantitative data were needed in order to add the dynamic dimension to the initial static process model (flowchart) defined above. As discussed earlier, during both the interviews and the workshops held during the *Initiation* stage, information was sought, amongst others, on quantitative information that would be necessary in order to compile the AS-IS simulation model. However, as expected, this data collection exercise (although extremely helpful in reducing the overall model development time) was far from being complete. Further data collection needs naturally emerged during simulation model development. Company representatives were asked to provide the needed information either directly or indirectly by means of providing researchers with access to company documents, computer-generated numerical data, and even the workplace itself. For example, the time needed to deliver products was calculated through an analysis of the delivery times that the drivers have to record on their daily route schedule. In a similar fashion, the schedule for forwarding orders for authorisation was derived from policy documents stating schedules for batch delivery of orders. On the other hand, some actual observation time also had to be spent in Ramma in order to measure the time needed, for example, to check inventory levels or pick and pack products for shipment.

For the purposes of our research, it is worth noting two issues. Firstly, the initial data collection performed during the *Initiation* stage was very helpful, as it significantly reduced the data collection needs at the *Simulation* stage. Had it not been for the initial data collection, we would probably need to organise two major data collection exercises (one for business process analysis and another for simulation model construction) which could frustrate the users and contribute to time delays and additional costs to the project. Secondly, it is worthwhile pointing out that the results of the data collection exercise constituted an additional learning outcome for decision-makers. For example, J&J managers had seriously underestimated the amount of time that typically elapsed between a backorder list arriving at J&J and actually being processed by the warehouse staff to generate replenishment schedules (see Appendix D).

5.5.3. AS-IS Model Construction

The static AS-IS model of Figure 27 was imported in Process Charter. Next, the quantitative data obtained during data collection were added to the model. A number of assumptions were made during model development. Due to space consideration, the detailed workings of the AS-IS model, together with the assumptions made during the model development process, are documented in detail in Appendix D of the dissertation.

5.6. Substantiation

The *Substantiation* stage can be broken down into three interrelated, yet distinct from each other, activities (Carson 1986, Sargent 1994, Law and Kelton 1991): model verification, model validation, and model credibility.

5.6.1. Model Verification

The first activity, *Model Verification*, is concerned with establishing that the conceptual simulation model is correctly transformed into an executable simulation program. In other words, verification deals with building the model *right*. Since a data-driven simulator was used for model construction, verification in our case was limited to monitoring the course of the simulation runs (using Process Charter's interaction features described in Appendix D) and verifying that activities, resources, and temporary entities ('flow objects' in Process Charter terminology) behaved as expected. Corrections were made where minor errors were identified until we were satisfied with the model's dynamic behaviour.

5.6.2. Model Validation

The second activity, *Model Validation*, is concerned with establishing that the simulation model is consistent with the study objectives and constitutes an adequate representation of the modelled system. In other words, validation deals with building the *right* model. In our case, validation was facilitated by obtaining the decision-makers' consensus that the model was an 'accurate' representation of the existing business processes and that the results obtained by the simulation runs bore a close resemblance to the actual process performance in the real-world system. To this end, pilot runs were made and the results were presented to representatives from both J&J and Ramma to obtain their agreement on the 'correctness' of the KPI values (order, backorder, and invoice lead times) as computed by the simulation runs.

5.6.3. Model Credibility

Finally, the third activity, *Model Credibility*, is concerned with establishing that the simulation model and its results are accepted by the decision-makers as being valid and are actually used in aiding decision making. Inasmuch as a simulation model can be regarded as *credible* without actually being *valid* or vice versa, credibility is probably as important as validation in terms of actual implementation of simulation results. In our case, the credibility of the model was fostered through the validation process described above, as well as through keeping the decision-makers closely involved throughout the whole process of system analysis and model development (as discussed earlier). This involvement, coupled with the use of familiar process representations in the form of flowcharts, was believed to contribute to increased acceptance of the simulation model and its results. In that sense, model credibility is not, strictly speaking, a distinct step in the *Substantiation* stage, but should rather be viewed as a continuous activity that should underpin the whole of the simulation study.

5.7. Utilisation

5.7.1. AS-IS Model Analysis

Since Process Charter offers no means of establishing when (and if) the model reaches a steady-state behaviour (see Appendix D), we chose to use an arbitrarily long run duration to 'ensure' that any initial transient model behaviour would not significantly affect the simulation results. Pilot runs were performed with alternative simulation run times. The results showed that KPI value differences between runs became insignificant for run times greater than two months. Finally, to provide an additional safety margin, a three-month (90 days) run duration was chosen.

Table 12 shows the KPIs obtained by the AS-IS model run. It is clear that the existing processes are far from producing results within the stated management targets. Orders are fulfilled in around 2½ days, while backorders need an average of nine days to reach the customers. It is worth noting that 94% of the order lead time and 69% of the backorder lead time are actually waiting times. In order words, orders and backorders spend more of their time waiting for something to happen rather than being processed. The same also holds true for invoices, where the lead time is over 11 days. The numbers for maximum times are more disappointing. There were orders that took up to six days to be delivered, backorders that needed almost 13 days, and invoices that took more than 25 days to reach the customers.

	Average Time	Average Wait	Max Time
Order	56h 12min	53h 05min (94%)	123h 04min
Backorder	213h 08min	147h 51min (69%)	310h 12min
Invoice	268h 24min	152h 37min (57%)	601h 43min

Table 12. Key Performance Indicators (AS-IS Model)

The above results point to problems in the system in the form of bottlenecks and time delays. In order to identify the sources of these problems, the KPIs were decomposed into their constituent elements. Average waiting times for activities, average and maximum queue lengths, and other output indicators were subsequently analysed. The findings were presented to and discussed with representatives from the two companies to gain further insight on the sources of the problems identified so that effective and efficient change proposals could be formulated. This process brought to light a number of reasons that contribute to the system inefficiencies. The major problems identified by the AS-IS model analysis are summarised in Table 13 in order of priority (as determined by agreement between the decision-makers).

I	*Information Exchange*	A number of communications take place between J&J and Ramma. Such communications refer, for example, to the exchange of backorder lists, despatch notes, invoices, and so on. Document exchange was found to be extremely slow and inefficient in most cases.
II	*Inventory Replenishment Policy*	The policy for scheduling replenishment of Ramma's warehouse by J&J seems also to be an acute source of problems in the system. The delays introduced by forwarding the backorder list to J&J, combined with the overall workload that the J&J warehouse in Mandra faces, contribute to an unacceptable backorder lead time.
III	*Data Inaccuracies*	This is not a problem identified by the simulation output analysis *per se*, but rather pinpointed by the management of J&J. As mentioned earlier, the two companies use different, standalone software packages for warehouse management. Ramma updates their inventory levels when they receive products from J&J and when they despatch products to customers. J&J update their own system when they ship products to Ramma or when they receive the despatch notes informing them that Ramma has sold products. However, in the former case they update their stock *before* Ramma has actually received the products, while in the latter case they update their stock long *after* Ramma has actually sold the products. This knock-on effect, combined with other errors due to, for example, product loss or expiry, results in discrepancies between the inventory levels reported by the two systems, hence contributing to inefficient inventory management in general.
IV	*Work Duplication*	Relating to the problem above, this problem refers to the need for J&J and Ramma to perform the same activities twice. For example, the information contained in the despatch notes has to be keyed in by J&J staff (as a matter of fact, J&J Athens employ one part-time employee *exclusively* for this task), while the same information already exists in Ramma's Information System.
V	*Order Authorisation Policy*	The whole structure of the Order Taking Process (OTP) appears to be a source of further delays. There is an unnecessary delay of orders received by Ramma before they are forwarded to J&J Thessaloniki for authorisation (average waiting time 5 ½ hours). The same holds true for the average time J&J Thessaloniki needs to authorise and fax the orders back to Ramma for further processing (11 hours).
VI	*Staff Inadequacies*	The authorised orders that arrive at Ramma from J&J Thessaloniki seem to generate a bottleneck in the system (up to 35 orders in the queue). The reason behind this may be that only one employee in the Ramma warehouse may be unable to cope with the existing demand (especially in view of his other activities as well).

Table 13. Major Problems of the AS-IS Process

5.7.2. Solution Finding and Experimental Design

Based on the results of the AS-IS model analysis, alternative process configurations were sketched and discussed with J&J and Ramma management for feasibility and acceptance. Solutions were firstly sought for each individual problem identified above. After an initial set of proposals was formed, possible solutions were merged into concrete alternative process layouts that were used as a basis for the TO-BE simulation models development. Due to space considerations, we will not discuss the detailed process of solution finding here. The interested reader can refer to Appendix D where this process is documented in detail.

The next step was to combine the potential solutions identified into concrete simulation experiments that would then be used in order to evaluate the proposed changes. Table 14 summarises the potential solutions as discussed in Appendix D. All solutions that were proposed for each problem are presented, regardless of whether they were ultimately accepted for further experimentation by simulation or rejected on the grounds of feasibility or other constraints. Accepted solutions are marked with an 'A' (and are shown in *italics*), while rejected solutions are marked with an 'R'.

Problem	Solution	A/R
I. Information Exchange	J&J Thessaloniki to issue invoices	R
	Send despatch notes once a day by EDI	*A*
II. Inventory Replenishment Policy	*Send backorders once a day by EDI*	*A*
	Deliver backorders directly to customers	R
	Increase replenishment levels	R
III. Data Inaccuracies	*Send backorders and despatch notes by EDI*	*A*
IV. Work Duplication	*Send backorders and despatch notes by EDI*	*A*
V. Order Authorisation Policy	J&J Thessaloniki and Ramma are electronically linked	R
	Automate order authorisation for J&J Thessaloniki	R
	Empower Ramma and salesmen to authorise orders	R
	Empower Ramma to proceed with orders before authorisation	*A*
	Encourage customers to submit orders to J&J Thessaloniki only	R
	Encourage customers to submit orders electronically	R
VI. Staff Inadequacies	*Employ an additional employee at the Ramma warehouse*	*A*

Table 14. Results of the Solution Finding Activity

The next step involved translating the accepted potential solutions of Table 14 into concrete simulation scenarios. To this end, the solutions were grouped into seven TO-BE scenarios, which represent all the possible combinations of the accepted solutions. These scenarios are illustrated in Table 15.

Scenario	*Description*
A	EDI is used to facilitate exchange of backorders and despatch notes between J&J and Ramma.
B	Ramma employs two employees at the warehouse.
C	Ramma is empowered to authorise the orders they receive.
D	Scenarios A and B combined
E	Scenarios A and C combined
F	Scenarios B and C combined
G	Scenarios A, B, and C combined

Table 15. TO-BE Scenarios

5.7.3. IS Impact Modelling Revisited

After the articulation of the aforementioned TO-BE scenarios, the next step involved translating them into modifications in the AS-IS simulation model that would drive the construction of the TO-BE simulations.

The seven scenarios outlined above refer basically to three proposed changes in different combinations. Two of these changes are of a *structural* nature (an additional employee in the Ramma warehouse, change of the order authorisation policy), while one change is of an *informational* nature (EDI introduction).

In line with the theoretical predictions, we found the structural changes to be easy and straightforward to model in the simulation:

a) An additional employee in the Ramma warehouse means changing only the number of resources in the simulation and rerunning the model.
b) Change of the authorisation policy means deleting the activity #5 (*Send Orders for Authorisation*) of the flowchart illustrated in Figure 27, so that orders received by Ramma are processed as soon as they are received.

In the case study discussed in Chapter 3, we saw that the incorporation of EDI impacts in the simulation model proved to be a difficult and elusive task, and required substantial additional analysis before we were able to translate the informational changes into structural ones. Indeed, this aspect was identified as the major potential problem of simulation-assisted IS evaluation then.

Even in this case study, and with the assistance of the design theory, earlier IS impact modelling attempts (see *Initiation* stage) were inconclusive. We saw earlier how the translation of EDI impacts into business process changes was made far easier by concentrating on the KPIs, but we also concluded that the inadequate understanding of TO-BE visions at that stage made detailed IS impact modelling difficult. We therefore suggested revisiting this issue at a later stage.

Here, before the construction of the TO-BE models, seems to be the best time to do that. At this stage we have acquired a detailed understanding of the existing system and we have also been able to envisage a more detailed scenario of EDI adoption. This scenario involves linking Ramma electronically with the J&J headquarters and warehouse, so that exchange of backorders and despatch notes can be performed via EDI. It is worth emphasising that even this more detailed understanding of how EDI will be implemented, still remains at the *organisational* level and it is not concerned with *technical* implementation details. Hence, one of the main meta-requirements of the design theory is still satisfied.

Returning to the issue of IS impact modelling, we found this step to be almost as easy and straightforward as the structural change modelling discussed above in this case. The detailed understanding and articulation of AS-IS model parameters made the process of identifying *where* and *how* EDI adoption would impact the business processes a rather effortless task. Since only backorder and despatch note exchange would be influenced, the EDI-induced changes were modelled in the simulation as follows (with reference to the flowchart of Figure 27):

a) Activities #15 (*Create Backorder List*) and #25 (*Create DN list*) were deleted to reflect the abolishment of backorder lists and despatch note lists in the EDI scenario.
b) Activities #16 (*Send Backorder*) and #26 (*Send DN*) were modified to reflect the fact that the exchange of documents was now to be performed via EDI (reduced duration of activities).
c) Activities #17 (*Wait to Process Backorder List*) and #27 (*Wait to Process DN List*) were also deleted, and instead a new *calendar* (see Appendix D) was added to reflect

the new schedule for warehouse replenishment (activity #18) and invoice issuing (activity #28).

It is worth emphasising that the articulation of the above IS-induced impacts, their translation to simulation model parameters, and the construction of the TO-BE models, were all completed in the course of one afternoon. Given that the same process in the case study discussed in Chapter 3, despite a comparable degree of complexity regarding IS impacts, was performed in a matter of weeks, we can deduce that the design theory does indeed provide support for more cost-effective and efficient simulation-assisted IS evaluation. However, we will postpone a detailed discussion of which of the theory components may contribute to this, and to what extent, until the following Chapter. In the remainder of this Chapter, we will conclude the discussion of the case study by discussing the remaining steps of the ISSUE method.

It is also worth emphasising that, in line with the discussion made earlier (see *Initiation* stage), we did not include potential benefits associated with the KPIs that were left outside the scope of modelling at this ISSUE cycle. In other words, although the adoption of EDI is also expected to influence the whole inventory management process (as discussed above and also in Chapter 3), and hence lead to fewer backorders needed, the KPI referring to the *number of backorders* was left outside the scope of analysis at this stage. Therefore, in the TO-BE models it is still assumed that the same number of backorders is generated even when EDI is used for inventory management. In the closing section of the *Estimation* stage we will discuss how incorporation of this parameter is expected to influence simulation results in a subsequent ISSUE cycle. However, even at this stage, we can assume that the TO-BE simulation results will be 'conservative' estimates, in the sense that further KPI improvements can be expected in practice where EDI is used (due to fewer backorders that can be anticipated).

5.7.4. TO-BE Model Construction

Based on the articulation of structural and informational changes described above, modifications were made to the AS-IS simulation model to develop the seven TO-BE scenarios discussed above. Figure 28 illustrates an example of the TO-BE flowchart, depicting scenario G of Table 15 above. By comparing the flowchart with the AS-IS model shown earlier (see Figure 27), the changes in the order authorisation policy and the

EDI-induced impact on the Warehouse Management Process and the Invoicing Process can be easily observed.

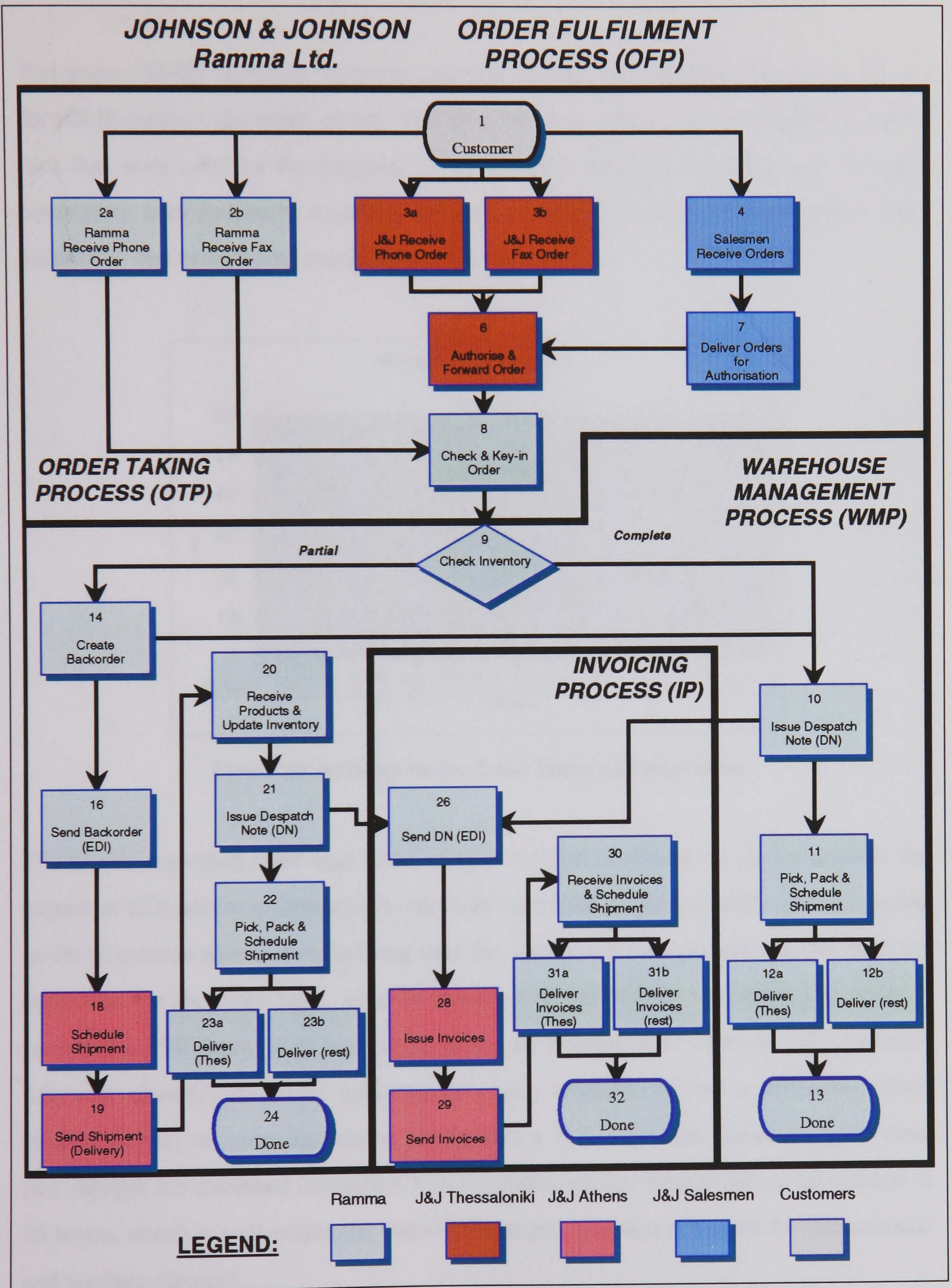
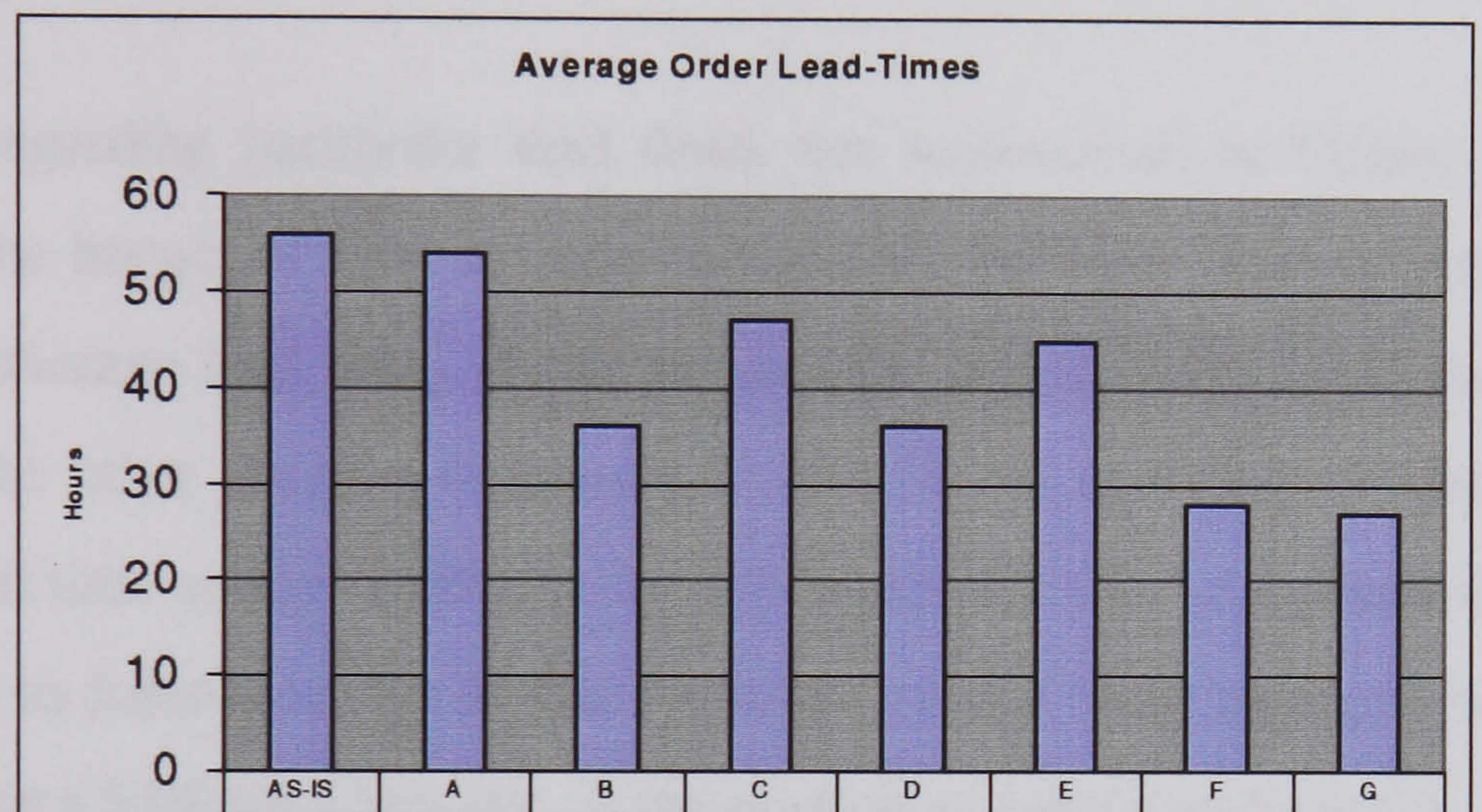


Figure 28. The TO-BE Static Process Model (Scenario G)

5.8. Estimation

5.8.1. Output Analysis

The seven TO-BE scenarios were run and their results were evaluated in comparison to the AS-IS outputs discussed earlier. The simulations produced a wide number of output data that were used for the purposes of the project's analysis. However, due to space constraints, only the results regarding the three main Key Performance Indicators (order, backorder, and invoice lead times) are presented here.



	AS-IS	A	B	C	D	E	F	G
Orders	56	54	36	47	36	45	28	27

Figure 29. Average Order Lead Times (All Scenarios)

The results regarding order lead times are summarised in Figure 29. As anticipated, the impact of EDI adoption (scenario A) on order lead time is minimal since EDI, according to the discussion above, is influencing only the warehouse management and the invoicing processes. On the other hand, an extra employee at the Ramma warehouse (scenario B) results in a 35% decrease of lead times, giving an average of 36 hours to fulfil an order. Likewise, changing the order authorisation policy (scenario C) has a noticeable, albeit smaller, impact on order lead times, resulting in a 16% reduction. However, when these two changes are combined (scenario F), order lead times fall dramatically to an average of 28 hours, which is well within the stated KPI targets (average of targets for Thessaloniki and northern Greece).

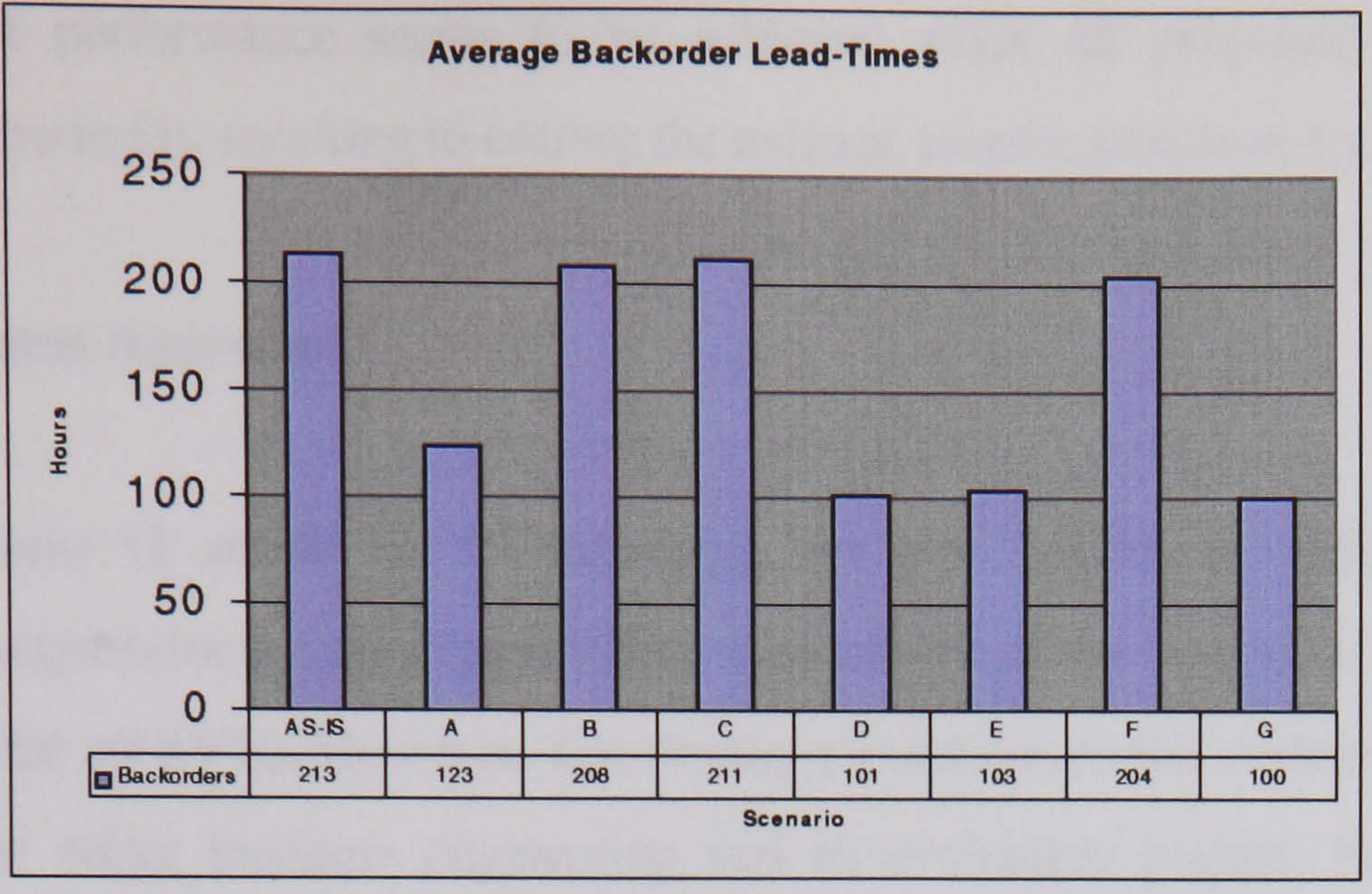


Figure 30. Average Backorder Lead Times (All Scenarios)

The results regarding backorder lead times are summarised in Figure 30. Regarding backorders, the impact of EDI is quite substantial. Scenario A alone results in a 42% reduction in average lead time, giving an average of 123 hours (or 5 days) to fulfil a backorder. The other changes (scenarios B and C), as expected, do not influence the backorder lead time at any significant degree. However, when combined with EDI, these changes seem to contribute to a further reduction of lead times, giving at best an average of 100 hours or a 53% improvement on the existing situation (scenario G).

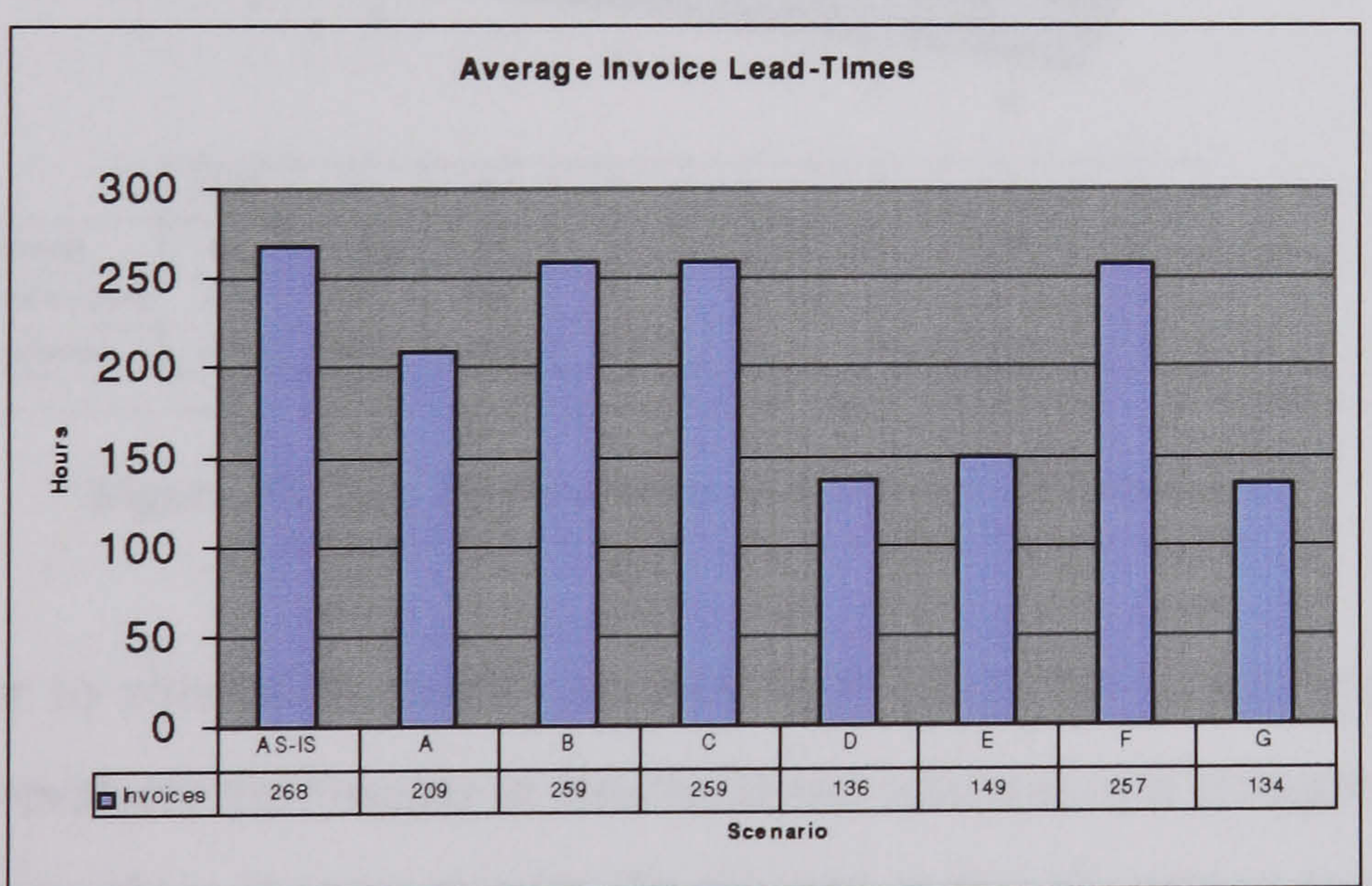
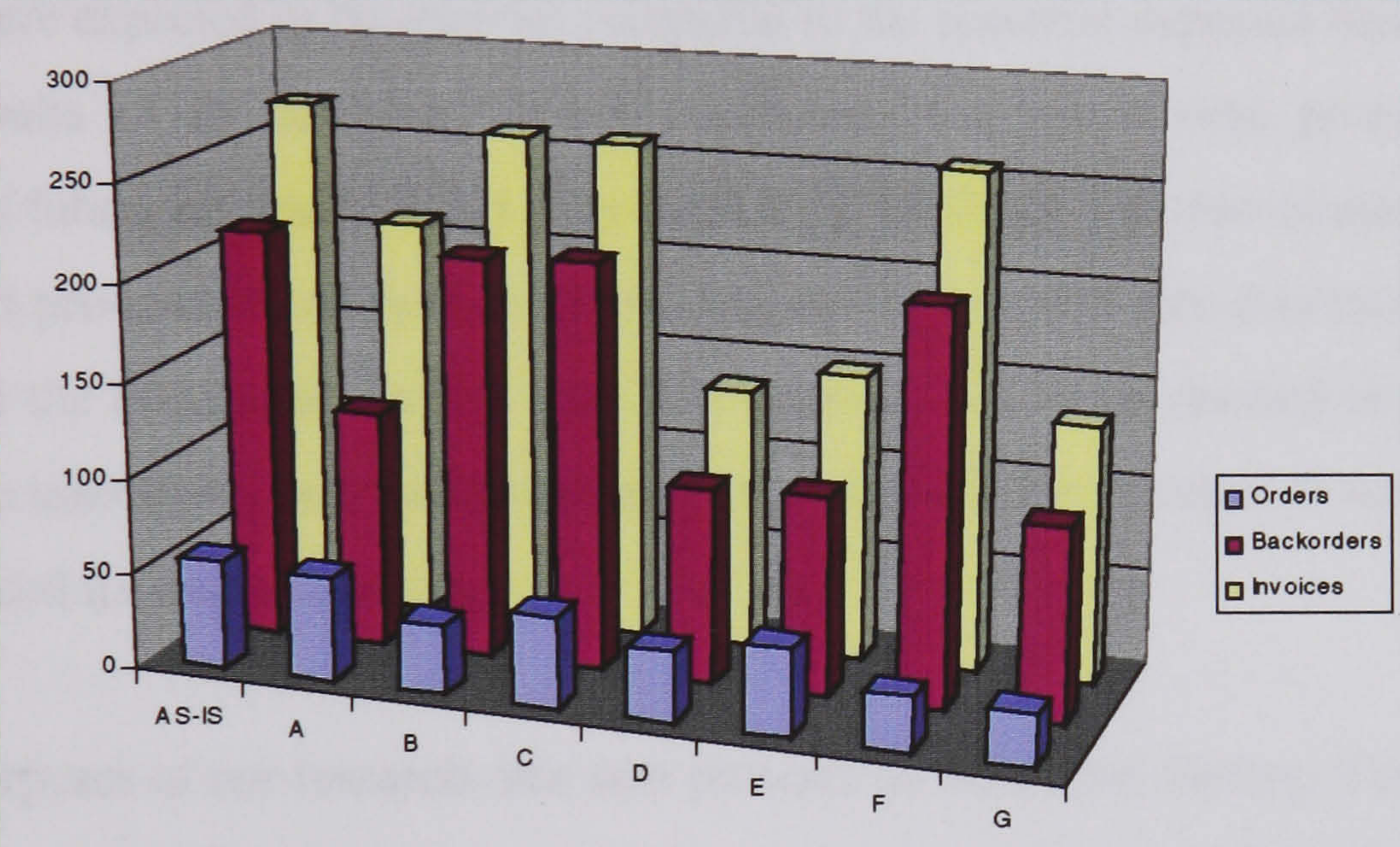


Figure 31. Average Invoice Lead Times (All Scenarios)

Finally, the results regarding invoice lead times are summarised in Figure 31. The adoption of EDI is again contributing to a noticeable performance improvement, by reducing the average time needed to deliver an invoice by 22%. Similar to the backorder improvement, the rest of the changes do not significantly influence the KPI by themselves, while the best performance seems to be achieved when all proposed solutions are combined (scenario G), resulting in cutting the average invoice lead time by half.

5.8.2. Investment Appraisal

Overall, scenario G seems to be delivering the best results in terms of process performance improvement (see Figure 32 for a summary of the results of all simulation scenario runs for all KPIs). However, this finding should not, in the context of our design theory and the wider business engineering and IS evaluation project, be taken as an indication of scenario G's superiority against the alternative proposals.



	AS-IS	A	B	C	D	E	F	G
Orders	56	54	36	47	36	45	28	27
Backorders	213	123	208	211	101	103	204	100
Invoices	268	209	259	259	136	149	257	134

Figure 32. Key Performance Indicators (All Scenarios)

Indeed, further to simulation results analysis, a thorough investment appraisal should comparatively evaluate the *benefits* of structural and informational changes with the *costs* of the investments these changes require. To this end, within the project to which the case study discussed in this Chapter belonged, the proposed changes were further scrutinised in order to develop a detailed understanding of implementation requirements and their associated costs. Such costs include, for example, the cost of an additional employee in the Ramma warehouse, the cost of developing, integrating, and maintaining the EDI applications for backorder and despatch note exchange, the cost of staff training, and so on.

The cost implications of each proposed change were assessed in broad terms and were comparatively evaluated to the benefits as indicated by the simulation runs. It must be noted that this process did not constitute a formal quantitative cost-benefit analysis as it was found that many of the benefits (for example, customer satisfaction because of more prompt deliveries), although quantifiable in terms of KPIs, were not easy to assess in monetary terms unless surrogate measures were used. The same applied for the costs, as some of them (especially those related to the IS investments) could not be assessed at any reasonable degree of accuracy before a more detailed IS project was put in place.

To this end, the cost-benefit comparison constituted mainly a management and decision-making process, the results of which quickly indicated that the costs of the proposed changes were expected to be minimal compared to the potential expected benefits. Based on the results of the analyses, detailed implementation plans were proposed and a schedule of future actions (in terms of projects to be initiated) was also created. However, the detailed presentation of these steps falls outside the scope of this dissertation. Suffice to say that the benefits associated with KPI improvements were deemed in all cases to surpass the associated costs and hence the change advocated in Scenario G was ultimately recommended for implementation.

For the purposes of our research, this step presents an additional finding. The process of simulation-assisted IS evaluation, although quantitative by its very definition, does not necessarily have to feed a quantitative technique of IS evaluation, as it was implicitly assumed in Chapter 4. Rather, the findings of the simulation analyses can highlight the magnitude of improvement in KPIs to support a value-based assessment to the proposed investments. Hence, the approach advocated in this dissertation is not necessarily confined to quantitative IS appraisals but can be equally applicable to the whole spectrum of quantitative and qualitative IS evaluation techniques.

5.8.3. Re-ISSUE?

Before closing the discussion of the case study, we need to comment on the final step of the ISSUE method: deciding whether the results of the first ISSUE cycle are sufficient for evaluating the investments. If the answer to this question is negative, a new ISSUE cycle should be initiated to address further KPIs that were left out in the first run.

In our case, as discussed in the previous section, the assessment process was positive, as it pointed to the desirability of the proposed changes based on the lead time-related KPIs alone. However, for the sake of completeness of analysis, we will assume here that the assessment was not satisfactory to discuss the likely course of the case study in that case.

A second ISSUE cycle should start from the *Initiation* stage again. However, this stage, as indeed any subsequent revisits to the method, does not need to include a full and complete analysis, like the ones presented earlier. Indeed, our purpose in subsequent ISSUE cycles is not to *repeat* the process, but rather to *enhance* its findings with new information that would support a more thorough (albeit also more complex) investment appraisal.

To this end, at the *Initiation* stage, we would need to include the fourth Key Performance Indicator that had initially been left outside the scope of analysis: number of backorders. As discussed earlier, the incorporation of this KPI, although not affecting the results of the *Initiation* stage, could have serious implications for the complexity of the *Simulation* stage, as the model would have to be considered at a lower level of granularity to address product-related, as opposed to business document-related, entities. To this end, it would be helpful if the software platform used for model development supported hierarchical decomposition of models and design modularity (see Chapter 4) so that the already developed AS-IS model (or at least portions of it) could be re-used and fine-grained to the level of detail needed. The *Simulation* stage would probably also require the collection of additional data referring to the lower-level details of the new simulation model.

Once the new simulation model is developed, the remaining stages of ISSUE (*Substantiation, Utilisation,* and *Estimation*) are not expected to be significantly influenced. Inasmuch as the same underlying principles are used to evaluate the model's validity and performance, and to drive experimental design and output analysis, it is expected that the steps discussed earlier would merely have to be enhanced to include the additional KPIs in the new simulation model. It can therefore be inferred that any subsequent ISSUE cycles are not expected to contribute significantly to increasing the overall project's complexity and will be mostly confined to enhancing the granularity of the simulation models developed earlier.

5.9. A Critique of the Case Study Process and Results

In this closing section of Chapter 5, we will briefly reflect on the practical results of the case study presented. In the following Chapter, we will concentrate on the theoretical issues addressed in the study to evaluate the design theory of IS evaluation by simulation, and complement those parts of the theory for which additional insight was gained.

Employing simulation as a means of studying and analysing the business situation was beneficial in many respects. Firstly, it brought participants from both companies and from different levels in the hierarchy to work together towards a solution that would be for the benefit of all parties. Second, it allowed for communication problems between business managers and IS specialists to be overcome, thus further contributing to the objectives of business engineering. Thirdly, it facilitated a structured debate, thus allowing for faster agreement and consensus reaching. It is important to note that, although representatives of the two companies had already spent significant amounts of time discussing the problems of the extant situation before the simulation project began, they had not been able to arrive at a consensus regarding the nature of the problems. The simulation-supported analysis helped them to structure and focus their discussions towards potential solutions to these problems.

Regarding the more specific issue of IS evaluation, the application of simulation proved to be a valuable mechanism for realising the real business value of EDI. J&J and Ramma management were able to see for themselves and assess the costs and benefits associated with various proposed options for change. This hands-on experience helped them to overcome some of their initial doubts and questions about EDI. It also helped them to build confidence in the technology without bearing the risk and cost of developing prototype applications and disrupting the everyday operation of their businesses.

It was further appreciated how simulation proved that the adoption of EDI alone would only marginally improve the performance of the order fulfilment process (at least as far as order lead times are concerned), contrary to what was initially expected. Decision-makers were able to identify, propose, and experiment with other options that would complement the EDI investment to achieve the desired results. If simulation had not been employed and the EDI application was adopted in the hope that all KPIs would be substantially decreased, as the two companies initially thought, it is very likely that the management of both companies would be disappointed by the practical results. Thus, they could develop a negative perception of the business value of innovative Information Systems in general and hence might be unwilling to further invest in similar systems. Thus, the case study provided empirical evidence to support the argument that simulation-assisted IS evaluation can provide an efficient mechanism for allowing organisations to assess the real business value of Information Systems and align IS introduction with business operations.

The detailed simulation analysis also brought to light that inefficiencies do not occur only in the interface between the two companies (as it was initially assumed), but also exist throughout the entire supply chain. In other words, it was not only the communication procedures between J&J and Ramma that were ineffective, but the same was true for some of the internal activities of the two companies. Taking this point further, the same may also hold true upstream in the supply chain, for example in the communication procedures between J&J and its parent company. Therefore, it became advisable to assess the potential of introducing similar changes throughout all stages of the value chain, even outside the boundaries of the system modelled in the study. For example, changes in the communication between J&J and its parent company may result in more efficient procedures for central warehouse replenishment in the same way as they supported regional warehouse control. To this end, J&J now envisage the development of further simulation applications to assess these points. This provides further evidence that, once in use, simulation models can change the perception of organisations regarding modelling and can support a culture of continuous measurement and improvement of business processes, an argument which is in line with MacArthur et al (1994).

5.10. Summary

In this Chapter we presented a detailed empirical study of IS evaluation by simulation that was carried out based on the design theory developed in Chapter 4. A 'chronological' account of the study process was presented and emphasis was placed on those steps that either provided empirical support for the design theory arguments and recommendations or highlighted weaknesses of the theory and issues where further development is needed.

The next Chapter will draw on the case study findings to discuss in more detail the theoretical robustness and practical usefulness of the IS evaluation by simulation approach in general and the design theory in particular. By comparatively evaluating the findings of this case study with the findings of the earlier study that was discussed in Chapter 3, we will articulate a number of improvements to the design theory and we will also address areas where further research was found to be required.

CHAPTER 6. THEORY EVALUATION AND EXTENSION

This Chapter draws on the findings of the case study presented in the previous Chapter and contrasts them with those obtained by the first case study analysis, which was discussed in Chapter 3. The aim is to abstract away from the particulars of the two cases and reflect on the theoretical robustness and practical usefulness of the design theory of IS evaluation by simulation. Based on this process, the theory is then extended further by articulating a number of improvements to its components.

Further to enhancing our theoretical propositions, this Chapter will also address a number of underlying issues that have been identified in the preceding Chapters as requiring further attention. Although a detailed coverage of these issues falls outside the scope of this research, this reflection process will assist in placing our research into an overall context of knowledge accumulation in business engineering's foundational disciplines. It will also allow for identifying avenues for future research to address the additional questions that our findings have generated.

6.1. The Case Studies Revisited: An Assessment of Findings

The purpose of this section is to bring together and synthesise the findings that were collected alongside the two case study discussions and classify them into a number of common themes. Thus, we will be able to reflect on the design theory's contribution in facilitating 'better' IS evaluations by contrasting the *theory-driven* work of Chapter 5 with the *exploratory* work of Chapter 3. This process will ultimately lead to developing a number of extensions to the design theory propositions.

6.1.1. Process Orientation

Both case studies adopted a clear horizontal process-based perspective in analysing the work activities of the modelled organisations as well as in developing the simulation models. For example, in the second study, the models depicted the overall *process* of order fulfilment and its constituent activities, without any explicit representation of the vertical organisational structure of the two companies. The same applied in the first study regarding the inventory-influencing business processes of all companies at all levels of the industry value chain. As far as simulation modelling is concerned, this process perspective may be the 'natural' choice for modelling. However, as far as business engineering and IS evaluation are concerned, the adoption of such a horizontal perspective had interesting and advantageous effects to the way both firms perceived their operations as well as for the success of the project itself.

For example, in the second case study, both J&J and Ramma managers were able to see the complete picture of process dynamics *for the first time* in the simulation model. Despite the fact that the Order Fulfilment Process (OFP) is amongst the most critical processes for both companies and despite the centrality of the process to inter-company co-operation, no single person in either J&J or Ramma was responsible for the performance of the process as a whole. As a matter of fact, in no previous analysis had the OFP been treated as a single process at all. Due to the vertical organisational structure of both companies, each department viewed only their own *decision territory* (i.e. the part of the process that the department managers control and are responsible for). This is not atypical in traditional, vertically structured organisations. For example, Davenport and Short (1990) report on a very similar example: '*In one manufacturing company studied, for example, no one had ever analysed the elapsed time from customer's order to delivery. Each department (sales, credit checking, shipping, and so on) felt that it had optimised its own performance, but in fact the overall process was quite lengthy and unwieldy*'.

The holistic, process-based organisational analysis allowed the two companies to perceive a problem not thought of before: *process fragmentation*. Different firms, sites, and departments had responsibility for parts of order fulfilment, but no one actually had the authority to oversee the whole process and monitor its performance. This fragmentation was primarily attributed to the vertical organisation of both firms and the lack of any process perspective for managing and controlling operations. As a result, previous efforts for improvement were mainly aiming at improving parts of the process confined to intra-function improvements, rather than addressing the process as a whole. The process-based analysis, further to its direct results, pointed to potential inefficiencies of the overall company operation (and inter-company co-operation), thus providing the decision-makers with an alternative means of studying other business problems in the future.

6.1.2. AS-IS Modelling

In both case studies, the process of business analysis and model development started from the depiction of the current (AS-IS) way of operation. Some advocates of radical business process change (especially in the BPR domain) may argue that the AS-IS processes should not be investigated in great detail as this might inhibit the development of radically alternative visions for change. For example, Hammer and Champy (1993) advocate the pursuit of a '*clean slate*' approach to business change, where after an initial brief analysis of the existing situation, process redesign starts from scratch without using any information regarding the AS-IS process structure.

While these arguments may hold some validity, the clean slate approach may not always be desirable, or even feasible (Harrison and Pratt 1993). With time, the absoluteness of this principle advocated by early BPR supporters was dispelled as a 'myth' (Davenport and Stoddard 1994) and alternative paths to process change were suggested. Stoddard et al (1996) found that 'clean slate' design is constrained by many factors, amongst them the presence of existing legacy systems and the lead time associated with the development of new applications. Similarly, Jarvenpaa and Stoddard (1998), in a field study of 15 BPR projects, found that 'clean slate' BPR was not typically practised by organisations.

We support these arguments and advocate that sufficient attention to AS-IS modelling should be paid within process-based organisational design. In line with Davenport (1993), the case studies pointed to a number of reasons for documenting and analysing existing processes before redesign. Firstly, understanding extant processes facilitates communication amongst participants in the redesign process and helps achieve greater participation and commitment throughout the project. Secondly, models of existing processes are an essential input to migration and implementation planning, useful for understanding the magnitude of anticipated changes and the tasks required in order to achieve the transition from the current to a new process. Thirdly, recognising the sources of problems in the existing processes can help ensure that they are not repeated in the new process. Finally, an understanding of the current process provides a comparative measure of value for the proposed changes.

6.1.3. Key Performance Indicators

Although the above discussion implies that AS-IS modelling and measurement may be essential, '*the process should not be measured for measurement's sake. Only the specific objectives of the redesign should be measured*' (Davenport and Short 1990). In line with this prescription, the design theory advocates a process of business goals articulation and identification of Key Performance Indicators (KPIs) that should be used as a basis for measuring and analysing process performance. As far as simulation-assisted IS evaluation is concerned, this 'narrowing' of focus can be extremely beneficial for many of the subsequent project steps (structuring the process of data collection, guiding the model development process, reducing the total model development effort, targeting the simulation output analysis task, and so on). It is worth noting that in the first case study, where KPI articulation was, at best, implicit, the processes of model development and IS impact modelling were more problematic and time-consuming.

6.1.4. IS Impact Modelling

IS impact modelling has been identified throughout this dissertation as one of the most critical determinants of successful simulation-assisted IS evaluations. The exploratory work of the first case study (as well as the theoretical review of Chapter 2) identified the issue of incorporating organisational IS impacts in BPS models as an elusive domain that has not received adequate attention in previous research. Conversely, the array of analytical resources that the design theory brought to the evaluation exercise in the second case study contributed to alleviating many IS impact modelling problems.

As argued in Chapter 4, the essence of IS impact modelling involves translating *informational* changes into *structural* ones, since the latter are easier to incorporate in a simulation. This approach was followed in both case studies. In the first case study, an exploratory process of IS impact identification allowed us (albeit after considerable additional analysis and effort) to propose operational hypotheses regarding the alleged ability of EDI to facilitate inventory reduction. In the second case study, the same process was made far easier by following the design theory prescriptions for translating anticipated IS impacts into operational Key Performance Indicators (KPIs) that were then used as the basis of actualising the impacts in simulation model terms. Figure 33 illustrates the underlying principle of this argument with examples from the second case study. Key Performance Indicators are articulated (during the *Initiation* stage of ISSUE) through an inductive analytical process that transforms business problems into visions for change (business goals) and then, through a detailed business process analysis, to operational statements for improvement (KPIs). Any subsequently proposed changes (business-induced or IS-induced) are expressed in the simulation models through an explicit translation of their impacts into structural model terms.

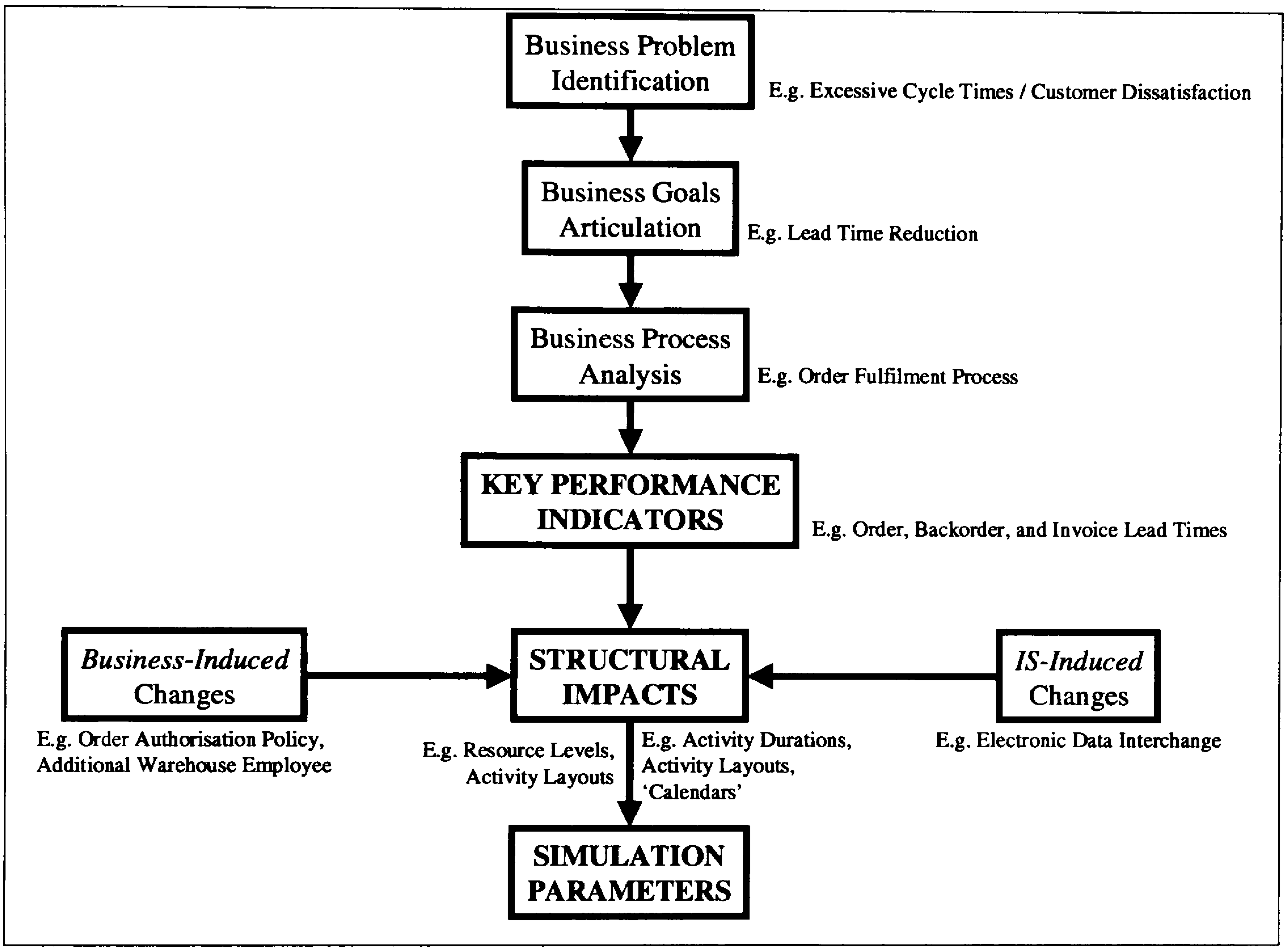


Figure 33. IS Impact Modelling Through Key Performance Indicators

As far as business engineering is concerned, the aforementioned approach means that a holistic approach to business process design and IS design is maintained throughout the evaluation. What is even more important is that this is achieved without having to go into any detail regarding IS specifications. As a matter of fact, the approach advocated by the design theory means that the IS itself does not even constitute part of the simulation models (just its effects on the business processes are incorporated). Such an approach also means that business-induced and IS-induced changes are evaluated against the same criteria, hence the requirement for evaluating heterogeneous investment proposals within the same method is also satisfied.

6.1.5. Level of Modelling Abstraction

As shown in the second case study, the choice of KPIs is also critical for determining the level of modelling abstraction or, in other words, the level of detail that is required for studying a particular situation. During the case study discussion, it was appreciated that the KPIs included in the first ISSUE cycle meant that the models could be developed and analysed at the level of the business documents being exchanged, while subsequent incorporation of additional KPIs might necessitate a more detailed approach at the level of the individual products. The design theory again proved beneficial in supporting an informed decision regarding the level of modelling abstraction needed, an issue that could not have been foreseen in the first case study.

The design theory advocates a process whereby successive ISSUE cycles may need to be launched until the IS evaluation is complete. At each subsequent cycle additional benefits are included and therefore additional KPIs are also incorporated. Consequently, the level of modelling abstraction is also likely to be modified so that more detailed parameters are taken into account. Further to the requirements regarding hierarchical decomposition of models and design modularity that naturally emerge from such an incremental modelling approach (which were discussed in the previous Chapters), we can gain some additional insight by following this argument further. Indeed, the additional details that will need to be incorporated in the simulation models in successive ISSUE cycles (as we move from hard towards more intangible and indirect IS benefits) may mean that the IS specifications will also need to be articulated in more detail. This incorporation of detailed specifications may, in some cases, need to go beyond the level of the *IS applications* (that formed the basis of our arguments throughout this dissertation) to include the more detailed level of the *IS infrastructure* as well. By IS infrastructure, we refer to the specific technological support on which IS applications will run. For example, in the case studies, IS infrastructure may be taken to include the computer networks that will host the EDI applications and facilitate the exchange of data between remote sites. *Computer Network Simulation (CNS)* (Sauer and MacNair 1983) is a mature application area of simulation, but has to date received only limited support regarding its potential integration with Business Process Simulation (Painter et al 1996, Giaglis et al 1999b). Hence, further research towards such integration becomes a theoretically interesting and practically relevant research direction, especially in the light of the increasing importance of networking applications for contemporary organisations. We will however postpone the discussion of the potential elements of such future research until the following Chapter.

6.1.6. Model Development Platform

The platform selected for model development in the second case study provided such features as user-friendly front-ends, animation and interaction capabilities, and so on. Compared to the generic programming language approach followed in the first case, this approach contributed to reduced total model development time and output analysis efforts and allowed for increased user participation throughout the process. Moreover, as far as the level of modelling abstraction is concerned, a platform that allows for hierarchical decomposition of models is believed to better fit the incremental IS evaluation approach advocated by the design theory.

This does not necessarily mean that a direct programming approach cannot accommodate this requirement. However, it is natural to expect that such an approach will lead to more costly and time-consuming modelling efforts if hierarchical model decomposition, design modularity, graphical front-ends, and similar facilities are to be developed from scratch by the modellers. A thorough assessment of development platforms is outside the scope of this research. However, the design theory components, especially the *meta-design* structure, can point to a number of criteria for effective software support for simulation-assisted IS evaluations. In the following Chapter we will discuss in more detail the implications of the design theory for the assessment and development of business process simulators capable of supporting the design theory prescriptions and principles.

6.2. The ISSUE Method Revisited

The case study presented in Chapter 5 provided substantial additional insight into the practical usefulness of ISSUE. Within the case study discussion, a number of propositions were made for extending the theoretical prescriptions of Chapter 4 by means of more detailed activities within the five core stages of ISSUE. Thus, based on the lessons learned from the case study and from the above analysis, we can now articulate a more detailed version of the ISSUE method. This version is illustrated in Table 16.

Stage	*Activity*	*Description*
Initiation	Step 1.a: Business Problem Identification	Identify Business Problems that necessitate process change and/or IS introduction.
	Step 1.b: Business Goals Articulation	Agree upon the business goals (visions) that will drive the improvement process.
	Step 1.c: Business Process Analysis and Data Collection	Establish system boundaries. Analyse the internal workings of the business processes that fall within these boundaries. Collect qualitative and quantitative data.
	Step 1.d: Static AS-IS Model Construction	Develop conceptual process model (preferably using a user-friendly notational formalism). Validate through obtaining client agreement.
	Step 1.e: KPI Articulation	Enumerate KPIs based on the business goals (step 1.b) and the process layout (step 1.c).
	Step 1.f: IS Impact Modelling	Express IS impacts in broad KPI terms and classify them for quantification/immediacy (*optional, if pre-conceived IS solution exists*).
	Step 1.g: Level of Modelling Abstraction	Decide on KPIs to include in the current ISSUE cycle.
Simulation	Step 2.a: Development Platform Selection	Select platform based on the design theory meta-requirements, meta-design, and characteristics of the project.
	Step 2.b: Supplementary Data Collection	Collect additional quantitative data needed for simulation model development.
	Step 2.c: AS-IS Model Construction	Develop AS-IS business process simulation model.
Substantiation	Step 3.a: Model Verification	Establish the AS-IS model's correct working behaviour.
	Step 3.b: Model Validation	Establish the AS-IS model's valid representation of the system under study.
	Step 3.c: Model Credibility	Establish decision-makers' confidence in the model (*continuous activity*).
Utilisation	Step 4.a: AS-IS Model Analysis	Run AS-IS model. Analyse output data and identify sources of problems.
	Step 4.b: Solution Finding	Brainstorm potential solutions to problems. Accept or reject solutions in agreement with the decision-makers.
	Step 4.c: Experimental Design	Translate accepted solutions into TO-BE simulation scenarios and design experiments.
	Step 4.d: IS Impact Modelling Revisited	Translate IS impacts into *detailed* KPI terms based on the TO-BE scenarios (using only the KPI set of the current ISSUE cycle).
	Step 4.e: TO-BE Model Construction	Develop TO-BE business process simulation models for all scenarios.
Estimation	Step 5.a: Simulation Output Analysis	Run TO-BE models. Analyse output data and compare performance.
	Step 5.b: Investment Appraisal	Assess the TO-BE scenarios in terms of benefits achieved versus costs of the investments they require.
	Step 5.c: Re-ISSUE?	Decide on whether the investment is justifiable or not. If inconclusive, re-initiate ISSUE with additional KPIs (step 1.g).

Table 16. The ISSUE Method Revisited

Although the major stages in the methodology remain the same, a number of individual activities that should be carried out within each stage have been added to further guide the evaluation process. In the following sections, we will briefly discuss the nature of these activities to complement and summarise the discussion of the previous Chapter.

6.2.1. Initiation

Step 1.a: Business Problem Identification. Business engineering should start from a careful examination and analysis of the problems that contribute to unsatisfactory business performance and necessitate the consideration of process changes and/or IS introduction. The identification and classification of such problems will then form the basis on which goals and visions are developed, and the effectiveness of changes is assessed.

Step 1.b: Business Goals Articulation. Drawing on the previous step, this step is concerned with translating the business problems identified above into specific visions for change. This process, which is comparable to the visioning process advocated by Davenport (1993), should remain at the strategic organisational level and not be concerned with expressing the goals in simulation parameters. Such 'technique-restricted' thinking at this point may inhibit the decision-makers' ability to articulate the whole spectrum of business goals they envisage, regardless of whether these goals will ultimately fall within the scope of the simulation or not.

Step 1.c: Business Process Analysis and Data Collection. Before translating the business goals into operational Key Performance Indicators, this step is concerned with analysing the business processes that affect and are affected by the scope of the business engineering project. For the purpose of simulation-assisted IS evaluation, this business process analysis is concerned with demarcating the boundaries of the system to be modelled and analysed via simulation. Since a range of qualitative data will necessarily need to be collected within the business process analysis, this step offers an opportunity for a parallel quantitative data collection exercise to provide some of the data that will later be used in the simulation models. It should however be acknowledged that data collection at this stage will be incomplete, since the development of the simulation model will almost certainly result in further data collection requirements (see step 2.b below). However, some data collection at this stage is believed to contribute to better management, reduced complexity, and lower costs of the overall model development exercise.

Step 1.d: Static AS-IS Model Construction. This step is concerned with developing a conceptual model of the system to be simulated, based on the results of the business process analysis above. Inasmuch as the business process analysis will require the interaction with decision-makers and the presentation of the conceptual modelling progress to them, conceptual model construction should be viewed as being 'parallel' to the previous step. In other words, it is expected that the static conceptual model will be developed and continuously revised throughout the process of business process analysis, as further insight is gained through the interaction between modellers and decision-makers. For reasons of user acceptance and economic efficiency, it is advisable to use a 'standard' notational formalism for conceptual model representation, ideally one that is familiar to the decision-makers and that can be easily translated into a dynamic simulation model later.

Step 1.e: KPI Articulation. This step combines the findings of all the previous activities to translate abstract business goals and process visions into operational statements for improvement that fit within the conceptual model and can be easily translated into simulation parameters. It must be noted that not all business goals will necessarily be translated into KPIs, as this will depend on the boundaries of the system to be modelled and the scope of the evaluation exercise.

Step 1.f: IS Impact Modelling. This step is concerned with an initial examination of any pre-conceived proposals for informational change and a translation of their expected impacts into the KPIs identified in the previous step. This identification of IS impacts should be complemented by their classification into hard, intangible, indirect, and strategic ones (according to the framework proposed in Chapter 4). This classification does not have to be absolute, since its purpose is to identify which impacts will be addressed within successive ISSUE cycles. At this point it should be noted that, since a pre-conceived IS solution will not necessarily be present in every business engineering project, IS impact modelling at this stage may not need to be performed. Moreover, even if a pre-conceived IS solution exists, IS impact modelling at this stage will not be definite, since the solution is not normally expected to be defined at any reasonable degree of detail. Therefore, it should be expected that the IS impact modelling step will be revisited later (see step 4.d below).

Step 1.g: Level of Modelling Abstraction. The last step in the Initiation stage is concerned with arriving at an informed decision regarding the level of the modelling abstraction to be adopted at each ISSUE cycle. The level of modelling abstraction will depend on the KPIs to be included at each cycle, as well as on the IS impacts to be modelled. It is expected that as we move from hard towards more intangible and indirect, and then to more strategic, IS impacts, the level of detail that will be needed for simulation modelling will be increased.

6.2.2. Simulation

Step 2.a: Development Platform Selection. The platform on which simulation model development will be performed should be chosen so that the meta-requirements and meta-design criteria of the design theory are effectively satisfied. However, it is acknowledged that different project characteristics may impose additional criteria or influence the relative importance of existing ones. Therefore, no strict prescriptions are imposed by the design theory on development platform selection. Instead, it is advocated that the selection should be based on a careful examination and critical appraisal of the facilities offered by alternative platforms against the characteristics and requirements of the particular modelling situation.

Step 2.b: Supplementary Data Collection. This step complements the data collection performed during the Initiation stage so that the complete range of data needed for the simulation model development is collected. In line with the previous discussion, it is not expected that data collection will be a linear and separate process, but it is expected to be performed in parallel with the AS-IS model construction in the next step.

Step 2.c: AS-IS Model Construction. This step is concerned with the actual transformation of the static conceptual model of step 1.d above into a dynamic simulation model representing the existing processes (i.e. before the introduction of any proposed structural and/or informational changes).

6.2.3. Substantiation

Step 3.a: Model Verification. This step is concerned with establishing the AS-IS model's correct functional behaviour.

Step 3.b: Model Validation. This step is concerned with establishing that the model is an adequate representation of the modelled system and that the model specifications are consistent with the study scope and objectives set out in the Initiation stage.

Step 3.c: Model Credibility. Finally, this step is concerned with establishing the decision-makers' confidence in the model and ensuring that the model and its results will indeed be used as decision-aiding tools in practice. By its very nature, this step should not be viewed as a separate activity in the Substantiation stage, but rather as a continuous process that should be carried out throughout the whole modelling exercise.

6.2.4. Utilisation

Step 4.a: AS-IS Model Analysis. After the AS-IS model development has been completed, this step is concerned with establishing model run parameters (such as run duration, warm-up period, and so on), running the AS-IS model, and obtaining results. Based on the results of the simulation runs, the model behaviour is then analysed so that the sources of any problems are identified and explained.

Step 4.b: Solution Finding. Based on the process of problem identification of the previous step, alternative paths to addressing these problems should be delineated and scrutinised for feasibility, cost implications, and so on. It must be stressed that this process does not constitute a simulation-driven experimental design exercise, but rather a business-driven decision-making process through which potential solutions are brainstormed and assessed in business terms.

Step 4.c: Experimental Design. Based on the business-driven assessment of the previous step, those solutions that are deemed to qualify for further examination are then further examined in simulation terms so that TO-BE experiments are designed.

Step 4.d: IS Impact Modelling Revisited. Before the construction of the TO-BE models that correspond to the above experiments, the proposed changes should be put under detailed examination so that their structural and informational impacts are identified and are also translated into changes to simulation model parameters. This translation is based on the KPIs articulated in step 1.e above, coupled with any previous IS impact modelling results (step 1.f). It is expected that the analytic rigour imposed by ISSUE will drive the translation of both business-induced and IS-induced changes into structural model terms in a direct and straightforward fashion. It should be noted here that the KPI set on which this process is based should include only those KPIs that were identified in step 1.g (Level of Modelling Abstraction) as forming part of the current ISSUE cycle.

Step 4.e: TO-BE Model Construction. Finally, based on the results of the IS impact modelling step above, the TO-BE simulation model(s) are developed for all simulation experiments.

6.2.5. Estimation

Step 5.a: Simulation Output Analysis. The TO-BE simulation models are then run and the results are comparatively evaluated between each scenario and against the AS-IS model performance. Based on this analysis, the proposed changes are examined in detail regarding their influence on the KPIs, and hence on the business goals set at the outset of the project.

Step 5.b: Investment Appraisal. Since the ISSUE method concentrates on benefit assessment only, it is not expected that the 'best' simulation scenario will always be the 'best' solution as well. In this step, the benefits obtained through the simulation analysis are evaluated against the cost and risk implications of each solution. This process can range from a formal quantitative cost-benefit analysis to a more subjective value analysis, depending on the characteristics and objectives of the particular project.

Step 5.c: Re-ISSUE? Finally, based on the results of the overall ISSUE cycle, a decision should be made regarding the justifiability of the proposed solutions. If the changes that emerge as a result of the ISSUE cycle are considered as either definitely justifiable or definitely unjustifiable by the decision-makers, then the simulation-assisted part of the IS evaluation is complete and the overall business engineering project can proceed as needed (for example, with implementation of the solutions). However, if the results of the current ISSUE cycle are not deemed to be conclusive, then an additional cycle can be re-initiated. For any subsequent cycles, the individual steps of the method remain the same, but the KPI set under consideration should be expanded to include more KPIs according to the classification made in the first Initiation stage.

6.3. Reflections on the Research

The aforementioned discussion concludes the development of the design theory of IS evaluation by simulation as far as this research is concerned. However, the analytic research process followed throughout this dissertation has pointed to a number of additional issues that, although they are not strictly within the scope of our analysis, are either complementary to our research objectives or have emerged as a direct consequence of our findings. Some of these issues have been previously addressed in this dissertation and will also be revisited in the following Chapter. In this section we will further reflect on the implications of our research to point towards some additional directions that have not been discussed earlier.

6.3.1. Inter-Organisational Business Engineering

Both the case studies that were pursued in the context of this research were of an *inter-organisational* nature, in the sense that they referred to process improvement and IS introduction efforts jointly undertaken by more than one company. As such, further to the generalised findings discussed earlier, the case studies have also pointed to a number of additional issues that can be considered as *context-specific* as they are mostly due to the inter-organisational nature of the studied projects.

Many of the critical processes in contemporary organisations are expected to include third parties and extend outside a single company's boundaries (Hammer and Champy 1993). For example, customer-facing processes typically extend beyond the boundaries of the firm to include the customers that necessarily influence the process. Similarly, the purchasing process in a typical firm will require, to different degrees, the co-operation of suppliers in order to be designed and executed efficiently. Therefore, the study of inter-organisational processes and Inter-Organisational Information Systems (IOS) has received the specific attention of both business and IS researchers (Cash and Konsynski 1985, Meier and Sprague 1991).

There are a number of additional issues and problems one might anticipate having to face when trying to understand, model, and analyse business processes that extend beyond the boundaries of a single organisation to include multiple partners in the value chain. To alleviate these problems, Davenport (1993) argues that an inter-organisational process should be jointly designed and managed by the organisations whose boundaries it crosses. That way, costs or bottlenecks can be designed out of the process altogether instead of being passed from one company to the other. J&J and Ramma were fortunate to have, albeit unknowingly, followed this approach in redesigning their shared order fulfilment process. Although most of the problems of inter-organisational business process modelling could ultimately be avoided when all firms co-operate in redesigning their shared processes, in this section we will discuss some of the issues that could arise and should be taken into consideration when this is not the case. Giaglis et al (1997) present a more thorough analysis of these issues.

When a process extends across organisational boundaries, to include, for example, customers or suppliers across the value chain, an organisation will probably not be able to redesign their part of a shared process without taking into consideration a number of constraining factors. For example, in the J&J/Ramma case study, one of the potential solutions we envisaged was to encourage customers to submit orders electronically. Although such a change may have been beneficial as far as the KPIs of the Order Fulfilment Process are concerned, it was perceived by the companies as potentially disrupting to other critical areas of business (for example, maintaining a personal contact with the customers, which was believed to contribute significantly to the success of customer acquisition and retention). Moreover, such a change would mean that the customers would have to modify their own Information Systems to facilitate electronic order submission, and (unless further analyses were carried out) it could not be assumed with any degree of certainty that the customers would be willing and capable of doing so.

In terms of business process modelling and simulation, the above means that the *degree of uncertainty* (which is anyway inherent in any modelling activity) can be substantially increased in inter-organisational modelling with possible implications for the validity and practical usefulness of the modelling analysis results. A single organisation cannot control or predict the behaviour of external parties with the same confidence that it can for its own resources. Therefore, modelling the behaviour of the organisation's environment will necessarily rely on additional assumptions. The effects of this problem were significantly reduced in our second case study since no simulation scenario involved the co-operation of third parties outside the project participants (i.e. J&J and Ramma). However, in the first case study, the simulation results depend on the assumption that *all* companies across the textile/clothing sector will be willing to adopt EDI and modify their business processes towards more frequent demand estimation and order plan submission. In decision-making terms, the increased uncertainty of inter-organisational modelling means that adequate attention should be paid towards clearly specifying the model boundaries and the assumptions built within the models. These assumptions should then form the analytic lens through which the simulation results should be viewed and interpreted. Moreover, it also means that the simulation study should not be treated as a complicated exercise in computer programming (an argument in line with Law and Kelton 1991), but rather as a tool to support the process of business analysis and IS evaluation. Therefore, managerial decision-making activities advocated by the design theory (such as *solution finding* and *investment appraisal*) should be treated with at least equal importance with their corresponding simulation-led activities (such as *experimental design* and *output analysis*).

A similar issue refers to the additional *complexity of data collection* needed to drive the development and analysis of inter-organisational business process simulation models. In the case of inter-organisational modelling, such data may not be available or easy to collect from external sources. In the absence of such data, the modeller may need to rely on additional assumptions, thus further threatening the validity of the derived business models and any managerial decisions based on them. This problem was also not of significant importance in the second case study since both companies could be relied upon to provided quantitative data where needed. Conversely, in the first case, the wider inter-organisational scope of the project meant that model development had to rely on aggregate data for the whole textile/clothing sector, since detailed data collection for each individual company would be prohibitively costly and time-consuming. Similarly to the above, this observation also points to the need of carefully interpreting simulation results against the assumptions and boundaries of the simulation model.

Multiplicity of decision-making levels might be another source of potential difficulties in inter-organisational business process modelling. When for example, a business process modelling project is jointly initiated by more than one company, company representatives may want to use the models to assess both their individual performance, as well as the performance of the inter-organisational system as a whole. Because the performance indicators for the whole system are not necessarily the same for every individual firm, there is a need for both 'global' and 'local' output analysis in inter-organisational business models. For example, in the first case study we saw that firms at different stages of the industry value chain (as well as firms of different sizes within the same stage) are expected to benefit in varying degrees from EDI adoption. Similarly, in the second case study, J&J can be expected to enjoy the majority of benefits that can be achieved through lead time reductions, while for Ramma the costs of setting up the necessary infrastructure may render the investment less attractive. This requirement calls for the development of models that can isolate 'decision territories' of individual firms and therefore be helpful to users during the decision making process. We have already outlined *design modularity* as a *meta-design* component of our design theory, but in the case of inter-organisational modelling this component may carry even bigger weight when designing the models and/or choosing appropriate software platforms for model development.

As far as the design theory is concerned, the above discussion points to an interesting observation. Inter-organisational business engineering, as argued in the preceding paragraphs, is essentially similar to generic business engineering, but it also possesses a number of additional, context-specific characteristics that can be translated into additional design requirements. To this end, our generic design theory of IS evaluation by simulation may need to be further 'specialised' to address such modelling situations. The object-orientation (O-O) paradigm that the ISDT structure follows, as discussed in Chapter 4, can prove extremely useful here. We envisage that, where needed due to the nature of more specific modelling situations, the general contents and structure of our design theory can be *inherited* by more specialised versions of any of the theory's components (kernel theories, meta-requirements, meta-design, and design method) in a direct O-O analogy. Thus, our design theory possesses another useful characteristic: it is sufficiently 'open' to accommodate future enhancements and specialisation, thus contributing to knowledge accumulation in the area.

6.3.2. Process-based Information Systems

Conventional wisdom in IS development holds that Information Systems should be tailored to fit business practice. This argument has a valid basis: Information Systems are just means of achieving organisational goals and therefore it is natural to modify the means in order to achieve the ends rather than vice versa. However, taking into account that most businesses have functionally oriented structures, this trend has resulted in most IS applications being functionally oriented as well. This trend was apparent in the case of J&J and Ramma: warehouse management applications were used to solve warehouse problems, ordering applications were used to facilitate order taking, invoicing applications were used to handle invoice issuing, and so on. A number of different and sometimes incompatible applications had to be co-ordinated for the successful execution of the order fulfilment process. Many of the problems that the two companies were facing can be attributed to this functional orientation and incompatibility of IS infrastructure between functions and across companies.

Such applications can 'imprison' data within functions, inhibiting the adoption of a process view of the organisation. This can have serious implications for measuring and analysing process performance. Davenport (1993) asserts that the functional focus of most extant IS applications inhibits the automated collection and reporting of information about process cycle times, costs, and other performance metrics. In terms of simulation modelling, the emergence of process-oriented IS applications, capable of automatically collecting and analysing process performance data, could dramatically reduce the time and complexity of data collection activities in simulation model development. Furthermore, such ability could provide a source of on-going performance measurement that could be used as a basis for problem identification and initiation of business engineering projects. A detailed discussion of this topic falls outside the scope of this dissertation. Suffice to say though that the recent emergence and popularity of process-based Enterprise Resource Planning (ERP) applications (Davenport 1998), aiming at addressing some of the problems of functional isolation, provides further evidence for the aforementioned arguments.

6.3.3. Information Systems as a 'Disabler' of Process Change

Much has been said in this dissertation (and in the IS literature in general) about the enabling role of Information Systems in driving business process change. However, although Information Technology can provide exciting opportunities for implementing new process designs, it can also equally impose considerable constraints on the degree of freedom business analysts and IS specialists have for envisaging these designs. A thorough analysis of the 'disabling' role of Information Systems for business process change falls outside the scope of this dissertation. However, in the interest of completeness of presentation, we will outline this 'dark side' of the impact of IS on business change and the implications it may have for business engineering and IS evaluation.

The primary root of the potential constraints that Information Systems may impose on business change is the presence of existing IS infrastructure and applications. Such, so called, 'legacy' Information Systems might inhibit an organisation's ability to envisage innovative process alternatives and design a new process starting from a clean slate. As argued in Chapter 2, most contemporary organisations have invested significant amounts of money, time, and human resources in building and maintaining such legacy systems. Such investments cannot just be assumed away, not only because of the investments made in them, but also because they are likely to be deeply embedded in the operating procedures, knowledge base, and culture of the organisation.

These considerations may have serious implications for the IS evaluation itself. A diverse range of additional cost and benefit factors may have to be taken into consideration when evaluating new IS investments in the presence of legacy systems. Such factors include, amongst others, additional costs for IS development (for example, the cost of integrating legacy and new systems) and what might be termed as 'opportunity benefits' (for example, the elimination of maintenance costs if legacy systems are abandoned). The consideration of such additional factors will necessarily render the IS evaluation process more complex, but is highly important for a thorough IS appraisal. This finding points to an additional opportunity for further enhancing or specialising our design theory through future research.

6.3.4. Information Systems Modelling vs. Information Modelling

One of the major areas identified throughout this research as deserving more attention by further research work is related to modelling the exact impact of Information Systems in business performance in a way that is straightforward to translate to simulation parameters. To address this problem, the design theory prescribes an approach whereby *informational* impacts are translated into simulation parameters through an intermediate step of *KPI* articulation and *structural* impact translation.

Although this approach satisfies effectively the objectives of our research, the problem of IS impact modelling in general has much more far reaching consequences than for the context discussed in this dissertation. Indeed, the issue of how Information Systems affect business performance in general is a topic that has yet to be addressed in a definite way in either the IS or the management science literature. Not that there have not been genuine and valid reasons for the difficulties that researchers have faced in addressing this issue in detail. As Boland (1987) argues, '*a problem that has plagued research on information systems since the very beginning ... is the elusive nature of information itself, and the way we as researchers have failed to address the essence of information in our work*'. As the above quotation implies, a definite understanding of the nature of information, its realisation through Information Systems, and its impact on business performance have yet to be developed. Although the research required for developing such an understanding is outside the scope of our work, we will outline some relevant thoughts here.

Information Systems and *Information* are many times used interchangeably in the literature, and, to a great extent, in this dissertation as well. However, the two terms are far from being the same. Information Systems are a resource that can be fairly well defined in an organisational context. Information, on the other hand, is a quite different resource, one that is less well understood and much more difficult to define and measure (King and Epstein 1976). Information, as Galliers (1993) argues, is both *enabling* and *contextual* while data produced and handled by Information Systems are context-free and simply the raw material from which information (meaning) may be attributed. This distinction has serious implications for the understanding and analysis of the impact of Information Systems on organisations. According to Checkland and Scholes (1990), the boundary of an Information System will always have to include the attribute of meaning and will consist of both data manipulation, which machines do, and the transformation of data into information, which humans do.

Information itself is inherently difficult to be explicitly modelled in a simulation because it does not obey some important 'conservation' rules (King et al 1988). If one uses some other resource (for example, time or money) the resource is no longer available for alternative uses. However, if one uses information, the resource remains still available for use by others. Similarly, if one uses a portion of some physical resource, the remainder has less value than the original amount. Conversely, the use of information not only does not reduce its value, but may even add 'value' to the 'remaining' information. Finally, as argued in Chapter 1, informational entities stored in Information Systems can be created and deleted at any time, and they can be present at more than one location at the same time.

Although the distinction between Information Systems and information is very real and relevant, the dichotomy between them cannot be absolute. In assessment terms, while the work presented in this dissertation concentrated on incorporating the impacts of *Information Systems* in business process simulation models, an extension of this work could be directed to incorporating the impacts of *information* on business processes, and hence in process simulations. To do so, we will need to refer to the *nature of information* in order to understand how this could be affected by an Information System and what implications this will have for organisational performance and simulation model changes.

To do so, we need to articulate what might be termed as *information attributes* or, in other words, the properties of information that, materialised through an Information System, can contribute to better organisational performance. As argued above, extant efforts to articulate such attributes are at best inconclusive to date. However, a number of researchers have attempted to address the issue. As an example, Table 17 elaborates on the discussion of Alter (1996) regarding information attributes and the potential roles of Information Systems in increasing overall information usefulness.

Information Attribute	Definition	Related Information System Role
Accuracy	Extent to which the information represents what it is supposed to represent	Control data; identify likely errors
Precision	Fineness of detail in the portrayal	Provide information with adequate precision
Completeness	Extent to which the available information is adequate for the task	Provide enough information; avoid swamping the users with excessive information
Age	Amount of time that has passed since the data were produced	Update information more frequently and transmit it to users more quickly
Timeliness	Extent to which the age of the data is appropriate for the task and user	Provide information quickly enough that it is useful
Source	The person or organisation that produced the data	Verify source; provide information from preferred sources; analyse information for bias
Availability	Extent to which the necessary information exists and can be accessed effectively	Make information available with minimum effort
Access Restrictions	Conditions under which specific items may be used	Prevent unauthorised users from accessing data
Level of Summarisation	Comparison between size of original data and size of data displayed	Manipulate data to the desired level of summarisation
Format	Arrangement and appearance of information displayed to the user	Manipulate data to the desired format

Table 17. Information Attributes and Related IS Roles (Alter 1996)

From the above, it can be inferred that the task of identifying information attributes is inherently complex, as it is dependent on many confounding factors. Amongst such factors we can identify organisational enablers and constraints (that may transform the way information attributes are realised), technological advances (that may shift the boundaries of IS-enabled information realisation), behavioural aspects (that may affect an individual's ability to perceive and utilise information), and even questions of a philosophical nature. To add to this complexity, we must note that even if a definite understanding of information attributes is achieved, it would still remain to assess how these attributes are affected by specific Information Systems and how they are 'operationalised' in business terms to impact organisational performance.

As far as simulation-assisted business engineering and IS evaluation are concerned, such an understanding would be a necessary prerequisite of translating information attributes into simulation model parameters in a direct fashion. Although clearly demanding and complicated, the above issues constitute an exciting and important field of further work with far reaching implications for both IS and management science research.

6.4. Summary

This Chapter began by discussing a synthesis of the lessons learnt from the two case studies presented earlier into a number of common themes. This reflection process was subsequently used to articulate a revised version of the ISSUE method, consisting of a number of detailed steps that can further structure and guide the process of simulation-assisted IS evaluation in practice. The rigour imposed by the revised ISSUE method, coupled with the additional support offered by the meta-requirements and meta-design, effectively contribute to attaining our initial research objective of supporting both the *products* and the *process* of simulation-assisted IS evaluation.

Furthermore, the additional insight gained throughout this research was used to reflect on our findings and identify a number of complementary or emergent research topics that we believe would be worth pursuing in future research efforts. The following Chapter will draw on these findings to summarise the arguments and contribution of this research and to identify its implications for both industrial practice and future academic research.

CHAPTER 7. SUMMARY AND CONCLUSIONS

For in much wisdom is great grief; and he that increaseth knowledge increaseth sorrow

Ecclesiastes 1:18

This Chapter concludes the discussion of the research presented in this dissertation. We begin by summarising the arguments and findings of the work discussed in the previous Chapters. We then proceed to discuss the achievements and contribution of this research as far as its underlying research disciplines and subject areas are concerned. Next, we discuss the boundaries of our analysis and provide a critique of the research findings. We conclude the Chapter by identifying and discussing a number of directions for future work that could be pursued to enhance and complement our findings here.

7.1. Summary of Research

The research described in this dissertation was primarily concerned with addressing the need for aligning *business process design and evaluation* with *IS design and evaluation* in the context of organisational change. We have argued for the need to treat *structural* and *informational* changes as a whole and we have contended that discrete-event simulation models of business processes can be an efficient means of doing so. We have also pointed out that in order to achieve such goals, simulation models will have to be capable of addressing in an explicit manner the ways in which IS introduction is expected to affect business performance. To assist in doing so effectively, a context-specific approach to simulation-assisted IS evaluation was developed.

This approach took the form of a *design theory* of IS evaluation by simulation. The theory was developed, empirically validated, and further enhanced through combining both theoretical and empirical research methods into a concrete research path, aimed at furthering our understanding and allowing for future improvements and extensions. To this end, the design theory consists of a set of *kernel theories*, a set of meta-*requirements*, a *meta-design*, and a *design method* that, when combined, can address the issues that this research has identified as the critical success factors of simulation-assisted IS evaluations. The structure of the design theory is summarised in Figure 34. A detailed discussion of all the components of the theory is made in Chapter 4, while the ISSUE design method was further elaborated through a number of more detailed activities in Chapter 6.

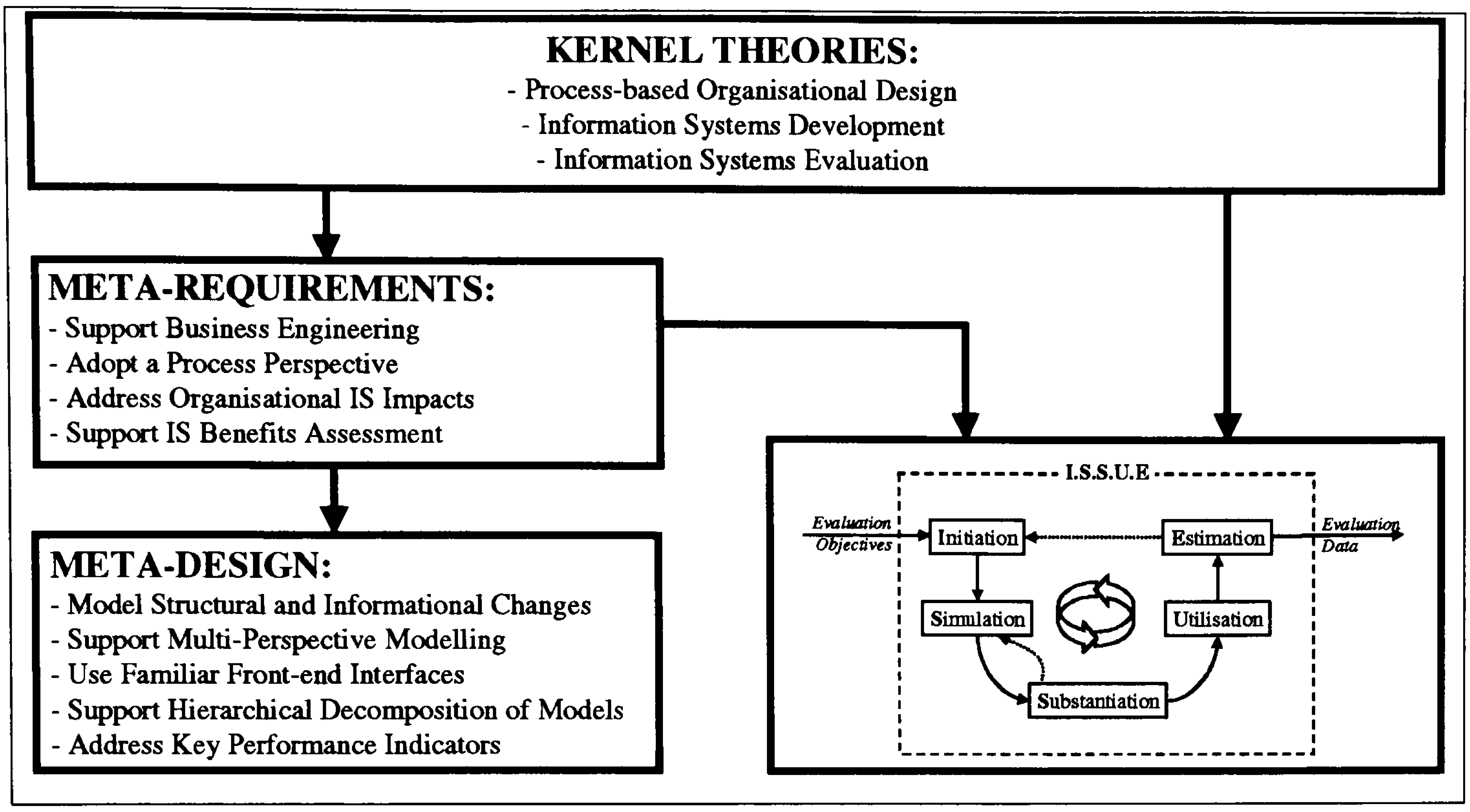


Figure 34. A Design Theory of IS Evaluation by Simulation

The development of the design theory was driven by a number of *IS evaluation principles*:

a) We have taken an *organisational* view of Information Systems aimed at supporting IS evaluation without the need of specifying technical IS implementation details. As a matter of fact, the design theory allows for IS evaluation by simulation without necessarily incorporating the IS itself in the simulation models.

b) We have argued for a systemic approach to IS evaluation at the level of the *business process*, as we believe that this analytic lens is better suited to organisational performance improvement than, say, the vertical organisational structure, the technical details of IS implementation, or the behavioural aspects of IS use. Further to representing a natural way of describing and modelling businesses, processes lend themselves better to analysis and measurement, and hence are better suited as the foundation of evaluation. Moreover, the importance of processes has been largely ignored in most extant IS evaluation techniques.

c) We have concentrated our efforts on the problems of *benefits assessment* and *data generation* for IS evaluation, as the review of previous research identified these areas as being underdeveloped and problematic. As such, we have not developed yet another IS evaluation method, but rather an approach to supporting extant methods by means of objective and reliable data regarding the expected benefits of IS introduction and any associated business changes. We chose to concentrate on the issue of measurement because measurement can be thought of as the underlying concept of evaluation, the '*sine qua non*' of decisions according to Mason and Swanson (1981). Moreover, since IS benefits are inherently difficult to isolate and predict, let alone quantify, measurement has been identified as one of the most important and elusive tasks of IS evaluation.

In summary, the underlying proposition of this research is that IS evaluation can be effectively supported by discrete-event simulation models representing the business processes that form the surrounding environment of a proposed Information System. With the guidance of the design theory, business-induced and/or IS-induced changes are then incorporated in the simulation in a systemic and focused manner. The impacts of these changes on model performance (and hence on organisational performance as well) can then be assessed and comparatively evaluated.

Such a simulation effects a 'virtual' implementation of the proposed changes, thus allowing the decision-makers to collect the necessary quantitative information needed to conduct further investment appraisal using established financial or other methods. Moreover, the simulation modelling process itself and the subsequent experimentation with alternative system and business configurations, constitute additional learning processes which can improve the understanding of the implications of the system to the business domain. Such understanding can be beneficial for business managers and IS specialists alike, and therefore it is useful in bringing the organisational and the software engineering domains closer, thus contributing to the goals of business engineering in a practical manner.

7.2. Achievements, Utilities, and Contribution

7.2.1. Design Theory

Arguably, the single most 'visible' contribution of this research has been the development of the design theory of IS evaluation by simulation. The components of the theory, as illustrated in Figure 34, encapsulate the majority of individual findings and insight gained throughout this research into a systemic, theoretically robust, and empirically validated instrument for simulation-assisted IS evaluations.

The *need* for the design theory was substantiated through both theoretical and practical means. A theoretical review of extant approaches to business process change, IS development, IS evaluation, and generic simulation methodologies, revealed a number of limitations that these approaches have when addressing simulation-assisted IS evaluation in the context of business engineering. Although extant approaches may be quite useful in their own domains, the issue of *domain integration* that was needed in our context was perceived to be inadequately supported. None of the extant approaches was believed to provide explicit guidance for our objectives, since none of these approaches was developed with this explicit objective in mind. This pointed to the need for the development of a context-specific method that would synthesise the underlying elements of extant methods according to the IS evaluation principles summarised in the previous section. In practical terms, the need for such a context-specific approach was further appreciated through comparing the process and findings of the first exploratory case study with those of the theory-driven second case study analysis. The theory-driven work resulted in more efficient and cost-effective IS evaluation, especially in those areas that the first case study work had identified as the most problematic (for example, IS impact modelling).

Similarly, the *utility* of the design theory is both theoretical and practical. In theoretical terms, the theory's rigorous underlying foundation, upon the concept of the ISDT, provides the basis for further enhancements in a targeted manner. Indeed, the 'openness' and 'structuredness' of ISDT encourages future improvements to the theory, either via the improvement of the theory's components or through 'inheriting' the generic theory properties into more specialised versions that will address more specific IS evaluation situations (for example, the evaluation of IOS or evaluation in the presence of legacy systems, as discussed in Chapter 6). In practical terms, the theory supports the *process* of carrying out simulation-assisted IS evaluations in practice (through the guidance provided by the *design method*) and at the same time addresses the necessary properties of the *products* of this process (through the criteria articulated in the *meta-requirements* and the *meta-design*). Moreover, the theory supports an incremental, iterative approach to IS benefits measurement that can promote learning, feedback, and cost-effectiveness when applied in practical situations.

The research discussed in this dissertation is by its definition multidisciplinary as it was driven, more than anything else, by the need to bring the foundational disciplines of business engineering together. To assist in summarising the detailed contributions of our work, we will assess our findings for each of these underlying research areas. However, it must be stressed that this dichotomy is somewhat artificial as the fundamental utility of our work lies in bringing together and studying some of the problems of process-based organisational design, IS development, and IS evaluation *as a whole.*

7.2.2. Process-based Organisational Design

The *design* phase is probably the most difficult and least structured of the components of a business process change project (Hammer and Champy 1993). Davenport (1993) asserts that '*the design activity is largely a matter of having a group of intelligent, creative people review the information collected in earlier phases of the initiative and synthesise it into a new process*'. While applying simulation in process redesign is by no means a substitute for such intelligent and creative thinking, we believe that the approach advocated in this research can impose a significant degree of rigour and structure to facilitate more informed decisions for change. Indeed, the ability to analyse existing problems, generate ideas for improvements, experiment with alternative process designs, and assess the impact of proposed changes on process performance, all contribute to providing the process redesign team with support that is necessary for business engineering.

7.2.3. IS Development

The organisational perspective taken in this research may give rise to arguments that the proposed approach is not 'technical' enough, in the sense that it does not provide focused attention to the problems associated with designing *detailed* IS structures in the aftermath of business engineering decisions. However, such a stance was intentional from the beginning of this research. IS design and implementation is generally a complex exercise and it may not be feasible to incorporate it into business engineering. Instead, we have argued in favour of a strategy where IS design is treated along two dimensions (one concerning the organisational impact of IS, and the other concerning the technical implementation details). This observation is further exacerbated by acknowledging that most extant IS development methods tend to become absorbed in the definition of individual functions and detailed requirements and to treat the IS as an independent artefact. The research discussed in this dissertation attempted to reverse this process of reductionism and reconstruct the whole picture that includes both the IS and its surrounding business environment.

Having said that, the need to design the details of an IS still remains after its evaluation has been completed and the system has been approved for implementation. Further to its direct contribution to *IS evaluation*, the approach advocated in this research goes some way to providing support for *IS development* as well. The process of developing, validating and using simulation models for IS evaluation can in itself be a useful learning exercise, as it generates greater awareness of both the specifications of the proposed system and the conditions of the business operations under which the system can produce the desired results. By establishing the broad requirements that the system should satisfy and the functionality it should embody to be beneficial to the organisational processes, the design theory provides valuable input to any subsequent IS development.

7.2.4. IS Evaluation

Willcocks (1992a) argues that '*a method of evaluation needs to be reliable, that is, consistent in its measurement over time, able to discriminate between good and indifferent investments, able to measure what it purports to measure, and be administratively/organisationally feasible in its application*'. The approach advocated in this research, although not an IS evaluation method as such, effectively satisfies all of the above criteria and goes beyond them to provide some other important facilities as well.

Information Systems are only one of many alternative claims on an organisation's resources, hence decision-makers need to be able to compare between heterogeneous investments and determine priorities between a range of alternative projects. Simulation models can facilitate such comparisons since they can be used for studying the organisational impact of a wide variety of diverse change proposals (both business-induced and IS-induced). As such, IS evaluation by simulation goes a step beyond the scope of most extant evaluation methods as it does not address only the IS to be evaluated, but it also encompasses the wider business processes that the system affects. This may have additional advantageous effects: according to Farbey et al (1993), non-automated processes, however trivial, may account for a large percentage of the overall process problems. It is therefore important that they become part of the evaluation exercise, something that cannot be achieved by evaluation methods that focus only on the immediate environment of the IS investment. An additional advantage of the design theory is that it does not impose a particular IS evaluation method on decision-makers, but can be equally applicable to the whole spectrum of evaluation techniques (quantitative or qualitative).

7.2.5. Business Process Simulation and Simulation of Information Systems

Although the idea of applying modelling and simulation for IS evaluation is not new, the approach followed in this research differs from earlier works both in terms of *purpose*, as well as in terms of *implementation*. Regarding *purpose*, most of the existing research and application of BPS/SIS up to date has been concerned either with evaluating aspects of the *technical* performance of Information Systems, or with addressing only the *structural* aspects of changes in business processes. Regarding *implementation*, our approach focuses on the expected impacts of Information Systems at the level of the *business process*, instead of the level of the IS application that has been the target of most previous efforts.

The use of simulation for IS evaluation can also contribute in addressing the problems of process-based organisational design and IS evaluation in a *holistic* manner. In both case studies, it was appreciated how the simulation at the level of the business processes demonstrated to the decision-makers that the adoption of the Information Systems alone can be expected to provide only marginal benefits, while if combined with orchestrated process changes, greater business performance improvements can be anticipated. As far as our initial research objectives are concerned, this means that the alignment between business processes and Information Systems can be maintained without needing to leave the sphere of organisational analysis to be concerned with technical IS implementation details.

The design theory has also pointed to a number of requirements that BPS/SIS software should meet if they are to be useful tools for simulation-assisted IS evaluations. Such requirements include, amongst others, the ability to define models at different hierarchical levels, the ability to define models in a modular and incremental fashion, the need for employing user-friendly front-ends to appeal to non-expert business users, and others. Although each of the above requirements are probably addressed in a more detailed fashion in the simulation literature, for the purposes of our research it is important to identify them, as they form the criteria for assessing and selecting business process simulators in practical situations.

7.3. A Critical View

7.3.1. Research Methodology

It could be argued that the research described in this dissertation is limited by the case study/action research methodology followed throughout its empirical part. Despite the case study method's strength at investigating phenomena in significant depth (Galliers 1992b), the method has also been criticised for providing little basis for scientific generalisations from a single study to a whole population. As argued in Chapter 3, the short answer to this critique is that case studies are generalisable to theoretical propositions and not to populations (Yin 1994). In this sense, the case study, like a laboratory experiment, does not represent a sample, and the investigator's role is to derive and generalise theories and not to enumerate frequencies.

As argued in Chapter 1, the choice of the methodological approach for this research was made consciously after a careful consideration of our research objectives against the range of research methods available. We have thus adopted a post-positivist epistemological stance, arguing that knowledge advancement is of paramount importance in multidisciplinary research domains where previous research has not been targeted to knowledge accumulation in a focused manner. Coupled with arguments in favour of methodological pluralism in IS research and the contribution of field-based research methods compared to laboratory-based ones, we carefully examined our research requirements and concluded that the case study/action research methods seem to be better suited to our purposes.

Having said that, the results of our research would certainly benefit from further analysis and scrutiny that could indeed take any methodological form. For example, *multiple case studies* can be pursued to further validate our findings, *surveys* can be undertaken to acquire a broader (but unfortunately not deeper) understanding of the phenomena under investigation here, *laboratory experiments* can be designed to study in detail a small subset of the variables approached in our research, and so on.

7.3.2. Suitability of the Approach

Organisational change, IS development, and IS evaluation can be approached in different ways. For example, the concept of process-based organisational design is not a monolithic one, but rather a continuum of approaches to organisational change management reflected in the diverse range of business process change approaches available (Business Process Re-engineering, Continuous Process Improvement, Total Quality Management, Organisational Transformation, and others). The choice of a particular approach in a specific situation depends on many factors including the organisational culture, the process under investigation, the degree of change required, the organisational resources available, the ability of Information Systems to enable change, and so on.

Varying project characteristics will almost certainly call for varying methodological choices and emphasis on different techniques. Inasmuch as the unique nature of a business change and/or IS introduction project determines the appropriateness of using a particular modelling and analysis technique, the role of simulation within business engineering and IS evaluation may well vary from critical to obstructive. In other words, we do not advocate that simulation-assisted IS evaluation will be a panacea for all evaluation problems. IS evaluation is not a straightforward task, essentially because the relationships between technical solutions (Information Systems) and organisational consequences are complex, diverse, and not yet well understood. Success may sometimes be due to sheer luck, while failures may often be due to our lack of ability to foresee the consequences of our actions. It should not be expected that simulation will miraculously point to the appropriate solutions or that any outcomes of the simulation analysis will necessarily be incontrovertible. As Hochstrasser (1993) argues, '*to succeed in justifying and prioritising IT investments, the whole decision-making process [...] must evolve from being based on acts of faith, entailing a high risk, to a calculated gamble where the odds are increasingly known*'. Simulation-supported IS evaluation is aimed more at supporting this calculated gamble, rather than making the evaluation process an exact science. Since decision-makers will always have to make decisions under conditions of uncertainty and risk, even imperfect assistance by informed analysis is likely to be better than intuition alone. Furthermore, simulation-assisted evaluation may allow for comparing alternatives even if absolute accuracy in predicting consequences is low. For example, if a model can identify a course of action that is consistently 'better' than alternative ones regardless of the assumptions made, then this course of action would generally be preferable even if we cannot accurately predict its quantitative impact.

7.3.3. Complexity and Cost-Effectiveness of the Approach

It may be argued that the approach advocated in this research constitutes a complex and laborious endeavour that may prove ineffective in practice, as simulation-assisted IS evaluation may result in more costs for the organisation than the benefits it can provide. Although such potential complexity is acknowledged (hence the aforementioned discussion regarding the non-universal applicability of the approach), the design theory includes provisions for supporting cost-effectiveness and economic efficiency. Difficult to capture and analyse IS benefits may not actually need to be assessed, thus saving time and effort. As argued in Chapter 4, where such benefits will *need* to be assessed, this can be taken as an indication of a high-risk investment, thus making the extra effort required for simulation-supported IS evaluation worthwhile.

Moreover, the design theory was also shown to have additional advantageous implications than simply supporting data generation for IS evaluations. Indeed, the incremental and analytic nature of the process can generate substantial awareness and knowledge amongst participants. Further to allowing for bridging the gap between the organisational and the IS domains, this knowledge can provide valuable feedback to the process of IS development, thus contributing to further cost and effort savings during subsequent IS development projects.

7.4. Avenues for Further Research

No single research work can claim to have solved all of the problems it set out to investigate. Kuhn (1970) argues that disciplines in which totally completed research seems to be possible, quickly cease to yield research problems at all and descend from scientific fields to engineering tools. It should be apparent from the work presented in this dissertation that our background research areas are highly unlikely to follow such a route.

Therefore, the completion of the research presented in this dissertation introduces a number of interesting and challenging research questions that could become the subject of further examination. It is worth re-iterating that the design theory is founded upon an inherently open and structured basis (the principles of the ISDT) that can further contribute to making such future research easier to integrate with the work presented in this dissertation.

7.4.1. Data-Driven Business/IS Simulators

ISDT-based design theories can be particularly relevant to the design and development of IS generators or, in other words, software products that provide automated guidance in developing the design products prescribed by the theory (Walls et al 1992). It is natural to expect that the capabilities of tools that automate some design aspect will be more efficient if they are derived from an underlying theory of the design process they are intended to support. To this end, an attractive future research direction would be towards using and enhancing the design theory components towards the development of integrated data-driven *Business/IS Simulators*. Such software would provide business users with the ability to develop business process models with relative ease and would also allow for direct incorporation of IS-induced changes in such models with little or no direct programming effort.

A central argument in this dissertation has been that a detailed and definite understanding of the issues pertaining to integrated business/IS simulation is still in emerging state both in practice and in academia. It is only quite recently that focused business process simulators have become commercially available. Generic properties of such simulators have evolved out of vendor efforts to provide efficient tools for business process modellers. As a result of this uncoordinated and unfocused process, most simulators provide only generic features that allow users to model business processes in an abstract fashion. We are aware of no commercial simulator that claims to provide explicit features for the modelling of and experimentation with IS structures.

As a result of this practice, design guidelines provided to users by extant simulators have been primarily based on using whatever features a specific vendor provides, rather than on a thorough understanding of the distinct needs and requirements of business/IS modelling. Providing such guidelines for the development of future business process simulators and the improvement of existing ones is an ambitious research goal, outside the limits of this dissertation. However, the meta-requirements and meta-design components of the design theory can provide a starting point for future investigation into this area. Although these components were not developed with this purpose in mind (but rather with a view of assisting users in selecting software platforms), our research has highlighted some important issues. For example, graphical representation of processes and their components (entities, activities, and queues), built-in libraries of icons that represent the workings of 'archetypal' business blocks, animation and interaction capabilities, hierarchical decomposition mechanisms, and so on, can be mentioned as some of the necessary features of such software. Giaglis and Paul (1996) provide a more detailed discussion on this issue.

7.4.2. Information Impact Modelling

The arguments made in Chapter 6 regarding the similarities and differences between *Information Systems impact modelling* (which was addressed in this dissertation) and *information impact modelling* (which was only briefly discussed) point to another challenging future research direction. Such research could start by synthesising existing knowledge on *information attributes* with the vast body of theoretical work on the organisational impacts of Information Technology in general (Laudon and Laudon 1996). Such a synthesis could contribute towards a better understanding of how Information Systems impact organisations *in operational terms*. This understanding could in turn be used to develop a taxonomy of IS impacts and identify ways for translating each of these impacts in business process simulation parameters. Giaglis (1999) provides an introductory discussion of such work, based on Davenport's (1993) classification of IS impacts.

7.4.3. Integrated Business Simulation and Network Simulation

As discussed in the previous Chapter, the holistic approach to business process design and IS design advocated by business engineering can provide further insight towards the integration of two largely distinct areas of discrete-event simulation application: Business Process Simulation (BPS) and Computer Network Simulation (CNS).

In cases where business processes are supported by Information Systems that themselves rely on network infrastructures, such integrated modelling can prove beneficial for all domains. At the organisational domain, network modelling can provide the data regarding activity times and other operating parameters that will drive the calibration of TO-BE simulation models with detailed data regarding the expected influence of the supporting infrastructure on the business process performance. At the network domain, the integration of BPS and CNS models can provide network engineers with the necessary input data regarding expected workloads at different parts of the network (as these workloads are generated by business process operations) and hence can assist modellers in better planning and designing network topologies, communication capacity requirements, and so on.

However, the integration of BPS and CNS models is far from easy to achieve. The levels of modelling abstraction in the two domains are radically different, since the former deals with business entities (for example, business documents) and expanded time frames (for example, hours or days), while the latter deals with data entities (for example, bytes or network packets) that travel through communication lines in matters of milliseconds. The integration of the two domains has then to rely on some form of intermediate structures that will allow the two models to communicate with each other effectively. The level of the *IS applications*, which support business processes and run on network infrastructures, can provide such a mediating mechanism.

A detailed analysis of the issues pertaining to BPS/CNS integration is outside the scope of our discussion here. A two-year research project, funded by the UK government through the *Systems Engineering for Business Process Change (SEBPC)* programme of EPSRC, has been launched to address such issues in detail. The project (Giaglis et al 1999b, Eatock et al 1999) builds on the research work discussed in this dissertation and extends the design theory findings to address the more specific issue of integrated business/IS/network simulation for business engineering.

7.4.4. Organisational Design Workbenches

Finally, the review of business and IS modelling techniques discussed in Appendix A of the dissertation provides another attractive direction for further research. Based on the evaluation framework and taxonomy of modelling techniques discussed in the Appendix, we envisage the development of '*organisational design workbenches*' that will go beyond the simulation-assisted IS evaluation to combine a number of computer-supported tools to assist the complete cycle of organisational design. Such tools may include:

a) *Process mapping tools*, such as flowcharting environments, to support human understanding and communication of models.

b) *Business/IS/Network Simulators*, to capture the quantitative and dynamic nature of processes and drive organisational improvement efforts at the level of business process modelling, Information Systems modelling, and network modelling.

c) *Project Management tools*, to support the on-going management of business process change and IS development projects.

d) *Computer-Aided Software Engineering (CASE) environments*, to provide the basis of application development in the aftermath of business engineering decisions.

e) *Workflow Management Systems (WFMS)*, to support automated process execution and on-going performance measurement, in order to provide feedback to future organisational improvement efforts.

Figure 35 illustrates the generic architecture of such organisational design workbenches. A more detailed discussion on the nature and utility of such tools can be found in Paul et al (1999).

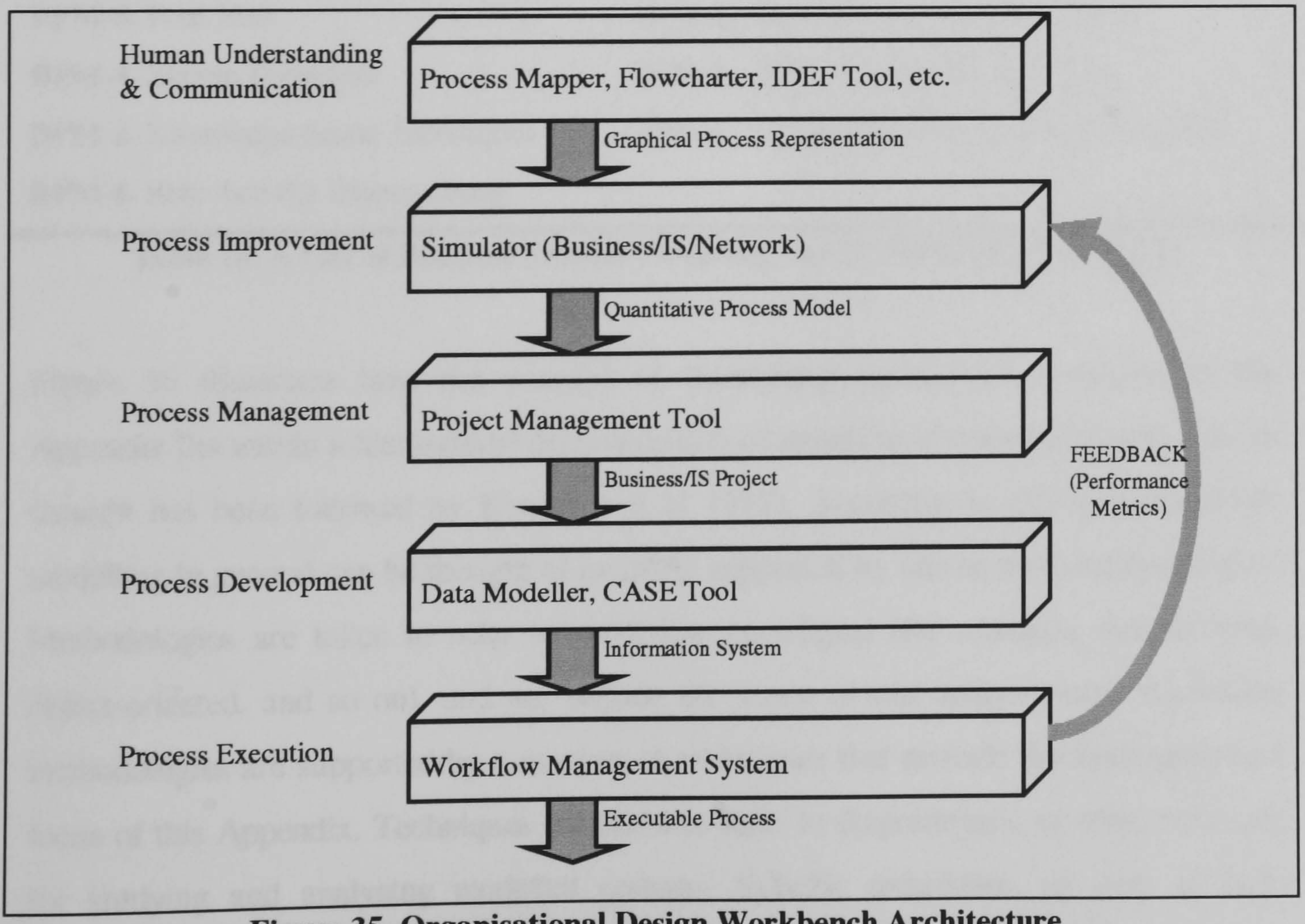


Figure 35. Organisational Design Workbench Architecture

APPENDIX A. A REVIEW OF MODELLING TECHNIQUES

A.1. Introduction

Although the focus of this research centres on discrete-event simulation as a facilitator of business engineering and IS evaluation, simulation is by no means the only technique that can be used for these purposes. Various researchers have attempted to approach the same or similar problems by means of other modelling techniques. In this Appendix we will provide a brief overview and a critical appraisal of some of these techniques. The overview presented herein is not intended to be exhaustive, merely illustrative of the variety and diversity of the modelling techniques that exist. The modelling techniques to be reviewed here, can be classified under two main categories: *Business Process Modelling Techniques* and *IS Modelling Techniques*. Table 18 summarises the techniques that will be briefly presented in this Appendix (with the exception of discrete-event simulation that is dealt with in the main body of the dissertation).

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. System Dynamics	**ISM-4.** IDEF Techniques (IDEF1x)
BPM-5. Knowledge-based Techniques	**ISM-5.** Unified Modelling Language (UML)
BPM-6. Role Activity Diagramming	

Table 18. A List of Business Process Modelling and IS Modelling Techniques

Figure 36 illustrates how the concept of '*modelling techniques*' reviewed in this Appendix 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 our analysis here. Modelling methodologies are supported by a number of *techniques* that provide the main analytical focus of this Appendix. 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 Appendix.

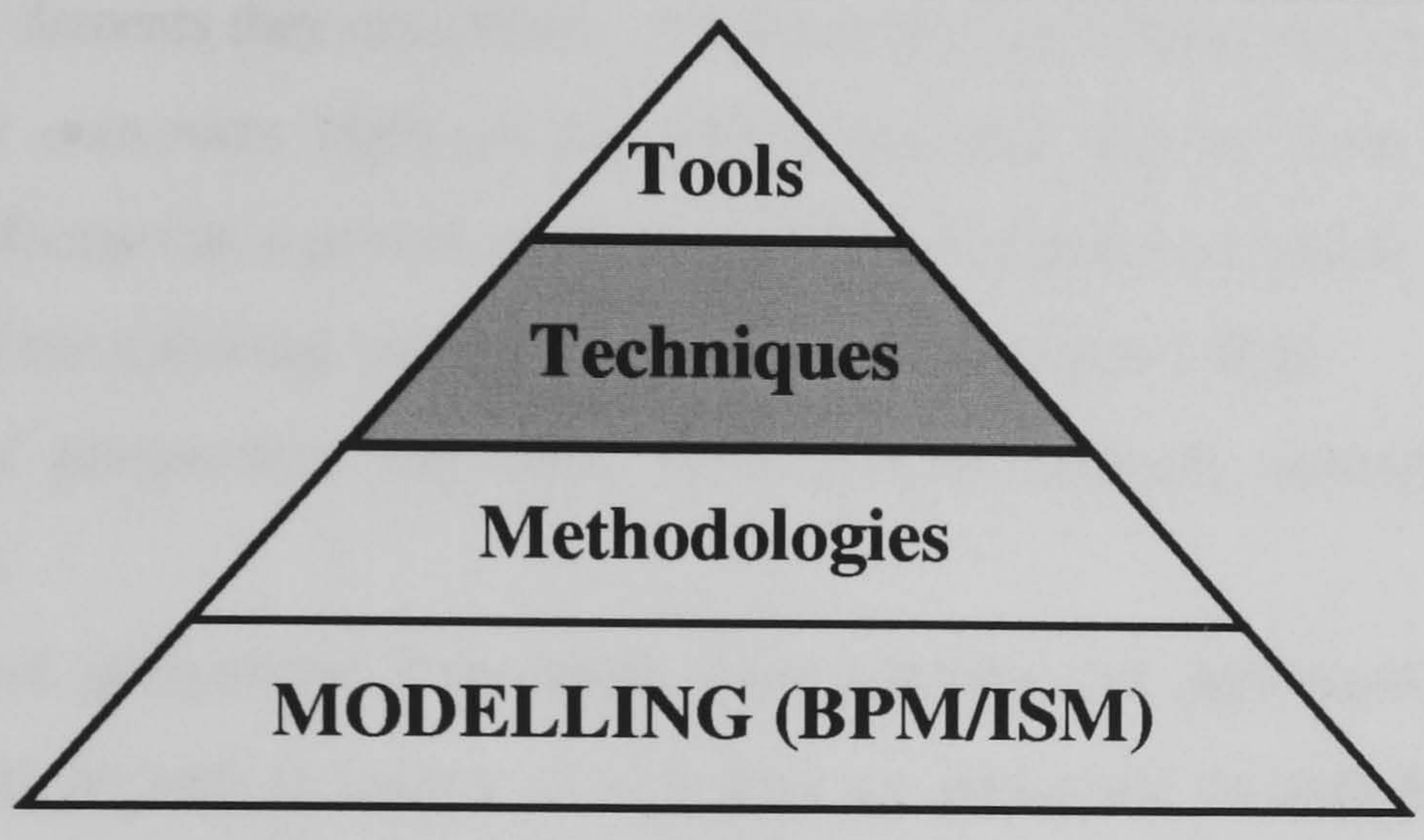


Figure 36. Modelling Methodologies, Techniques, and Tools

A.2. A Framework for Evaluating Modelling Techniques

Business process models and IS models can be used in a variety of contexts, which obviously extend beyond business engineering, IS development, and IS evaluation. 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 19 illustrates typical BPM/ISM goals and objectives, along with associated requirements for modelling techniques in each case (Curtis et al 1992).

Process Modelling Goals and Objectives	Requirements for Modelling Techniques
Facilitate Human Understanding and Communication	Comprehensibility, Communicability
Support Process Improvement	Model Process Components, Reusability, Measurability, Comparability, Support Technology Selection and Incorporation, Support Process Evolution
Support Process Management	Support Reasoning, Forecasting, Measurement, Monitoring, Management, and Co-ordination
Automated Guidance in Performing Process	Integrate with development environments, Support for Process Documentation, Reusability
Automated Execution Support	Automate Process Tasks, Support Co-operative Work, Automate Performance Measurement, Check Process Integrity

Table 19. Process Modelling Goals and Requirements (adapted from Curtis et al 1992)

To be able to accommodate the aforementioned goals and objectives, a process 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. Process modelling techniques differ in the extent to which their constructs highlight the information that answers these questions. To provide this information, a process modelling technique should be capable of representing one or more of the following 'process perspectives' (Curtis et al 1992):

e) *Functional perspective*: Represents *what* process elements (activities) are being performed.

f) *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.

g) *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.

h) *Informational perspective*: Represents the informational entities (*data*) produced or manipulated by a process and their relationships.

The combination of modelling goals with the aforementioned perspectives of modelling can provide the basis of an evaluation framework for studying, analysing, and comparing BPM and ISM techniques. This framework is illustrated in Figure 37. 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 37, 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.

FIT

	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

DEPTH

BREADTH

Figure 37. An Evaluation Framework for BPM/ISM Techniques

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 & 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 Appendix, a selected number of popular BPM and ISM techniques will be reviewed. In the last section of the Appendix this review will be used to position these techniques within the evaluation framework of Figure 37.

A.3. Business Process Modelling Techniques

A.3.1. Flowcharting

Flowcharting is amongst the first graphical modelling techniques, dating back to the 1960s (Schriber 1969). Flowcharting is a static graphical technique that can be used to depict processes by illustrating their components (individual activities) and the relationships between them. The purpose of flowcharting is to help in visualising and presenting a process in an unambiguous way that cannot be achieved by textual descriptions. 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 uses standard graphical symbols to depict activities, inputs and outputs, decision points, and other model elements. Some of these symbols are illustrated in Figure 38.

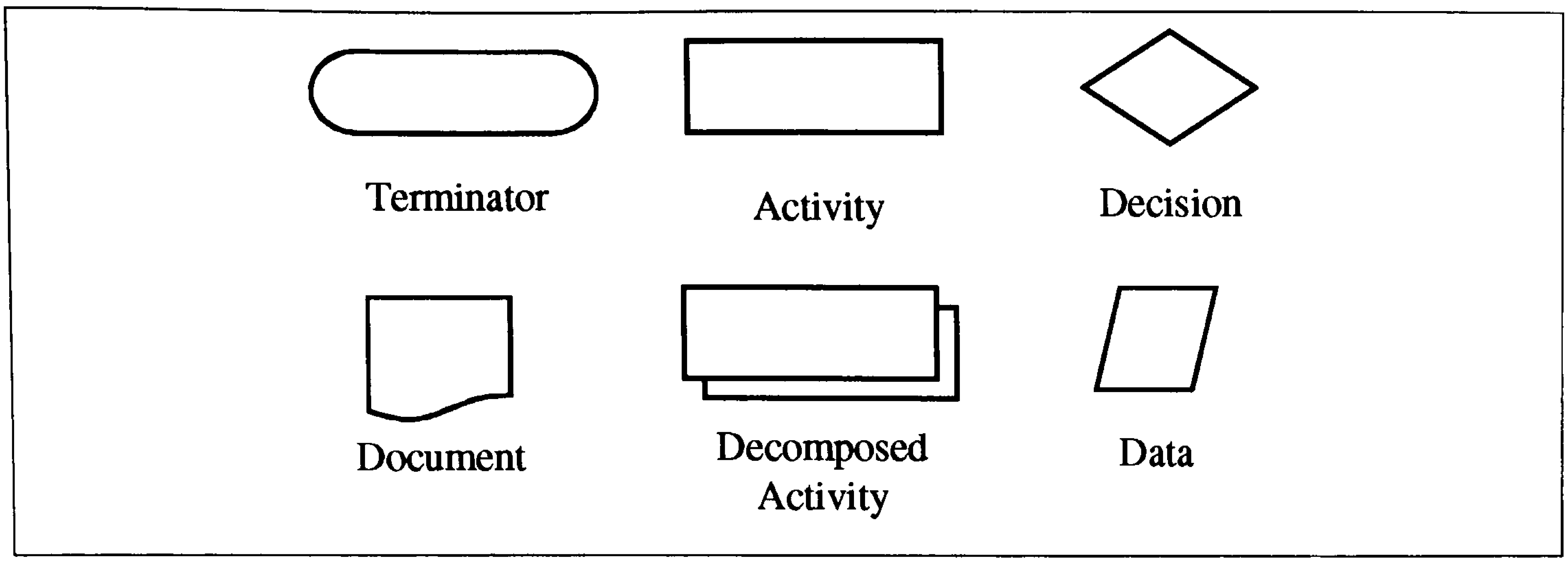


Figure 38. Basic Flowcharting Notation

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.

To overcome some of the limitations of the basic flowcharting approach, a number of extensions to basic flowcharting models have been developed. For example, because basic flowcharts cannot depict temporal relations or indicate where business activities take place, the use of *time/location-enabled flowcharts* has been proposed. Figure 39 illustrates such a flowchart where time is depicted on the vertical axis and location is depicted on the horizontal axis.

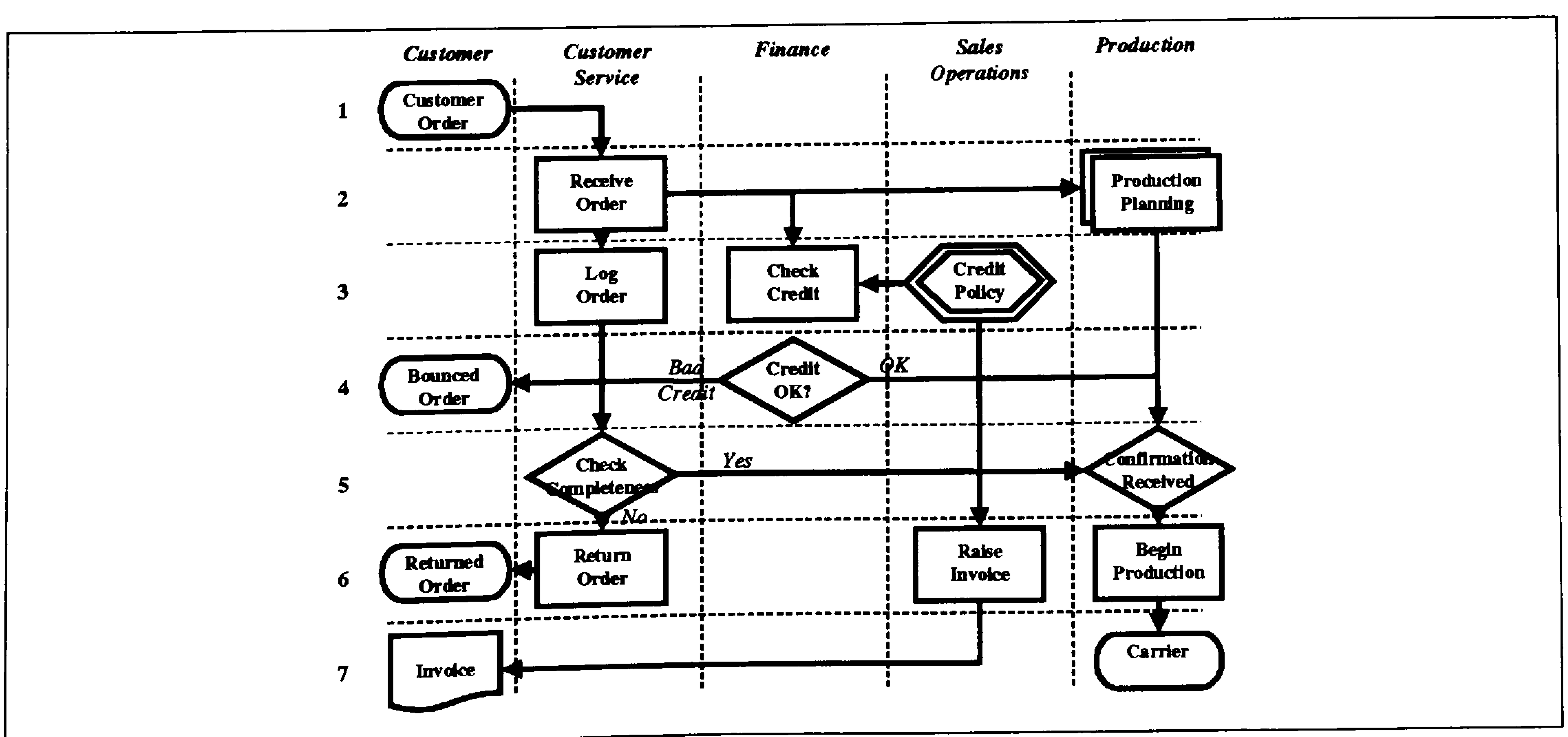


Figure 39. Flowcharting Example (Time/Location-enabled)

A.3.2. IDEF Techniques (IDEF0, IDEF3)

The IDEF family of modelling techniques was developed by the US Department of Defence (DoD) 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 mostly targeted towards addressing the functional perspective of a system (Mayer et al 1995). 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 40). IDEF0 supports process modelling by progressively decomposing higher-level ICOMs into more detailed models that depict the hierarchical decomposition of activities. Figure 41 illustrates an example of a top-level IDEF0 diagram (called the *context diagram*), while Figure 42 shows an IDEF0 diagram at a lower level of detail (called the *decomposition diagram*).

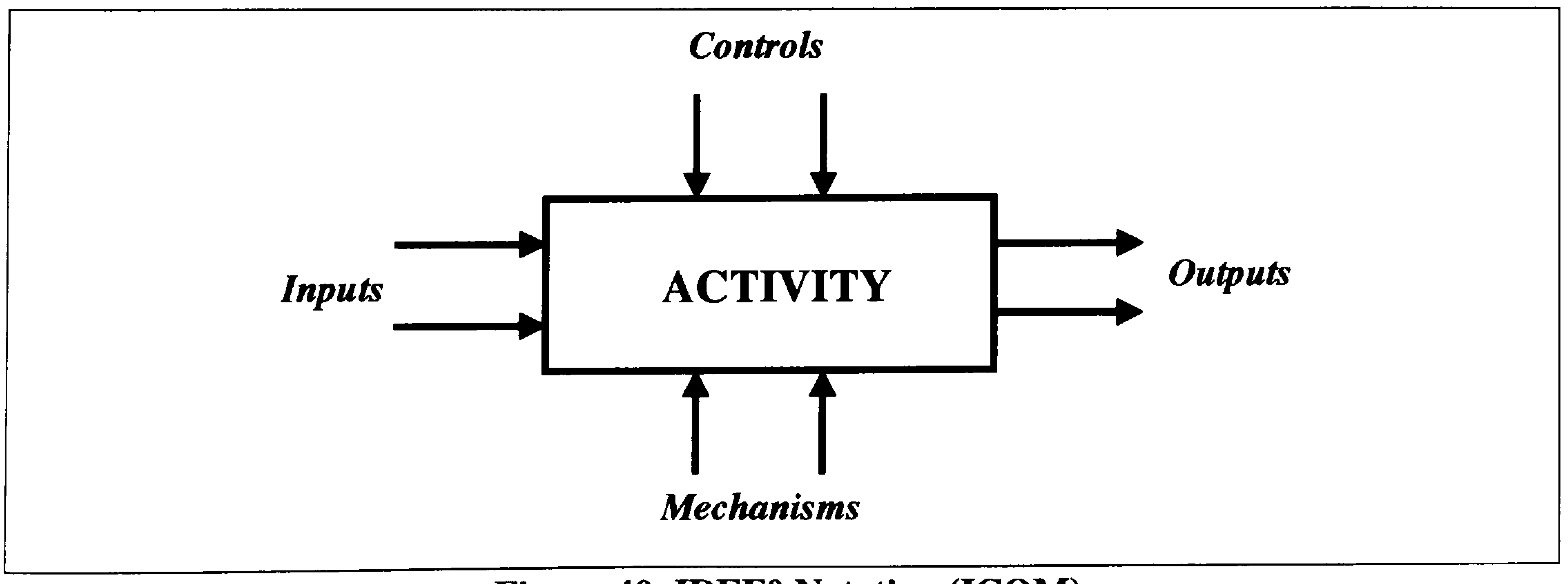


Figure 40. IDEF0 Notation (ICOM)

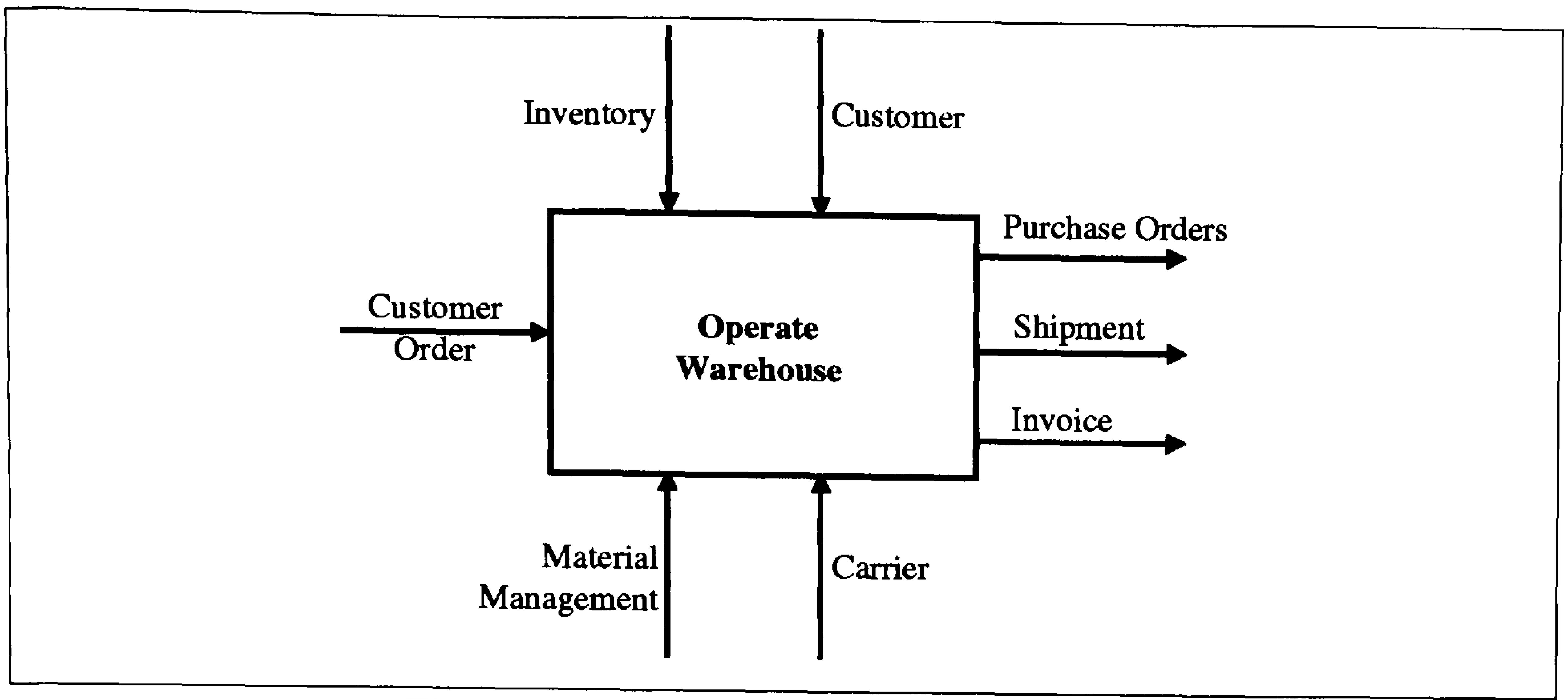


Figure 41. IDEF0 Example (Context Diagram)

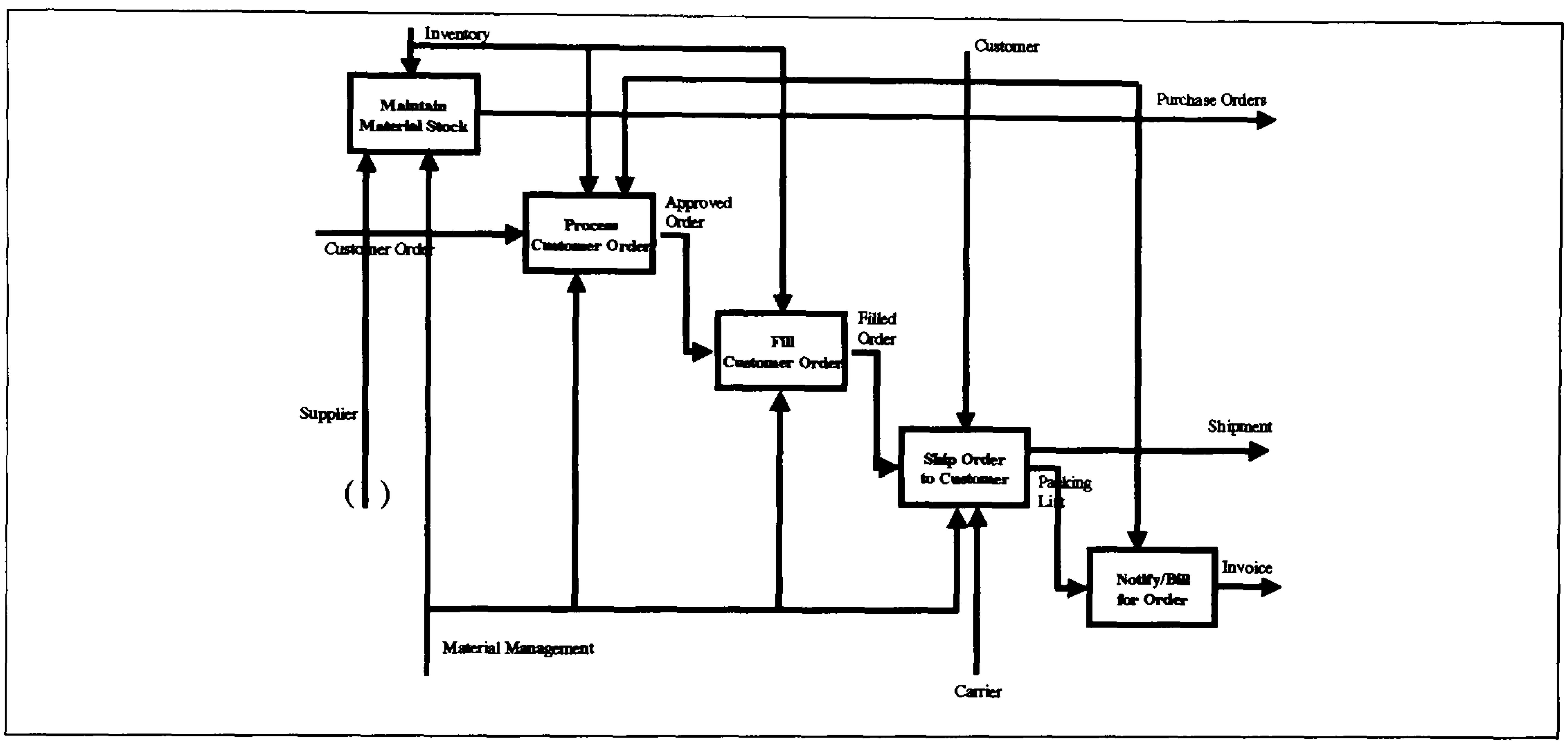


Figure 42. IDEF0 Example (Decomposition Diagram)

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* perspectives of process models.

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).

Similar to IDEF0, IDEF3 relies on only one basic construct, called the UOB (Unit of Behaviour), which is complemented by other secondary facilities. Figure 43 depicts a detailed listing of IDEF3 notational constructs.

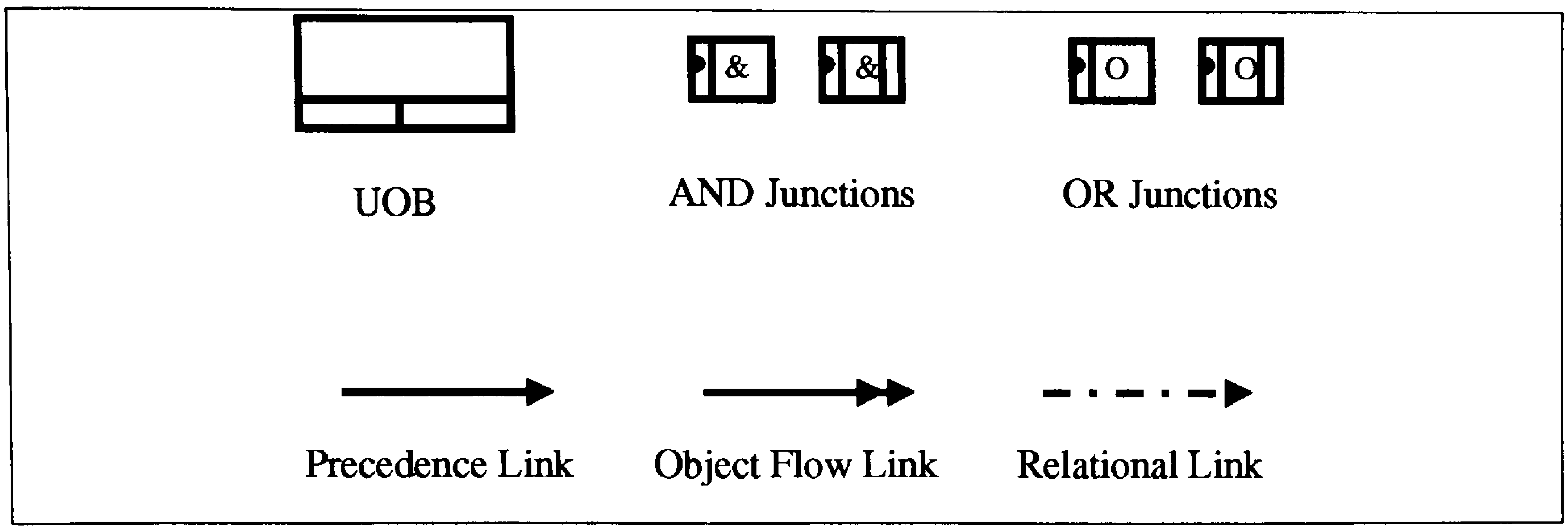


Figure 43. IDEF3 Notation

IDEF3 makes use of two complementary diagrammatic representations of process models. *Process Flow Diagrams* (Figure 44) depict the flow of activities within a process, while *Object State Transition Diagrams* (Figure 45) represent the different states of entities as they flow through the process. The temporal relations in IDEF3 diagrams provide some support for time representation in the process model, albeit not an explicit one (the models remain mainly static representations).

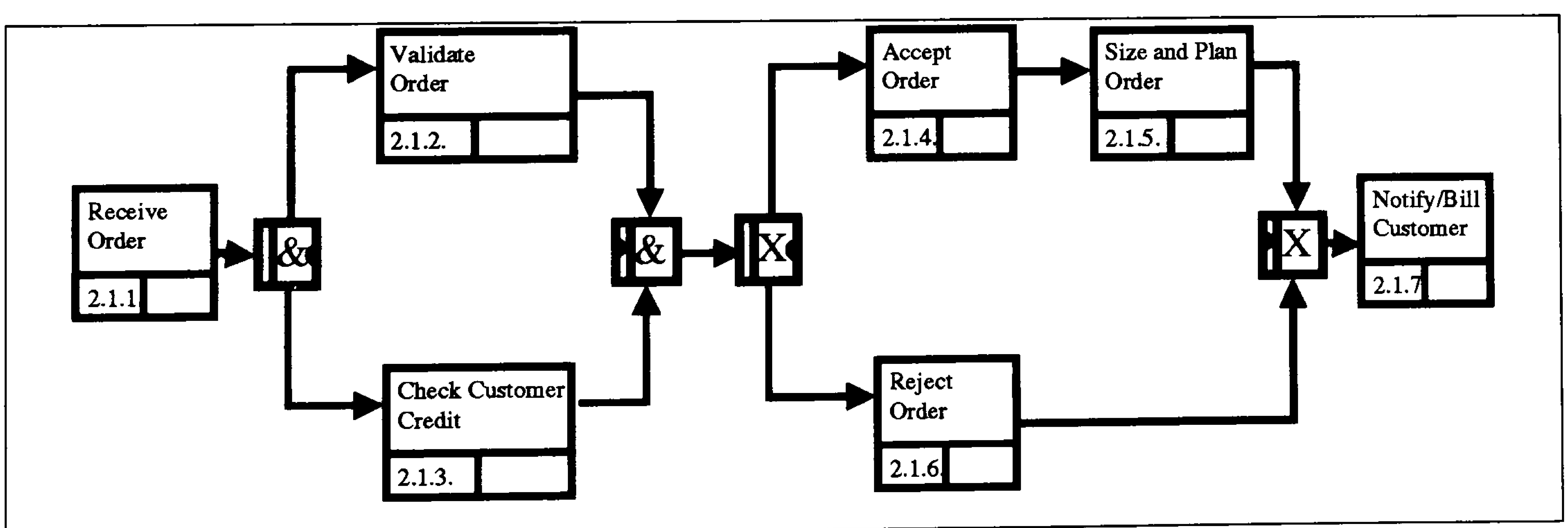


Figure 44. IDEF3 Example (Process Flow Diagram)

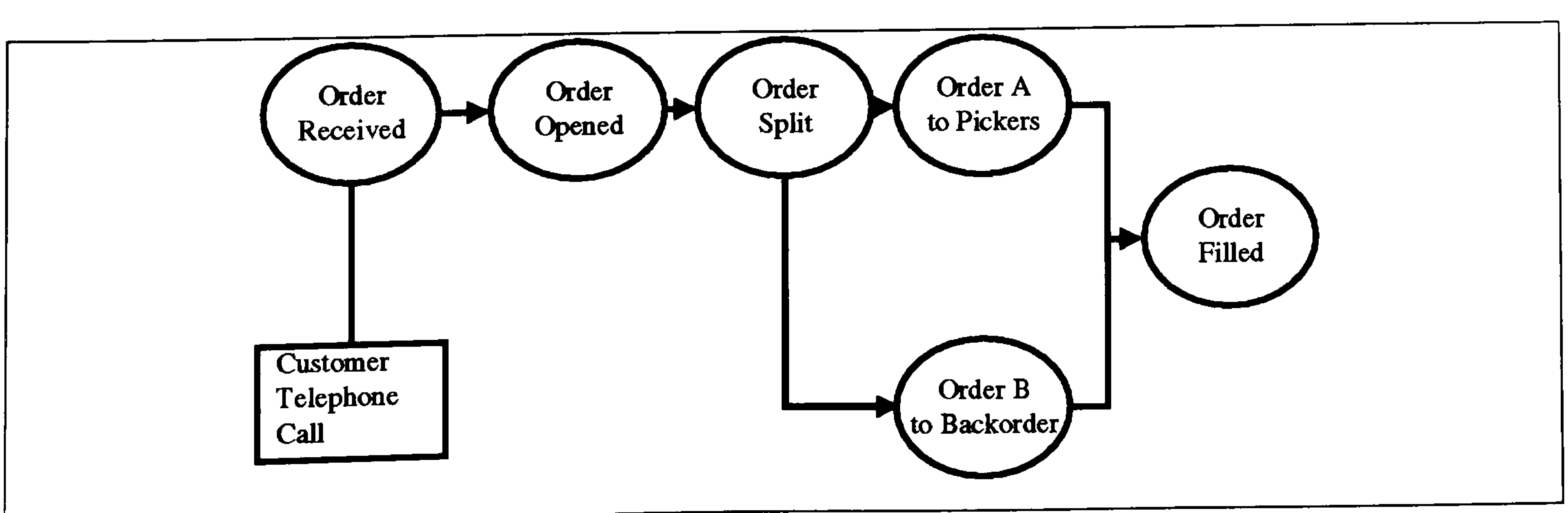


Figure 45. IDEF3 Example (Object State Transition Diagram)

Liles and Presley (1996) present an example of how different IDEF modelling techniques can be combined to provide a holistic representation of a system. Different modelling perspectives can be represented using different IDEF methods. When combined, these models can provide a comprehensive picture of the organisation. Due to the need for combining different modelling techniques within the same project, the approach may present a high degree of complexity. Furthermore, IDEF techniques are pseudo-dynamic in the sense that they provide precedence relations between model components, but no explicit time dimension (Dur and Bots 1992). As such, IDEF models cannot effectively satisfy the requirements for measurement and comparison between alternative process designs.

A.3.3. 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, Petri Nets have also received significant attention as a potential candidate for business process modelling as well (Reising et al 1992). Basic Petri Nets are mathematical/graphical representations 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 46 illustrates an example of a basic Petri Net.

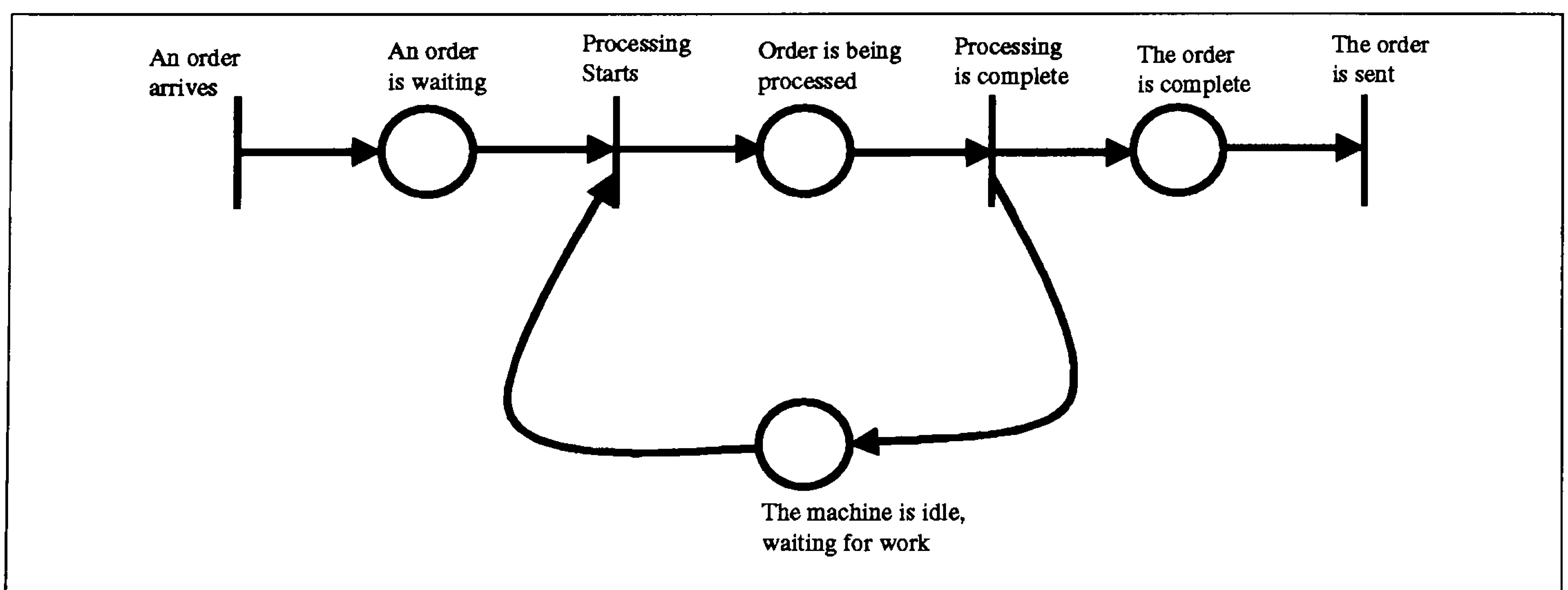


Figure 46. Petri Net Example (Peterson 1981)

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' (Aalst and Hee 1996) and include, for example, Generalised Stochastic Petri Nets (GSPN) (Marsan et al 1995), Coloured Petri Nets (CPN) (Jensen 1996), and others.

As an example of Petri Net use for integrated business and IS modelling, Tsalgatidou et al (1997) propose the use of Multilevel Modified Petri Nets (MPN) as an appropriate representational formalism for modelling and simulating organisational systems behaviour at various abstraction levels. They define a structure for MPNs, discuss their appropriateness, and demonstrate their feasibility and usefulness in a real-life case study. A prototype environment is presented that allows for the creation of decomposable business models using MPNs, which are implemented, evaluated, and simulated to facilitate experimentation and decision making in a business setting. The authors identify formality as the major disadvantage of their approach (developers and users need to be accustomed to the MPN formalism). Moreover, they point to the inappropriateness of MPNs to be used for Information Systems design and they propose that future research should be concerned with coupling MPNs with other representations, of a lower level of formalism, to allow concurrent design of business processes and Information Systems.

A.3.4. 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. System Dynamics is primarily based on ideas of feedback and control, such as encountered in electrical and mechanical control systems.

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 47 illustrates typical examples of notational conventions used in pipe diagrams, while Figure 48 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.

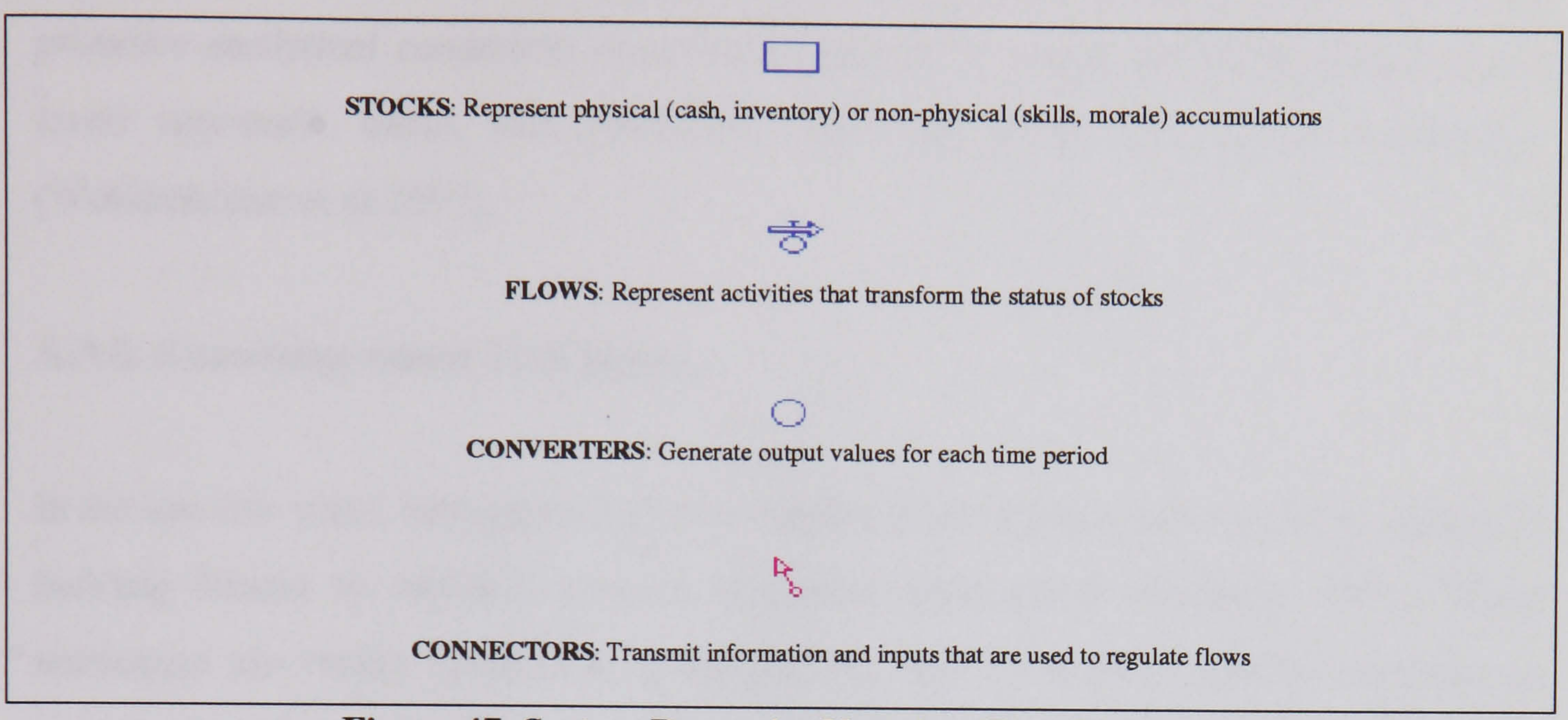


Figure 47. System Dynamics Notation (Pipe Diagram)

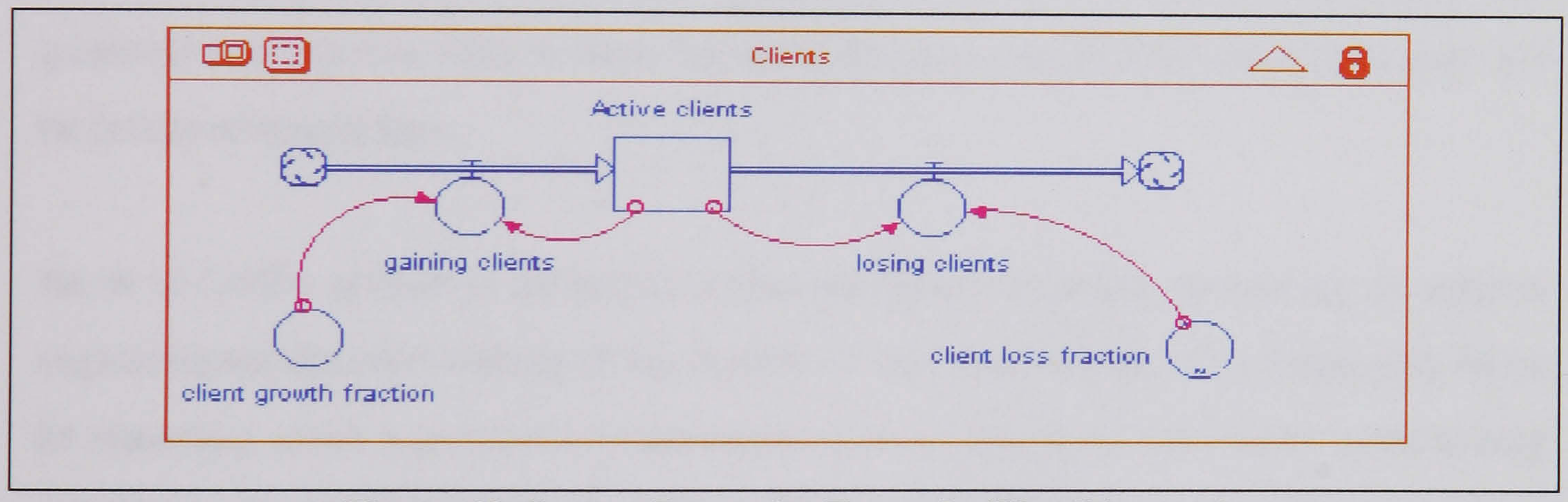


Figure 48. System Dynamics Example (Pipe Diagram)

Wolstenholme et al (1993) advocate the application of an approach based on system dynamics for the evaluation of Information Systems. The authors present the BISEM methodology for IS evaluation, as well as two case studies that were carried out based on this methodology. BISEM proposes a way of representing the structure of organisational processes in a system dynamics model in order to understand how a proposed Information System could augment organisational performance by providing better information for the execution of business activities.

The application of system dynamics advocated by the authors indeed provides a powerful way of modelling organisational processes for the explicit objective of IS evaluation. However, the application of system dynamics as a modelling technique for this purpose also presents 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 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 the authors, '*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*' (Wolstenholme et al 1993).

A.3.5. 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 briefly reviewed here.

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.

Nissen (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 fundamental technology of the common-sense reasoning branch of AI and exploits the use of knowledge to support 'intelligent' reasoning about modelled phenomena. Nissen argues that many important aspects of business processes are inherently qualitative and not well understood, and therefore they do not easily lend themselves to the level of quantification needed to develop discrete-event simulation models. 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 serious 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.

A.3.6. 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 49 illustrates the basic constructs of RAD notation, while Figure 50 presents an example of a RAD model for a simple process.

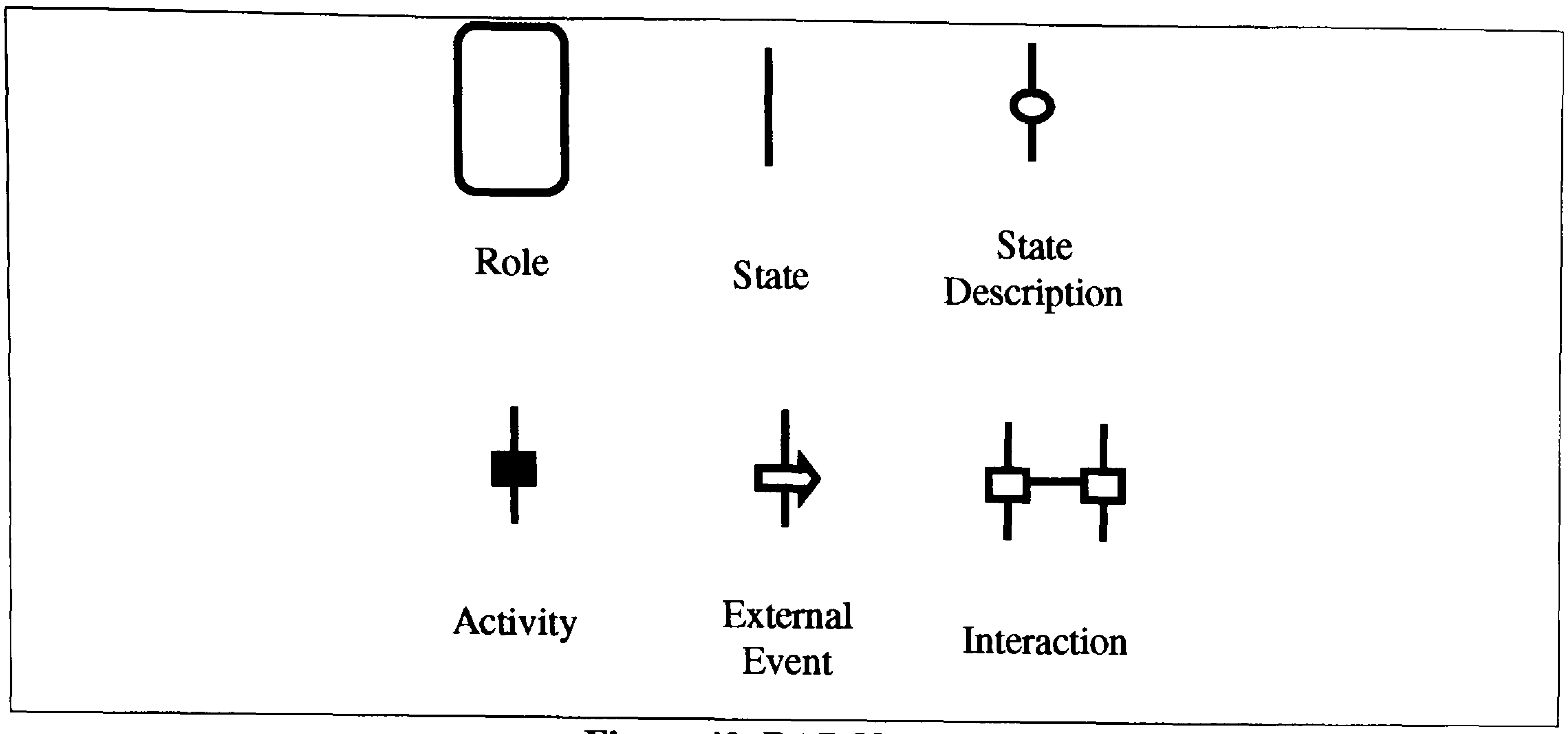


Figure 49. RAD Notation

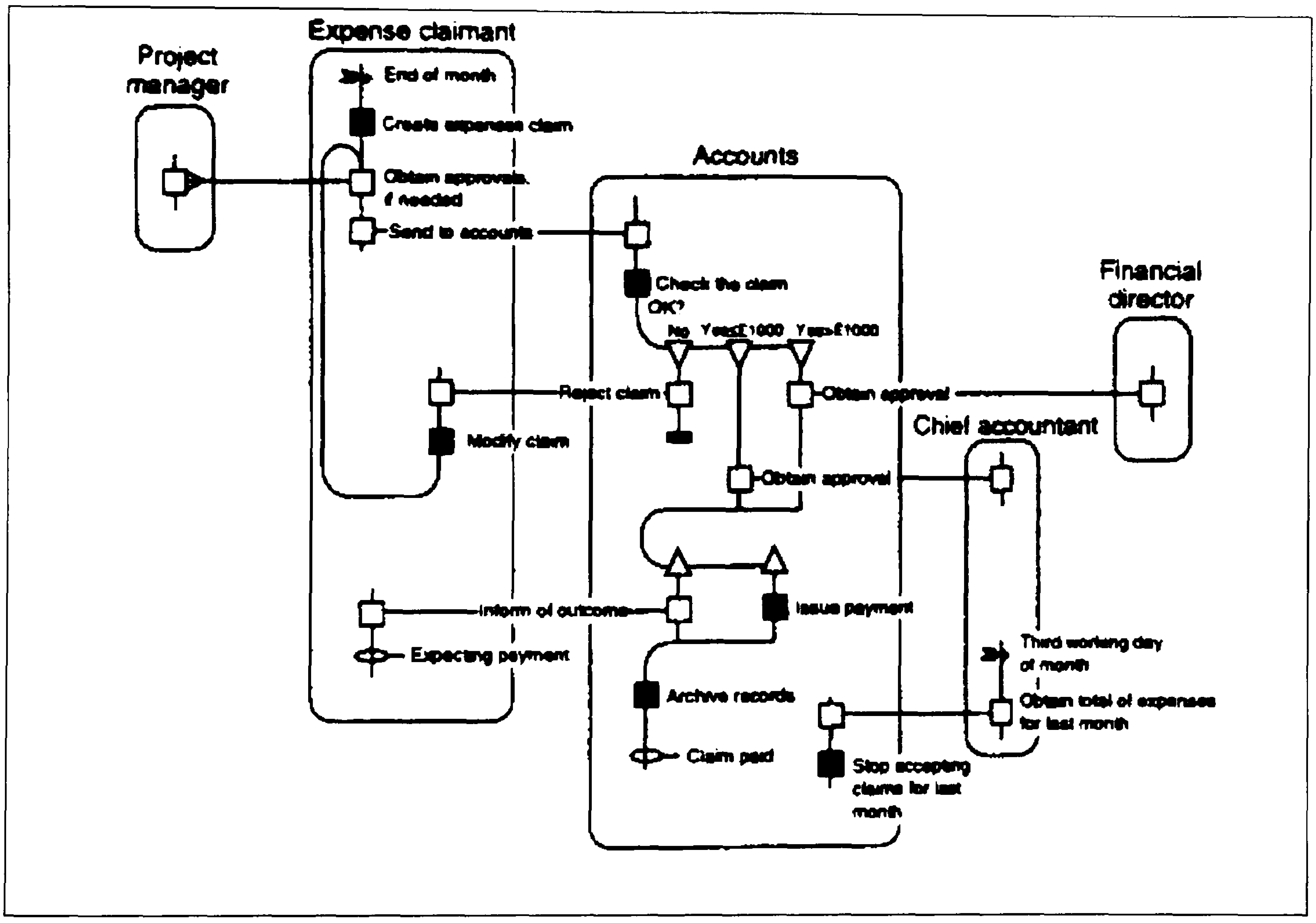


Figure 50. RAD Example (Huckvale and Ould 1995)

RADs differ from most other process diagrammatic notations in that they adopt the *role*, as opposed to the *activity*, as their primary unit of reference 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.

Ould (1995) has developed the STRIM methodology for business process modelling based on combining RADs with entity modelling diagrams and a textual language (called SPML) for business process description. STRIM is a detailed approach to modelling role interactions within processes and as such it may be effectively used in situations where RADs are an appropriate process modelling technique (i.e. in situations where human roles and interactions are the primary focus of analysis). However, according to Ould (1995), STRIM '*is designed primarily for qualitative analysis; quantitative analysis requires different and complementary methods*'.

A.4. IS Modelling Techniques

A.4.1. 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). Figure 51 illustrates the basic DFD notations.

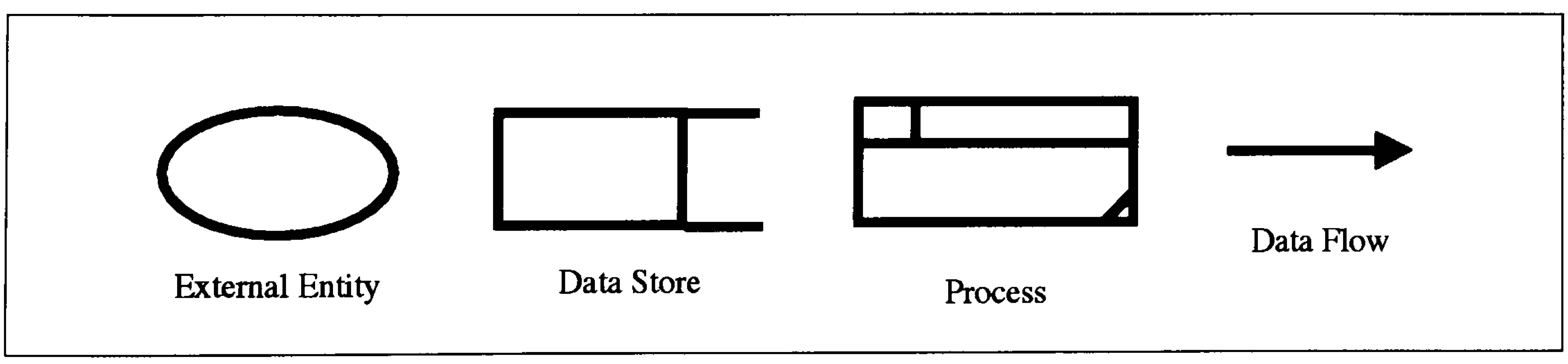


Figure 51. Data Flow Diagram Notation

DFDs allow for model decomposition (referred to as *diagram levelling*) in a fashion similar to IDEF0 models. At the top level, the *context diagram* shows only external entities, one process, and the data flows between the diagram entities. At subsequent levels, processes may be decomposed into more elementary sub-processes.

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 when applied to business process modelling. Firstly, they focus exclusively (or at least primarily) on data and they do not provide modelling constructs on which to base representation of work flows, 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).

A.4.2. 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. There are four major components of a typical ER diagram: Object types, Relationships, Associative object type indicators, and Supertype/Subtype indicators. Figure 52 illustrates the notations typically used for the first two of these components.

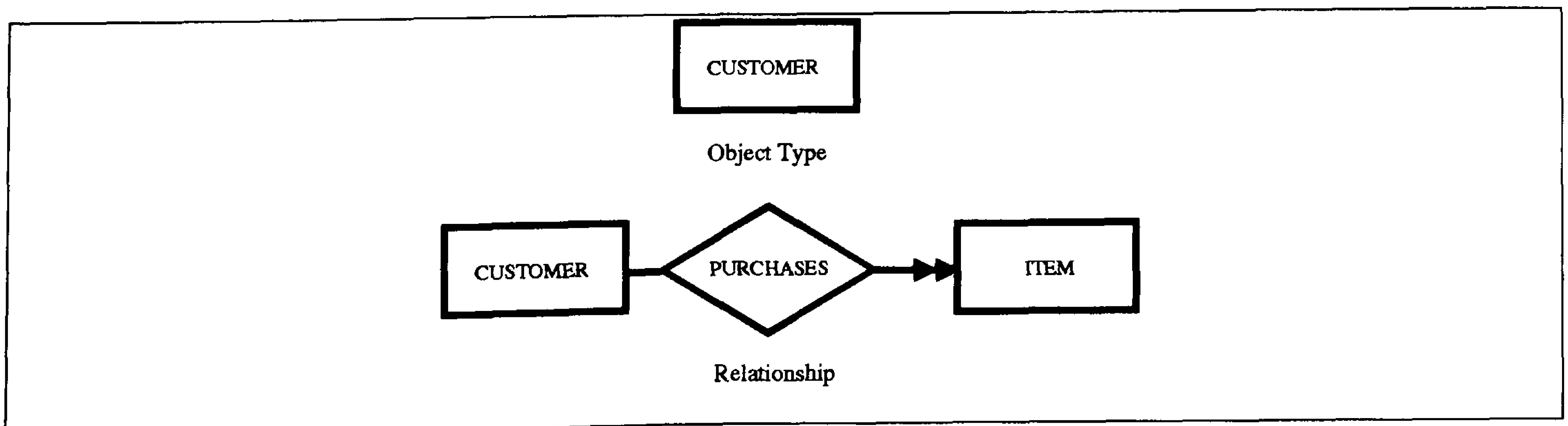


Figure 52. Entity-Relationship Diagram Notation

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 and do not provide any time-related information that could perhaps drive analysis, measurement, and decision-making.

A.4.3. 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). Figure 53 illustrates a simple ST diagram showing the behaviour of a typical telephone answering machine.

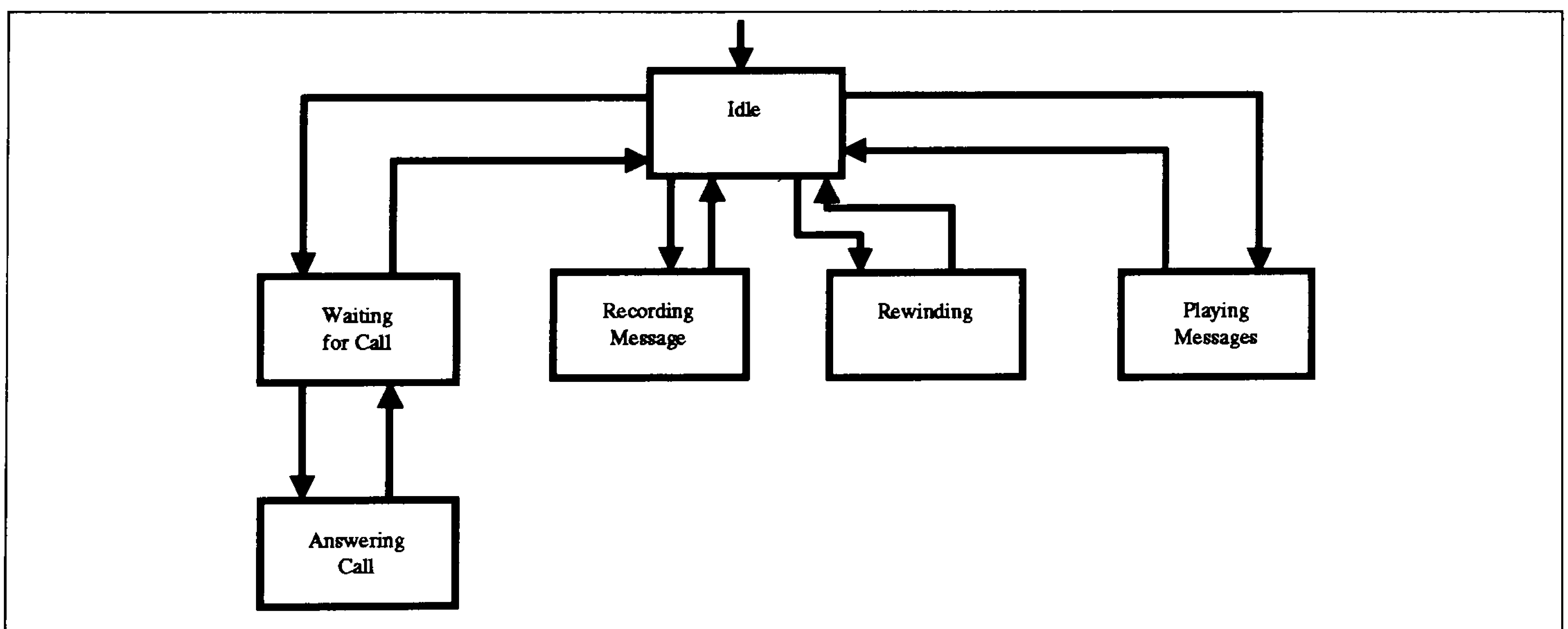


Figure 53. State-Transition Diagram Example (Yourdon 1989)

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.

A.4.4. 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 54) to express sets of rules and relationships between entity classes in a fashion similar to Entity-Relationship diagrams.

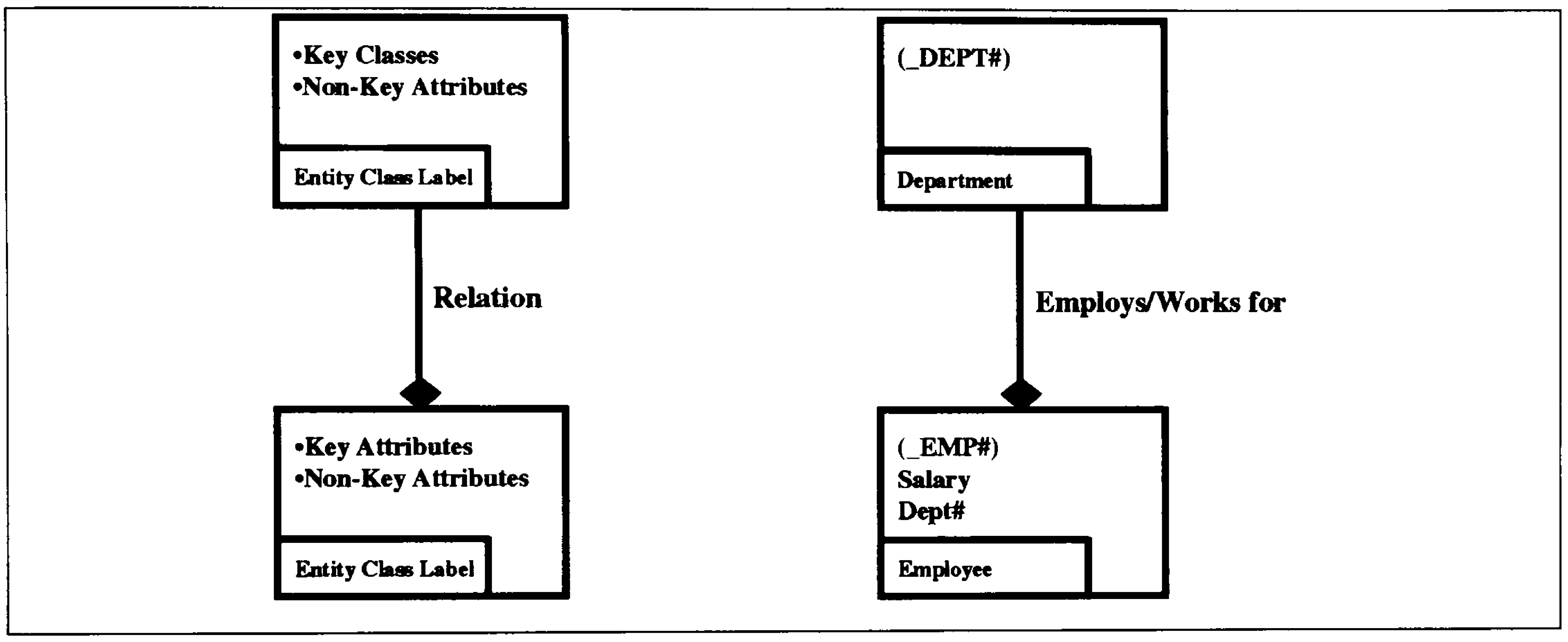


Figure 54. IDEF1x Notation and Example

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.

A.4.5. 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 55).
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).

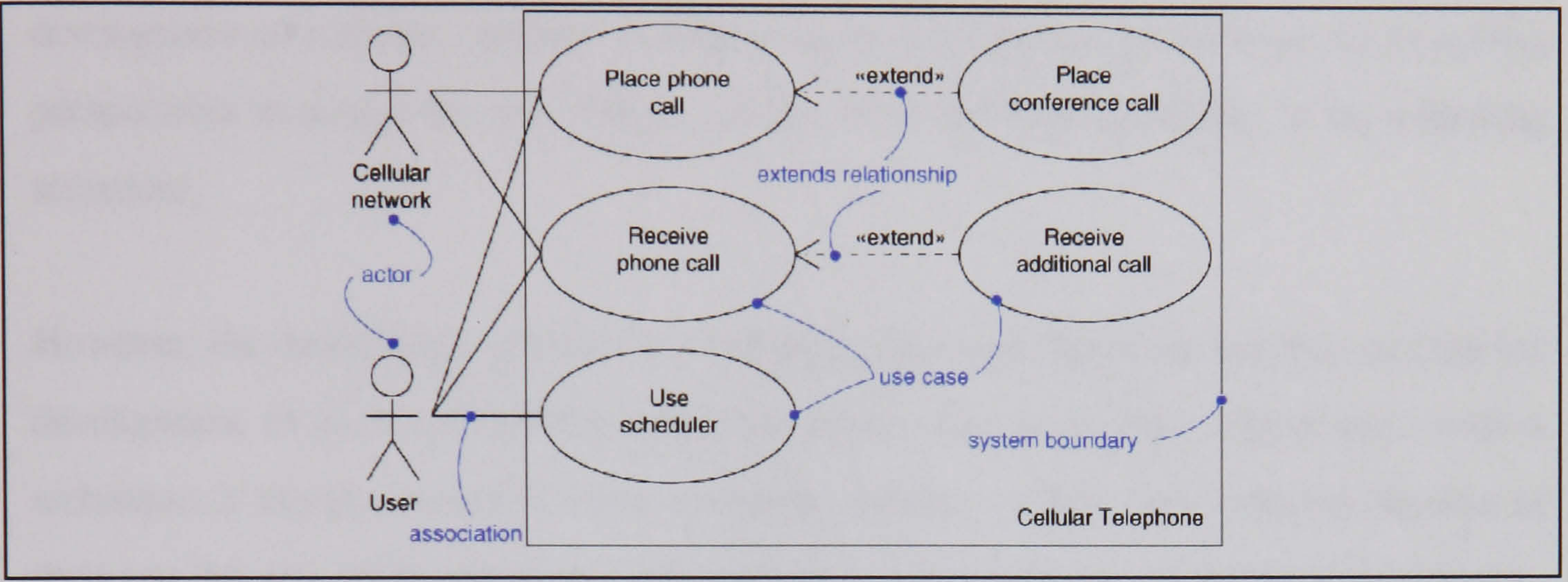


Figure 55. Use Case Diagram (Example)

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.

A.5. Discussion: Towards a Taxonomy of BPM/ISM Techniques

The above review 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 their use for any single particular application. To deal with this problem of complexity, each of the techniques presented chooses to concentrate on addressing a subset of modelling perspectives and therefore provides support for specific modelling goals and objectives. By providing constructs and concepts that allow for modelling only specific views of an organisation, a technique can maintain its appropriateness and usability for its intended use, but cannot be effectively utilised across organisational projects of a different nature and focus (Curtis et al 1992).

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 37, in order to develop a taxonomy of BPM/ISM techniques. As a starting point, Table 20 illustrates the degrees to which the techniques reviewed above (together with discrete-event simulation modelling that is dealt with in the main body of the dissertation) provide support for representing the process modelling perspectives of the evaluation framework (*Depth* of modelling).

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 20. Depth of BPM/ISM Techniques (Modelling Perspectives)

Based on the above findings, Figure 56 proposes a classification of BPM/ISM techniques in terms of the evaluation framework of Figure 37. 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 37) 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 according to Figure 56: 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.

DEPTH / BREADTH

	Understanding & Communication	Process Improvement	Process Management	Process Development	Process Execution
Informational Perspective (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 Perspective (Where, Who)	(IDEF0) (Simulation) System Dynamics RAD	(IDEF0) Simulation System Dynamics RAD	(IDEF0) Simulation System Dynamics RAD	Simulation (UML) (RAD)	-----
Behavioural Perspective (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 Perspective (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 56. A Taxonomy of BPM/ISM Techniques

Both the evaluation framework of Figure 37 and the taxonomy of Figure 56 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 earlier. Chapter 7 of the dissertation provides a more detailed discussion of this issue.

For the purposes of the research presented in this dissertation, our main aim was to comparatively evaluate modelling techniques in terms of their potential relationships to discrete-event simulation. To this end, the majority of the techniques reviewed can be considered as being related to simulation, in one or more of a number of dimensions:

a) Some techniques can be considered as *complementary* to simulation, in the sense of being able to provide insight on process and system aspects that simulation may not be able to accommodate so effectively. System dynamics, role activity diagrams, and knowledge-based techniques can be considered as falling within this category (to address feedback and control issues, human aspects, and reasoning issues respectively).

b) Other techniques can be used as *front-end* simulation tools to facilitate a more integrated approach to business and IS modelling. For example, flowcharts, Petri Nets, IDEF0/IDEF3 diagrams, and most data modelling techniques can be used as front-end tools on which to base simulation model development. Under such an approach, a model is initially developed using one of these static techniques and is then enhanced with quantitative information that adds the dynamic dimension needed for simulation model development. This approach has been followed in the case study discussed in Chapter 5 of this dissertation. Moreover, a number of researchers have used this concept to develop integrated static/dynamic models using a number of different modelling techniques. For example, Harrel and Field (1996) present an approach for integrating simulation models with IDEF-based and flowcharting tools and argue that '*the successful integration of process mapping and simulation is a major step towards a complete integration of process reengineering technologies*'. Similarly, Bruno et al (1995) and Warren et al (1996) discuss the development of simulation models based on Data Flow Diagrams, while Dalal et al (1997) discuss *ProSim*, a knowledge-based business process simulator that is based on IDEF3 process representations. Finally, Opdahl and Sindre (1996) discuss an approach for DFD-based and ER-based development of simulation model specifications.

APPENDIX B. SUPPLEMENTARY DATA FOR CASE I

This Appendix will document in more detail the process of simulation model development for the case study that is described in Chapter 3 of the main body of the dissertation. The material of the Appendix includes a discussion of the modelling assumptions made during the case study, a description of the detailed behaviour of the companies in the simulation model, an example of a manual simulation run to verify the program's correct behaviour, and a listing of the Pascal simulation code.

B.1. Modelling Assumptions

Great effort was exerted in clearly specifying the assumptions built into the model and in investigating their expected impact on the results. The basic assumptions made during model development are:

a) For simplification purposes, companies in the same stage of the value chain are homogeneous in the way they operate. For example, there is no distinction between spinners, dyers, and weavers in the top level of the chain, but all materials suppliers are hypothesised to be homogeneous. Furthermore, all companies in the model are assumed to use the same method for estimating the optimal level of inventory for a future period, based on the Economic Order Quantity (EOQ) model with backordering and uncertain demand (Winston 1987). This model is described in the following section. Given the objectives of the study, it was deemed unnecessary (and perhaps even impossible in practice) to develop a detailed model depicting the individual operating policies of all companies in the industry. This would have required collecting data from every company that operates in the sector, without adding a commensurate degree of usefulness to the results.

b) It was assumed that only one type of product is traded in the value chain. In other words, retailers sell only one piece of clothing, which is produced by the manufacturers. One unit of final product requires one unit of raw material to be produced. Similarly, there is only one type of raw material supplied by the materials suppliers. This assumption was also made for simplification purposes. Including the numerous different products and materials usually traded between companies would dramatically increase the complexity of the model without significantly affecting the usefulness of the results since the objective is to study inventories in general rather than the movement of individual product lines. Furthermore, incorporating individual products would require additional data (for example, historical sales data for each product) that were not available.

c) Each retailer purchases products from all available manufacturers at proportions commensurate to their market shares. Similarly, the distribution of the total order quantity from a manufacturer to the various materials suppliers is again based on their relative market shares.

d) Retailers have equal market shares (fully competitive industry structure), while the simulated market shares of manufacturers and materials suppliers follow the distribution of actual market shares in the sector at the time of the case study. The assumption regarding retailers is consistent with the large number and small size of retailers in the actual market. Furthermore, it is also consistent with the aforementioned assumption regarding a unique product being traded (since different market shares of retailers in practice are usually a function of the penetration of different product lines in the market).

e) Two basic assumptions are made regarding the production process of clothing manufacturers and textile companies. First, the flow of products is not constant, but all units comprising a production bunch become available simultaneously when their production is completed. Second, there is no maximum production capacity, therefore companies are assumed to always be able to schedule production for the orders they receive.

B.2. The Simulation Sub-Models

B.2.1. Retail companies

Sales

Each retail company faces a daily customer demand, which is satisfied in full or in part, according to the retailer's current level of product inventory.

Demand Forecasting

Retailers forecast future customer demand based on historical sales data from previous seasons. Based on their forecasts, they formulate order plans, which they submit to their suppliers at the start of each season to assist them with their own production and material requirements planning. EDI-enabled retailers re-estimate expected customer demand at regular intervals during the season using a forecasting algorithm that relates realised sales for the current season to historical data. These companies resubmit revised order plans to their suppliers each time they re-estimate customer demand.

Inventory Management (Products)

Retail companies estimate the optimal level of product inventory based on the total expected customer demand. The calculation of the optimal inventory levels is based on the Economic Order Quantity (EOQ) model with backordering and uncertain demand (Winston 1987), as follows:

$$q^* = \sqrt{\frac{2KE(D)}{h}} \quad \text{and} \quad P(X \geq r^*) = \frac{hq^*}{sE(D)}$$

where:

q^*:	Economic Order Quantity.
r^*:	Reorder Point (safety inventory level).
D:	Random variable representing annual demand.
$E(D)$:	Mean of the above variable.
K:	Ordering cost (independent of order size).
h:	Inventory holding cost (per unit per year).
s:	Stock-out cost (per unit short).
X:	Random variable representing lead-time demand.
$P(X \geq r^*)$:	Probability that demand is greater than reorder point during lead-time.

As mentioned above, every time that a retailer estimates the optimal inventory levels, they also calculate the expected order placing times and submit a plan containing all expected future order dates and quantities to the manufacturers to assist them in scheduling their own product inventories, production plans, and materials inventories. Of course, the actual times and the respective quantities of the realised orders are not eventually the same as those contained in the plan due to fluctuations in the actual (stochastic) demand.

B.2.2. Manufacturing companies

Inventory Management (Products)

Based on the order plans received by the retail companies, each manufacturing company schedules its optimal inventory levels using the same inventory management method outlined above.

Production Planning

Production scheduling is based on inventory planning. Each manufacturer schedules their production so that production of a quantity that needs to be in inventory a given day must be finished by the beginning of the day it is due (or at the end of the previous day). When servicing actual orders, if product inventory is not enough to satisfy the whole demand, the remaining orders are placed into backorders. Amongst backorders, priority is given to older orders and, among orders of the same day, to bigger ones.

Materials Requirements Planning

The master production plan serves as the basic input for scheduling the materials inventory. To the needed material quantities, the manufacturer adds the safety inventory level for raw materials, which is calculated using the same equations as above.

Inventory Management (Materials)

Using the same procedure, order plans for materials are formed and sent to the materials suppliers. Every time inventory levels fall below the safety point, actual orders are also distributed to materials suppliers according to their relative market shares. EDI-enabled clothing manufacturers re-estimate their materials requirements and submit revised order plans to textile companies in the same way as they have received order plans from retailers.

B.2.3. Materials suppliers

Materials suppliers operate similarly to manufacturers. The only difference is that the model does not simulate the material inventory for these companies (i.e. the way materials suppliers may communicate with their own suppliers).

B.3. Manual Simulation

Table 21, Table 22, Table 23, and Table 24 show the results of a manual simulation exercise used to verify the correctness of the model. For the purposes of this manual experiment, the following modifications were made to the final program code:

a) All stochastic data were substituted with constants so that the behaviour of the model could be manually predicted and compared to the program results.
b) Only one company operates per sector in the industry value chain.

For the purposes of the manual simulation, 'checkpoints' were introduced in the program code where test files were generated to compare the program results with those predicted by the manual simulation runs. These checkpoints are shown in the program listing that follows in the next section. Regarding the Tables that follow, 'Code Segment' refers to the procedure tested (*IniCompanies* or *Current Measurements* – see program listing) and the specific part of the procedure as indicated in the program listing. Data taken from input files are shown in *italics* in the following Tables. The Tables show the results obtained from the first run of all procedures (i.e. depict the model state at the end of day 1) in the AS-IS scenario.

Overall, the manual simulation proved to be a very efficient means of exposing minor errors in the computer program that were otherwise likely to be overlooked. Based on these findings, a number of corrections were made to the model and the manual simulation was re-run. The manual simulation results shown in the following pages relate to the final simulation code. Additional manual simulations were also run for important and complex program segments, as well as for testing the modifications made during the TO-BE model development.

	CODE SEGMENT	Name	Sector	Custo-mers	Supp-liers	Market Share	EOQ		Reorder Points		Inventories		Expected Demand
							Prodct	materl	prodct	materl	prodct	materl	
R	**IniCompanies-A**	1	Retail	nil	Nil	100.0	0	0	0	0	0	0	0
E	**IniCompanies-D**				Clothin								
T	**Retail-A**						1200		104		1304		96000
A	**Retail-B**										1241		
I													
L													
C	**IniCompanies-B**	1	Clothin	Retail	Nil	*100.0*	0	0	0	0	0	0	0
L	**IniCompanies-D**				Textile								
O	**Clothing-D**						1169		52		1221		
T	**Clothing-E**							3170		56		3226	
H													
I													
N													
T	**IniCompanies-C**	1	Textile	Clothin	nil	*100.0*	0	0	0	0	0	0	0
E	**Textile-D**						1132		17		1149		
X													
T													
I													
L													
E													

Table 21. Manual Simulation Data (page 1/3)

	CODE	Outstanding Orders			Dem	Booleans		Deli-	Production		Sales		Pending	SeasonEst	
	SEGMENT	TotalQ	Head	Trail	EstTim	HasEDI	Pending	veries	Season	Rate	Season	Lost	OrdQ	[1]	[2]
R	**IniCompanies-A**	0	nil	nil	60	False	False	0	0	0	0	0	0		
E	**Retail-A**													*96000*	*1*
T	**Retail-B**										63				
A															
I															
L															
C	**IniCompanies-B**	0	nil	nil	60	False	False	0	0	*0.005*	0	0	0	0	0
L	**Clothing-A**								0		0	0			
O															
T															
H															
I															
N															
T	**IniCompanies-C**	0	nil	nil	0	False	False	0	0	*0.0003*	0	0	0	0	0
E	**Textile-A**								0		0	0			
X															
T															
I															
L															
E															

Table 22. Manual Simulation Data (page 2/3)

	CODE SEGMENT	MRP TABLE				TEST FILES
		Orders [1..360]	Total Demand [1..360]	Total Materials Needs [1..360]	Production Plan [1..360]	
R	IniCompanies-A	All=0	All=0	All=0	All=nil	
E						
T						
A						
I						
L						
C	IniCompanies-B	All=0	All=0	All=0	All=nil	
L	Retail-A	All=0				
O	Retail-A	[6]=1200, [11]5[351]=1304				
T	Clothing-D		[11]=1335,[16]5[351]=1356, rest=52		All=nil	
H	Clothing-D	All=0	All=0		See TESTLOG (Table 24)	TESTLOG
I	Clothing-E			See TESTLOG2 (Table 24)		TESTLOG2
N						
T	IniCompanies-C	All=0	All=0	All=0	All=nil	
E	Clothing-C	All=0				
X	Clothing-C	[6]=1169,[11]=1221, [16]5[351]=1304				
T	Textile-D		See TESTLOG4 (Table 24)		All=nil	TESTLOG4
I	Textile-D	All=0	All=0		See TESTLOG5 (Table 24)	TESTLOG5
L						
E						

Table 23. Manual Simulation Data (page 3/3)

Time	TESTLOG ProdPlan			TESTLOG2 MatNeed	TESTLOG4 TotalDemand	TESTLOG5 ProdPlan		
1	Nil			56	17	Nil		
2	52	52	52	56	17	17	17	17
3	52			56	17	17		
4	1335	52		56	17	17		
5	1335	52		56	17	37		
6	1335	52		1199	37	17		
7	1335	52		1443	17	17		
8	1335	52		1443	17	17		
9	1356	1335	52	2799	17	17		
10	1356	1335		2747	17	1238		
11	1356	52		1464	1238	17		
12	1356	52		1464	17	17		
13	1356	52		1464	17	17		
14	1356	1356	52	2820	17	17		
15	1356	1356		2768	17	1238		
16	1356	52		1464	1238	17		
17	1356	52		1464	17	17		
18	1356	52		1464	17	17		
19	1356	1356	52	2820	17	17		
20	1356	1356		2768	17	1238		
21	1356	52		1464	1238	17		
22	1356	52		1464	17	17		
23	1356	52		1464	17	17		
24	1356	1356	52	2820	17	17		
25	1356	1356		2768	17	1238		
26	1356	52		1464	1238	17		
27	1356	52		1464	17	17		
28	1356	52		1464	17	17		
29	1356	1356	52	2820	17	17		
30	1356	1356		2768	17	1238		
31	1356	52		1464	1238	17		
32	1356	52		1464	17	17		
33	1356	52		1464	17	17		
34	1356	1356	52	2820	17	17		
35	1356	1356		2768	17	1238		
36	1356	52		1464	1238	17		
37	1356	52		1464	17	17		
38	1356	52		1464	17	17		
39	1356	1356	52	2820	17	17		
40	1356	1356		2768	17	1238		
41	1356	52		1464	1238	17		
42	1356	52		1464	17	17		
43	1356	52		1464	17	17		
44	1356	1356	52	2820	17	17		
45	1356	1356		2768	17	1238		
46	1356	52		1464	1238	17		
47	1356	52		1464	17	17		
48	1356	52		1464	17	17		
49	1356	1356	52	2820	17	17		
50	1356	1356		2768	17	1238		
51	1356	52		1464	1238	17		
52	1356	52		1464	17	17		
53	1356	52		1464	17	17		
54	1356	1356	52	2820	17	17		
55	1356	1356		2768	17	1238		
56	1356	52		1464	1238	17		
57	1356	52		1464	17	17		
58	1356	52		1464	17	17		
59	1356	1356	52	2820	17	17		
60	1356	1356		2768	17	1238		
61	1356	52		1464	1238	17		
62	1356	52		1464	17	17		
63	1356	52		1464	17	17		
64	1356	1356	52	2820	17	17		
65	1356	1356		2768	17	1238		
66	1356	52		1464	1238	17		
67	1356	52		1464	17	17		
68	1356	52		1464	17	17		
69	1356	1356	52	2820	17	17		
70	1356	1356		2768	17	1238		
71	1356	52		1464	1238	17		
72	1356	52		1464	17	17		
73	1356	52		1464	17	17		
74	1356	1356	52	2820	17	17		
75	1356	1356		2768	17	1238		
76	1356	52		1464	1238	17		
77	1356	52		1464	17	17		
78	1356	52		1464	17	17		
79	1356	1356	52	2820	17	17		
80	1356	1356		2768	17	1238		
81	1356	52		1464	1238	17		
82	1356	52		1464	17	17		
83	1356	52		1464	17	17		
84	1356	1356	52	2820	17	17		
85	1356	1356		2768	17	1238		
86	1356	52		1464	1238	17		
87	1356	52		1464	17	17		
88	1356	52		1464	17	17		
89	1356	1356	52	2820	17	17		
90	1356	1356		2768	17	1238		
91	1356	52		1464	1238	17		
92	1356	52		1464	17	17		
93	1356	52		1464	17	17		
94	1356	1356	52	2820	17	17		
95	1356	1356		2768	17	1238		
96	1356	52		1464	1238	17		
97	1356	52		1464	17	17		
98	1356	52		1464	17	17		
99	1356	1356	52	2820	17	17		
100	1356	1356		2768	17	1238		
101	1356	52		1464	1238	17		
102	1356	52		1464	17	17		
103	1356	52		1464	17	17		
104	1356	1356	52	2820	17	17		
105	1356	1356		2768	17	1238		
106	1356	52		1464	1238	17		
107	1356	52		1464	17	17		
108	1356	52		1464	17	17		
109	1356	1356	52	2820	17	17		
110	1356	1356		2768	17	1238		
111	1356	52		1464	1238	17		
112	1356	52		1464	17	17		
113	1356	52		1464	17	17		
114	1356	1356	52	2820	17	17		
115	1356	1356		2768	17	1238		
116	1356	52		1464	1238	17		
117	1356	52		1464	17	17		
118	1356	52		1464	17	17		
119	1356	1356	52	2820	17	17		
120	1356	1356		2768	17	1238		
121	1356	52		1464	1238	17		
122	1356	52		1464	17	17		
123	1356	52		1464	17	17		
124	1356	1356	52	2820	17	17		
125	1356	1356		2768	17	1238		
126	1356	52		1464	1238	17		
127	1356	52		1464	17	17		
128	1356	52		1464	17	17		
129	1356	1356	52	2820	17	17		
130	1356	1356		2768	17	1238		
131	1356	52		1464	1238	17		
132	1356	52		1464	17	17		
133	1356	52		1464	17	17		
134	1356	1356	52	2820	17	17		
135	1356	1356		2768	17	1238		
136	1356	52		1464	1238	17		
137	1356	52		1464	17	17		
138	1356	52		1464	17	17		
139	1356	1356	52	2820	17	17		
140	1356	1356		2768	17	1238		
141	1356	52		1464	1238	17		
142	1356	52		1464	17	17		
143	1356	52		1464	17	17		
144	1356	1356	52	2820	17	17		
145	1356	1356		2768	17	1238		
146	1356	52		1464	1238	17		
147	1356	52		1464	17	17		
148	1356	52		1464	17	17		
149	1356	1356	52	2820	17	17		
150	1356	1356		2768	17	1238		
151	1356	52		1464	1238	17		
152	1356	52		1464	17	17		
153	1356	52		1464	17	17		
154	1356	1356	52	2820	17	17		
155	1356	1356		2768	17	1238		
156	1356	52		1464	1238	17		
157	1356	52		1464	17	17		
158	1356	52		1464	17	17		
159	1356	1356	52	2820	17	17		
160	1356	1356		2768	17	1238		
161	1356	52		1464	1238	17		
162	1356	52		1464	17	17		
163	1356	52		1464	17	17		
164	1356	1356	52	2820	17	17		
165	1356	1356		2768	17	1238		
166	1356	52		1464	1238	17		
167	1356	52		1464	17	17		
168	1356	52		1464	17	17		
169	1356	1356	52	2820	17	17		
170	1356	1356		2768	17	1238		
171	1356	52		1464	1238	17		
172	1356	52		1464	17	17		
173	1356	52		1464	17	17		
174	1356	1356	52	2820	17	17		
175	1356	1356		2768	17	1238		
176	1356	52		1464	1238	17		
177	1356	52		1464	17	17		
178	1356	52		1464	17	17		
179	1356	1356	52	2820	17	17		
180	1356	1356		2768	17	1238		
181	1356	52		1464	1238	17		
182	1356	52		1464	17	17		
183	1356	52		1464	17	17		
184	1356	1356	52	2820	17	17		
185	1356	1356		2768	17	1238		
186	1356	52		1464	1238	17		
187	1356	52		1464	17	17		
188	1356	52		1464	17	17		
189	1356	1356	52	2820	17	17		
190	1356	1356		2768	17	1238		
191	1356	52		1464	1238	17		
192	1356	52		1464	17	17		
193	1356	52		1464	17	17		
194	1356	1356	52	2820	17	17		
195	1356	1356		2768	17	1238		
196	1356	52		1464	1238	17		
197	1356	52		1464	17	17		
198	1356	52		1464	17	17		

199	1356	1356	52	2820	17	17
200	1356	1356		2768	17	1238
201	1356	52		1464	1238	17
202	1356	52		1464	17	17
203	1356	52		1464	17	17
204	1356	1356	52	2820	17	17
205	1356	1356		2768	17	1238
206	1356	52		1464	1238	17
207	1356	52		1464	17	17
208	1356	52		1464	17	17
209	1356	1356	52	2820	17	17
210	1356	1356		2768	17	1238
211	1356	52		1464	1238	17
212	1356	52		1464	17	17
213	1356	52		1464	17	17
214	1356	1356	52	2820	17	17
215	1356	1356		2768	17	1238
216	1356	52		1464	1238	17
217	1356	52		1464	17	17
218	1356	52		1464	17	17
219	1356	1356	52	2820	17	17
220	1356	1356		2768	17	1238
221	1356	52		1464	1238	17
222	1356	52		1464	17	17
223	1356	52		1464	17	17
224	1356	1356	52	2820	17	17
225	1356	1356		2768	17	1238
226	1356	52		1464	1238	17
227	1356	52		1464	17	17
228	1356	52		1464	17	17
229	1356	1356	52	2820	17	17
230	1356	1356		2768	17	1238
231	1356	52		1464	1238	17
232	1356	52		1464	17	17
233	1356	52		1464	17	17
234	1356	1356	52	2820	17	17
235	1356	1356		2768	17	1238
236	1356	52		1464	1238	17
237	1356	52		1464	17	17
238	1356	52		1464	17	17
239	1356	1356	52	2820	17	17
240	1356	1356		2768	17	1238
241	1356	52		1464	1238	17
242	1356	52		1464	17	17
243	1356	52		1464	17	17
244	1356	1356	52	2820	17	17
245	1356	1356		2768	17	1238
246	1356	52		1464	1238	17
247	1356	52		1464	17	17
248	1356	52		1464	17	17
249	1356	1356	52	2820	17	17
250	1356	1356		2768	17	1238
251	1356	52		1464	1238	17
252	1356	52		1464	17	17
253	1356	52		1464	17	17
254	1356	1356	52	2820	17	17
255	1356	1356		2768	17	1238
256	1356	52		1464	1238	17
257	1356	52		1464	17	17
258	1356	52		1464	17	17
259	1356	1356	52	2820	17	17
260	1356	1356		2768	17	1238
261	1356	52		1464	1238	17
262	1356	52		1464	17	17
263	1356	52		1464	17	17
264	1356	1356	52	2820	17	17
265	1356	1356		2768	17	1238
266	1356	52		1464	1238	17
267	1356	52		1464	17	17
268	1356	52		1464	17	17
269	1356	1356	52	2820	17	17
270	1356	1356		2768	17	1238
271	1356	52		1464	1238	17
272	1356	52		1464	17	17
273	1356	52		1464	17	17
274	1356	1356	52	2820	17	17
275	1356	1356		2768	17	1238
276	1356	52		1464	1238	17
277	1356	52		1464	17	17
278	1356	52		1464	17	17
279	1356	1356	52	2820	17	17
280	1356	1356		2768	17	1238
281	1356	52		1464	1238	17
282	1356	52		1464	17	17
283	1356	52		1464	17	17
284	1356	1356	52	2820	17	17
285	1356	1356		2768	17	1238
286	1356	52		1464	1238	17
287	1356	52		1464	17	17
288	1356	52		1464	17	17
289	1356	1356	52	2820	17	17
290	1356	1356		2768	17	1238
291	1356	52		1464	1238	17
292	1356	52		1464	17	17
293	1356	52		1464	17	17
294	1356	1356	52	2820	17	17
295	1356	1356		2768	17	1238
296	1356	52		1464	1238	17
297	1356	52		1464	17	17
298	1356	52		1464	17	17
299	1356	1356	52	2820	17	17
300	1356	1356		2768	17	1238
301	1356	52		1464	1238	17
302	1356	52		1464	17	17
303	1356	52		1464	17	17
304	1356	1356	52	2820	17	17
305	1356	1356		2768	17	1238
306	1356	52		1464	1238	17
307	1356	52		1464	17	17
308	1356	52		1464	17	17
309	1356	1356	52	2820	17	17
310	1356	1356		2768	17	1238
311	1356	52		1464	1238	17
312	1356	52		1464	17	17
313	1356	52		1464	17	17
314	1356	1356	52	2820	17	17
315	1356	1356		2768	17	1238
316	1356	52		1464	1238	17
317	1356	52		1464	17	17
318	1356	52		1464	17	17
319	1356	1356	52	2820	17	17
320	1356	1356		2768	17	1238
321	1356	52		1464	1238	17
322	1356	52		1464	17	17
323	1356	52		1464	17	17
324	1356	1356	52	2820	17	17
325	1356	1356		2768	17	1238
326	1356	52		1464	1238	17
327	1356	52		1464	17	17
328	1356	52		1464	17	17
329	1356	1356	52	2820	17	17
330	1356	1356		2768	17	1238
331	1356	52		1464	1238	17
332	1356	52		1464	17	17
333	1356	52		1464	17	17
334	1356	1356	52	2820	17	17
335	1356	1356		2768	17	1238
336	1356	52		1464	1238	17
337	1356	52		1464	17	17
338	1356	52		1464	17	17
339	1356	1356	52	2820	17	17
340	1356	1356		2768	17	1238
341	1356	52		1464	1238	17
342	1356	52		1464	17	17
343	1356	52		1464	17	17
344	1356	1356	52	2820	17	17
345	1356	1356		2768	17	1238
346	1356	52		1464	1238	17
347	1356	52		1464	17	17
348	1356	52		1464	17	17
349	1356	52		1464	17	17
350	1356			1412	17	1238
351	52			108	1238	17
352	52			108	17	17
353	52			108	17	17
354	52			108	17	17
355	52			108	17	17
356	52			108	17	17
357	52			108	17	17
358	52			108	17	17
359	52			108	17	17
360	Nil			56	17	Nil

Table 24. Manual Simulation Test Files

B.4. Simulation Code

```
program EDITEX;

{-Simulation of EDI adoption in the textile/clothing industry in Greece.
 -The model simulates a number of companies operating at three levels of the
  industry value chain: textile companies, clothing companies, and retail companies.
 -Data about demand levels and daily product and materials inventories are recorded
  for all companies
 -This is the model of the AS-IS scenario: no company uses EDI
 -For the TO-BE scenario, only the REDI,CEDI,TEDI constants need to be modified
  to be equal to the NoORetail,NoOfClothing,NoOfTextile constants respectively
}


{=================================CONSTANTS DEFINITIONS==================================}

const

  {Number of companies simulated}
  NoOfRetail=11;
  NoOfClothing=6;
  NoOfTextile=3;

  {in the manual simulation tests, substitute the above lines with:
  NoOfRetail=1;
  NoOfClothing=1;
  NoOfTextile=1;}

  {Number of companies using EDI}
  {AS-IS Scenario}    {TO-BE Scenario}
  REDI=0;             {REDI=NoOfRetail;}
  CEDI=0;             {CEDI=NoOfClothing;}
  TEDI=0;             {TEDI=NoOfTextile;}

  {Season Data}
  SeasonLength=360;     {360 days per year}

  {Interval between submission of order plans for EDI-enabled companies}
  DemEstInterval=60;    {EDI-enabled companies resubmit order plans every two months}

  {Warm-up period before data start to be recorded}
  WarmupPeriod=360;

  {Total Simulation Run Duration (in days)}
  EndOfTime=1080+WarmupPeriod;       {data collected for three seasons}


{===================================TYPES DEFINITIONS====================================}

type

   SectorType=(Textile,Clothing,Retail);

   InventoryType=(Product,Materials);

   CompanyListType=^CompanyListNode;
   CompanyPointer=^CompanyType;

   {definition of B-events (starting events)}
   BeventPointer=^BeventNode;
   BeventNode=record
                 Company:CompanyPointer;
                 Quantity:longint;
                 AtTime:integer;
                 StartDate:integer;
                 Next:BeventPointer;
              end;

   {definition of orders}
   OrderPointer=^OrderType;
   OrderType=record
                Quantity:longint;
                Customer:CompanyPointer;
                Next:OrderPointer;
             end;

   {list of quantities used in ProductionPlan (see CompanyType definition below)}
   BlockPointer=^BlockType;
   BlockType=record
                quant:integer;
                Next:BlockPointer;
             end;

   {definition of company profiles}
   CompanyType=record
                  Name:integer; {number from 1 to maximum number of companies in the sector}
                  Sector:SectorType; {Retail, Textile, or Clothing}
                  Customers,Suppliers:CompanyListType; {points to list of customers/suppliers}
                  OutstandingOrders:record  {list of outstanding orders received from customers}
```

```
                                        TotalQ:longint; {total quantity of outstanding orders}
                                        Head:OrderPointer; {first node in the list}
                                        LastTrail:OrderPointer; {daily update of the list}
                                     end;
                  {company market share}
                  MShare:real;
                  {Economic Order Quantity for products/materials}
                  EOQ, MaterialsEOQ:longint;
                  {Reorder Points level for products/materials}
                  ReorderPoint,MaterialsReorderPoint:longint;
                  {Inventory levels for products/materials}
                  Inventory,MaterialsInventory:longint;
                  {Expected demand for the season}
                  ExpDemand:longint;
                  {Production related data}
                  SeasonProduction:longint;
                  ProductionRate:real;
                  {Realised and Lost Sales for a season}
                  SeasonSales,LostSeasonSales:longint;
                  {Quantity of pending orders submitted to suppliers}
                  PendingOrdQ:longint;
                  {Remaining Time for submitting demand estimations - EDI only}
                  DemEstTime:longint;
                  {Lead time data for products and materials}
                  RandLeadTime,RandLeadTimeStd,MatRandLeadTime,MatRandLeadTimeStd:longint;
                  {Inventory and order costs - used in EOQ calculations}
                  StockoutCost,InvHoldingCost,OrderCost,OrderCostEDI:integer;
                  {EDI-use and Pending order flags}
                  HasEDI,PendingOrder:boolean;
                  {Number of Full Deliveries per pending Order}
                  Deliveries:integer;
                  {Total sales in the first column, Number of seasons in the second column.
                   Used to calculate expected demand for the season}
                  SeasonEstimates:array[1..2] of longint;
                  {Production related information}
                  MRPtable:record
                             {the following tables hold data for each day of the season}
                             {Outstanding orders from customers}
                             Orders:array [1..SeasonLength] of longint;
                             {Expected demand for production}
                             TotalDemand:array [1..SeasonLength] of longint;
                             {Materials needed to satisfy scheduled production}
                             TotMatNeed:array [1..SeasonLength] of longint;
                             {Production plan - holds lists of production quantities}
                             ProductionPlan:array[1..SeasonLength] of BlockPointer;
                          end;
               end; {CompanyType}

    {list of companies at each stage of the value chain}
    CompanyListNode=record
                       Company:CompanyPointer;
                       Next:CompanyListType;
                    end;


{================================VARIABLES DEFINITIONS=================================}

var

   {Input data files for: expected demand for the first season,
    initialisation data for retail/clothing/textile companies,
    Z distribution data (used in EOQ calculations),
    demand data for the first season}
   SeasonSalesEstimates,Retdata,Clodata,Texdata,Zdistr,Demand:text;

   {Output data files for: demand, inventory, materials inventory}
   demlog,invlog,matinvlog:text;

   {lists of companies}
   RetailCompanies,TextileCompanies,ClothingCompanies:CompanyListType;

   {Simulation time (in days)}
   Time:integer;

   {Time within a season, i.e. day between 1 and SeasonLength}
   Today:integer;

   {list of events due to begin}
   BeventList:BeventPointer;

   {demand data for each day of the season:
    mean value in the first column, standard deviation in the second}
   SeasonDemand:array[1..SeasonLength,1..2] of real;

   {cumulative demand data for the season (as percentage of seasonal demand)}
   CumulSeasonDemand:array [1..SeasonLength] of real;

   {Z distribution values - taken from statistical tables}
   Zvalues:array [0..400,1..2] of real;


{===========================FUNCTIONS/PROCEDURES DEFINITIONS===========================}

function Normal(m,s:real):longint;
```

```
{normal distribution}
begin
   Normal:=round(m+s*(sqrt(-2*ln(random))*cos(2*3.14159*random)));
end;

                    {**********************************************}

procedure error(Message:string);
{displays error messages}
begin
   writeln(chr(7),'ERROR: ',Message);
   readln;
end;

                    {**********************************************}

procedure Insert(Company:CompanyPointer;var CompanyList:CompanyListType);
{inserts a company record into the company list}
var
   temp:CompanyListType;
begin
   new(temp);
   temp^.Company:=Company;
   temp^.Next:=CompanyList;
   CompanyList:=temp;
end;{Insert}

                    {**********************************************}

procedure CalculateEOQ(KindOfInventory:InventoryType;Company:CompanyPointer;TotalD:longint);
{calculates EOQ levels and Reorder Points}
var
   tempordercost,temprp,i:integer;
   tempeoq,temprf:real;
begin

   {different ordering costs before and after EDI}
   if Company^.HasEDI then
      tempordercost:=Company^.OrderCostEDI
   else
      tempordercost:=Company^.OrderCost;

   {EOQ Calculation}
   tempeoq:=sqrt(2*tempOrderCost/Company^.InvHoldingCost*TotalD);

   {r* Calculation}
   temprf:=1.0-abs(Company^.InvHoldingCost*tempeoq/(Company^.StockoutCost*TotalD));
   if (temprf<0.5) or (temprf>=1.0) then
   begin
      writeln('R* = ',temprf:10:9);
      error('Incorrect R* value=');
   end;

   {obtain Z distribution value closer to r*}
   i:=0;
   repeat
      i:=i+1;
   until Zvalues[i,2]>temprf;

   {calculate EOQ and Reorder Points depending on type of inventory}
   case KindOfInventory of
     Product:
        begin
           Company^.EOQ:=round(tempeoq);
           temprp:=round(Zvalues[i-1,1]*Company^.Randleadtime+Company^.RandLeadTimeStd);
           Company^.ReorderPoint:=temprp;
        end;
     Materials:
        begin
           Company^.MaterialsEOQ:=round(tempeoq);
           temprp:=round(Zvalues[i-1,1]*Company^.MatRandleadtime+Company^.MatRandLeadTimeStd);
           Company^.MaterialsReorderPoint:=temprp;
        end;
   end;{case}
end;{CalculateEOQ}

                    {**********************************************}

procedure DeliverGoods(Company:CompanyPointer;Quantity:longint;InvKind:InventoryType);
{Perform delivery of goods from supplier to customer}
begin
   case InvKind of
      Product:Company^.Inventory:=Company^.Inventory+Quantity;
      Materials:Company^.MaterialsInventory:=Company^.MaterialsInventory+Quantity;
   end;{case}

   Company^.PendingOrdQ:=Company^.PendingOrdQ-Quantity;

end;{DeliverGoods}

                    {**********************************************}

procedure AddBevent(bevent:BeventPointer;var BeventList:BeventPointer);
{Add a (production) event to the B-events list sorted by time of completion
 (the insertion mechanism ensures ascending nodes according to the Attime veriable)}
begin
```

```
   if (BeventList<>nil) and (bevent^.AtTime>BeventList^.Attime) then
      AddBevent(bevent,BeventList^.Next)
   else
   begin
      bevent^.Next:=BeventList;
      BeventList:=bevent;
   end;
end;{AddBevent}

                    {************************************************}

procedure ScheduleProduction(Company:CompanyPointer;Quantity:longint;Duration,today:integer);
{Schedule a production event and add it to the B-events list}
var
   temp:BeventPointer;
begin
   new(temp);
   temp^.Company:=Company;
   temp^.Quantity:=Quantity;
   temp^.AtTime:=Time+Duration;
   temp^.StartDate:=today;
   AddBevent(temp,BeventList);
end;{FinishProduction}

                    {************************************************}

procedure Order(Company:CompanyPointer;Quantity:longint);
{Submit an order to one's suppliers}
var
   p:CompanyListType;

      procedure InsertOrder(Quant:longint;Company:CompanyPointer;
                            var OrderList:OrderPointer);
      {Insert an order in the company's order list
       (the insertion mechanism ensures descending nodes according to the Quantity veriable)}
      var
         Ord:OrderPointer;
      begin
         if (OrderList<>nil) and (Quant<OrderList^.Quantity) then
            InsertOrder(Quant,Company,OrderList^.Next)
         else
         begin
            {the new order is placed in the beginning of the (remaining) list}
            new(Ord);
            Ord^.Quantity:=Quant;
            Ord^.Customer:=Company;
            Ord^.Next:=OrderList;
            OrderList:=Ord;
            p^.Company^.OutstandingOrders.TotalQ:=p^.Company^.OutstandingOrders.TotalQ+Quant;
         end;
      end;{InsertOrder}

begin {Order}
   p:=Company^.Suppliers;
   while p<>nil do
   begin
      InsertOrder(round(Quantity*p^.Company^.MShare/100.0),
                  Company,p^.Company^.OutstandingOrders.LastTrail);
      {the LastTrail pointer ensures that the order is inserted in the current day's order list}
      p:=p^.Next;
   end;
end;{Order}

                    {************************************************}

procedure PlaceOrderPlan(thetime:integer;quant:longint;company:CompanyPointer);
{Order Plan Submission to Suppliers}
var
   p:CompanyListType;
begin
   {update MRP table for each supplier}
   p:=Company^.Suppliers;
   while p<>nil do
   begin
      p^.Company^.MRPtable.Orders[thetime]:=p^.Company^.MRPtable.Orders[thetime]+
           round(Quant*p^.Company^.MShare/100.0);
      p:=p^.Next;
   end;
end;{PlaceOrderPlan}

                    {************************************************}

procedure OrderPlanV(fromtime,totime:integer;EOQ,RP:longint;Company:CompanyPointer);
{Create order plans for variable demand}
var
   j,prevj,tempquant:longint;
   q:CompanyListType;
begin

   {initialise suppliers' order lists}
   q:=Company^.Suppliers;
   while q<>nil do
   begin
     for j:=1 to SeasonLength do q^.Company^.MRPTable.Orders[j]:=0;
     q:=q^.next;
   end;
```

```
   {submit new order plans}
   j:=fromtime;
   while j<=totime do
   begin
      prevj:=j;
      tempquant:=0;
      while (tempquant<=EOQ+RP) and (j<=totime) do
      begin
         tempquant:=tempquant+Company^.MRPtable.TotMatNeed[j];
         j:=j+1;
      end;
      PlaceOrderPlan(prevj,tempquant,Company);
   end
end;{OrderPlanV}

                    {***********************************************}

procedure OrderPlanC(fromtime,totime,TotalQ,EOQ,RP,invq:longint;Company:CompanyPointer);
{Create order plans for constant demand}
var
   i,orderinterval:integer;
   q:CompanyListType;
begin

   {initialise suppliers' order lists}
   q:=Company^.Suppliers;
   while q<>nil do
   begin
     for i:=1 to SeasonLength do q^.Company^.MRPTable.Orders[i]:=0;
     q:=q^.next;
   end;

   {calculate ordering intervals}
   orderinterval:=round((totime-fromtime+1)*(EOQ/TotalQ));
   if orderinterval=0 then orderinterval:=1;
   if orderinterval<0 then
   begin
      error('Negative order interval!');
      halt;
   end;

   {submit new order plans}
   i:=fromtime;
   while i<=totime-orderinterval do
   begin
      if invq>=EOQ then {there is no need for an order as the existing inventory is enough}
         invq:=invq-EOQ
      else
         if invq>0 then
         begin
            PlaceOrderPlan(i,EOQ+RP-invq,Company);
            invq:=0;
         end
         else
            PlaceOrderPlan(i,EOQ+RP,Company);
      i:=i+orderinterval;
   end;
end;{OrderPlanC}

                    {***********************************************}

procedure CurrentMeasurements;
{This is the main procedure where companies perform their basic activities:
 Satisfy demand, submit orders and order plans, schedule production, etc.
 See comments within the procedure for details}
var
   FullDelivery:boolean;
   Orders,tempord,op,pop:OrderPointer;
   p:CompanyListType;
   i,j,k,dur,FromDate,ToDate,CompanyDemand:longint;
   totalorders,totalproduction,prodsize:longint;
   tempq,totq,temptime:longint;
   b:BeventPointer;
   q,tq,blocktmp:BlockPointer;
   {the following variables are used in the manual simulations only
   testlog,testlog2,testlog3,testlog4,testlog5:text;
   pp:CompanyListType;}
begin {Current Measurements}


{WE START FROM RETAILERS WHO:
 A. INITIALISE VALUES AND SUBMIT ORDER PLANS (IF FIRST DAY OF SEASON)
 B. SATISFY CUSTOMER DEMAND
 C. (IF USING EDI) SUBMIT NEW ORDER PLANS TO CLOTHING COMPANIES
 D. PLACE ACTUAL ORDERS TO CLOTHING COMPANIES
}
   p:=RetailCompanies;
   while p<>nil do
   begin {1}

{A. INITIALISE VALUES (IF FIRST DAY OF SEASON)}

      if Today=1 then
      begin {2}
```

```
        {update historical sales data}
        if Time=1 then
        begin {3}
           {Sales estimates for the first season are taken from historical sales data}
           assign(SeasonSalesEstimates,'c:\edi_sim\data\ssest.dat');
           reset(SeasonSalesEstimates);
           readln(SeasonSalesEstimates,p^.Company^.SeasonEstimates[1],
                                       p^.Company^.SeasonEstimates[2]);
           close(SeasonSalesEstimates);
        end {3}
        else
        begin {4}
           p^.Company^.SeasonEstimates[1]:=p^.Company^.SeasonEstimates[1]+
                                           p^.Company^.SeasonSales;
           p^.Company^.SeasonEstimates[2]:=p^.Company^.SeasonEstimates[2]+1;
           p^.Company^.SeasonSales:=0;
           p^.Company^.LostSeasonSales:=0;
        end; {4}

        p^.Company^.ExpDemand:=round(p^.Company^.SeasonEstimates[1]/
                               p^.Company^.SeasonEstimates[2]);

        {Calculate EOQ and Reorder Point for the season}
        if p^.Company^.ExpDemand>0 then
           CalculateEOQ(Product,p^.Company,p^.Company^.ExpDemand)
        else
           begin {5}
              error(concat('Product EOQ for retail company ',
                           chr(48+p^.Company^.Name),' is zero!'));
              halt;
           end; {5}

        if Time=1 then {initialise inventory levels}
           p^.Company^.Inventory:=p^.Company^.EOQ+p^.Company^.ReorderPoint;

        {submit new order plans to clothing manufacturers for the season}
        OrderPlanC(1,SeasonLength,p^.Company^.ExpDemand,p^.Company^.EOQ,
                   p^.Company^.ReorderPoint,
                   p^.Company^.Inventory+p^.Company^.PendingOrdQ,
                   p^.Company);
     end; {2}

{B. SATISFY CUSTOMER DEMAND}

     {calculate daily realised demand}
     CompanyDemand:=abs(Normal(SeasonDemand[Today,1],SeasonDemand[Today,2]));
     {in the manual simulation tests substitute the above line with:
     CompanyDemand:=63;}

     {record realised demand levels}
     if Time>WarmupPeriod then
        writeln(demlog,Time,' ',p^.Company^.Name,' ',CompanyDemand);

     {satisfy demand}
     if p^.Company^.Inventory>=CompanyDemand then
     {fully...}
        begin {6}
           p^.Company^.Inventory:=p^.Company^.Inventory-CompanyDemand;
           p^.Company^.SeasonSales:=p^.Company^.SeasonSales+CompanyDemand;
        end {6}
     else
     {...or not}
        begin {7}
           p^.Company^.LostSeasonSales:=p^.Company^.LostSeasonSales+
                                        CompanyDemand-p^.Company^.Inventory;
           p^.Company^.SeasonSales:=p^.Company^.SeasonSales+p^.Company^.Inventory;
           p^.Company^.Inventory:=0;
        end; {7}

     {record actual inventory level after satisfying demand}
     if Time>WarmupPeriod then
        writeln(invlog,Time,' ',p^.Company^.Name,' ',1{retail},' ',
                      p^.Company^.Inventory,' ',p^.Company^.EOQ);

{C. (IF USING EDI) SUBMIT NEW ORDER PLANS TO CLOTHING COMPANIES}

     {The companies that use EDI update and send their order plans more frequently}
     if (p^.Company^.HasEDI) and (Today>1) then
     begin {8}
        if p^.Company^.DemEstTime=0 then
        begin {9}
           {Calculate total expected demand for the remainder of the season
            based on realised demand up to date and historical sales data}
           p^.Company^.ExpDemand:=round((p^.Company^.SeasonSales+
                                         p^.Company^.LostSeasonSales)/
                                        CumulSeasonDemand[Today]);
           if p^.Company^.ExpDemand>0 then
           begin {10}
              CalculateEOQ(Product,p^.Company,p^.Company^.ExpDemand);
              {submit order plans for the remainder of the season}
              OrderPlanC(Today,SeasonLength,p^.Company^.ExpDemand,
                         p^.Company^.EOQ,p^.Company^.ReorderPoint,
                         p^.Company^.Inventory+p^.Company^.PendingOrdQ,
                         p^.Company);
           end {10}
           else
```

```
          begin {11}
             error(concat('Product EOQ for retail company ',
                          chr(48+p^.Company^.Name),' is zero!'));
             halt;
          end; {11}

          p^.Company^.DemEstTime:=DemEstInterval;
       end {9}
       else
          p^.Company^.DemEstTime:=p^.Company^.DemEstTime-1;
    end; {8}

{D. PLACE ACTUAL ORDERS TO CLOTHING COMPANIES}

    if (not p^.Company^.PendingOrder) and
       (p^.Company^.Inventory<=p^.Company^.ReorderPoint) then
       begin {12}
          {place actual orders}
          Order(p^.Company,
                p^.Company^.EOQ+p^.Company^.ReorderPoint-p^.Company^.Inventory);
          p^.Company^.PendingOrder:=true;
          p^.Company^.PendingOrdQ:=p^.Company^.PendingOrdQ+p^.Company^.EOQ+
                                   p^.Company^.ReorderPoint-p^.Company^.Inventory;
       end; {12}


    {go to the next company in the list}
    p:=p^.Next;

  end; {Retail Companies} {1}


{WE THEN MOVE TO CLOTHING COMPANIES WHO:
 A. INITIALISE VALUES (IF FIRST DAY OF THE SEASON)
 B. PERFORM SALES TO RETAILERS
 C. SCHEDULE PRODUCTION
 D. CALCULATE TOTAL EXPECTED DEMAND FOR PRODUCTION
 E. CALCULATE TOTAL MATERIALS NEED
 F. (IF USING EDI) PLACE ORDER PLANS TO TEXTILE COMPANIES
 G. SUBMIT ACTUAL ORDERS TO TEXTILE COMPANIES
}
  p:=ClothingCompanies;
  while p<>nil do
  begin {1}


{A. INITIALISE VALUES (IF FIRST DAY OF THE SEASON)}

    if Today=1 then
    begin {2}
       p^.Company^.SeasonSales:=0;
       p^.Company^.LostSeasonSales:=0;
       p^.Company^.SeasonProduction:=0;
    end; {2}

{B. PERFORM SALES TO RETAILERS}

    {Update outstanding orders list with last trail before performing sales}
    op:=p^.Company^.OutstandingOrders.Head;
    pop:=op;
    while op<>nil do {run through list, pop is the last node after this}
    begin {3}
       pop:=op;
       op:=op^.Next;
    end; {3}
    if pop<>nil then
       {connect list to last trail}
       pop^.Next:=p^.Company^.OutstandingOrders.LastTrail
    else {i.e. there were no outstanding orders}
       {last trail becomes the outstanding orders list}
       p^.Company^.OutstandingOrders.Head:=p^.Company^.OutstandingOrders.LastTrail;
    p^.Company^.OutstandingOrders.LastTrail:=nil;

    {run through the complete outstanding orders list and satisfy demand}
    Orders:=p^.Company^.OutstandingOrders.Head;
    while Orders<>nil do
    begin {4}
       if Orders^.Quantity <= p^.Company^.Inventory then
       begin {5}
          tempq:=Orders^.Quantity;
          FullDelivery:=true;
       end {5}
       else
       begin {6}
          tempq:=p^.Company^.Inventory;
          FullDelivery:=false;
       end; {6}
       if tempq=0 then
          Orders:=Orders^.Next
       else
       begin {7}
          {priority is given to older orders and, between orders of the same day,
           to larger ones - see also the Order and InsertOrder procedures}
          DeliverGoods(Orders^.Customer,tempq,Product);
          p^.Company^.Inventory:=p^.Company^.Inventory-tempq;
          p^.Company^.SeasonSales:=p^.Company^.SeasonSales+tempq;
```

```
            p^.Company^.LostSeasonSales:=p^.Company^.LostSeasonSales+
                                            Orders^.Quantity-tempq;
            p^.Company^.OutstandingOrders.TotalQ:=
                             p^.Company^.OutstandingOrders.TotalQ-tempq;

            tempord:=Orders;
            if FullDelivery then
            begin {8}
               {update number of deliveries}
               Orders^.Customer^.Deliveries:=Orders^.Customer^.Deliveries+1;
               {signal when order is fully executed}
               if Orders^.Customer^.Deliveries = NoOfClothing then
               begin {9}
                  Orders^.Customer^.PendingOrder:=false;
                  Orders^.Customer^.Deliveries:=0;
               end; {9}
               if Orders=p^.Company^.OutstandingOrders.Head then
                  p^.Company^.OutstandingOrders.Head:=Orders^.Next;
               Orders:=Orders^.Next;
               dispose(tempord);
            end {8}
            else {if not FullDelivery}
            begin {10}
               Orders^.Quantity:=Orders^.Quantity-tempq;
               Orders:=Orders^.Next;
            end; {10}
         end; {7}
      end; {4}

      {record actual inventory level after satisfying demand}
      if Time>WarmupPeriod then
         writeln(invlog,Time,' ',p^.Company^.Name,' ',2{clothing},' ',
                    p^.Company^.Inventory,' ',p^.Company^.EOQ);

{C. SCHEDULE PRODUCTION}

      q:=p^.Company^.MRPtable.ProductionPlan[Today];

      {run through the entire ProductionPlan list}
      while q<>nil do
      begin {11}
         {if there is enough materials inventory for the production bunch}
         if p^.Company^.MaterialsInventory>=q^.quant then
         begin {12}
            prodsize:=q^.quant+p^.Company^.OutstandingOrders.TotalQ;
            ScheduleProduction(p^.Company,prodsize,
                              round(prodsize*p^.Company^.ProductionRate),Today);
            {reserve materials inventory for production:
             one unit of material for every unit of product}
            p^.Company^.MaterialsInventory:=p^.Company^.MaterialsInventory-q^.quant;
            p^.Company^.SeasonProduction:=p^.Company^.SeasonProduction+q^.quant;
         end {12}
         else {if there is not enough materials inventory for the bunch}
         begin {13}
            ScheduleProduction(p^.Company,p^.Company^.MaterialsInventory,
               round(p^.Company^.MaterialsInventory*p^.Company^.ProductionRate),Today);
            p^.Company^.MaterialsInventory:=0;
            p^.Company^.SeasonProduction:=p^.Company^.SeasonProduction+
                                          p^.Company^.MaterialsInventory;
         end; {13}
         q:=q^.Next;
      end; {11}

      {record actual materials inventory level after scheduling production}
      if Time>WarmupPeriod then
         writeln(matinvlog,Time,' ',p^.Company^.Name,' ',2{clothing},' ',
               p^.Company^.MaterialsInventory,' ',p^.Company^.MaterialsEOQ);


{D. CALCULATE TOTAL EXPECTED DEMAND FOR PRODUCTION}

      {calculate EOQ based on realised and expected season demand}
      totalorders:=0;
      for i:=Today to SeasonLength do
          totalorders:=totalorders+p^.Company^.MRPtable.Orders[i];
      totalorders:=totalorders+p^.Company^.SeasonSales+
                   p^.Company^.LostSeasonSales;

      if totalorders=0 then totalorders:=1;
      if totalorders<0 then
      begin {14}
         error('Negative sum of total orders - 1');
         halt;
      end; {14}
      CalculateEOQ(Product,p^.Company,totalorders);
      if Time=1 then {initialise inventory}
         p^.Company^.Inventory:=p^.Company^.EOQ+p^.Company^.ReorderPoint;
      {if first day of season, submit order plans to textile companies}
      if Today=1 then
         OrderPlanC(1,SeasonLength,totalorders,
                   p^.Company^.EOQ,p^.Company^.ReorderPoint,
                   p^.Company^.Inventory+p^.Company^.PendingOrdQ,
                   p^.Company);

      {calculate daily production demand to satisfy orders}
      {Note:there is a supplement to the demand calculation later}
```

```
      totq:=p^.Company^.Inventory-p^.Company^.OutstandingOrders.TotalQ;
      for i:=Today to SeasonLength do
          if totq>=p^.company^.MRPtable.Orders[i] then
          begin {15}
              totq:=totq-p^.Company^.MRPtable.Orders[i];
              p^.Company^.MRPtable.TotalDemand[i]:=p^.Company^.ReorderPoint;
          end {15}
          else
          begin {16}
              p^.Company^.MRPtable.TotalDemand[i]:=p^.Company^.MRPtable.Orders[i]-totq+
                                                   p^.Company^.ReorderPoint;
              totq:=0;
          end; {16}

      {delete production plan}
      for i:=1 to SeasonLength do
      begin {17}
         q:=p^.Company^.MRPtable.ProductionPlan[i];
         while q<>nil do
         begin {18}
            tq:=q;
            q:=q^.Next;
            dispose(tq);
         end; {18}
         p^.Company^.MRPtable.ProductionPlan[i]:=nil;
      end; {17}

      {supplement to the calculation of production demand}
      b:=BeventList;
      while b<>nil do
      begin {19}
         if b^.Company=p^.Company then
         begin {20}
            temptime:=b^.AtTime mod SeasonLength;
            if temptime=0 then temptime:=SeasonLength;
            if p^.Company^.MRPtable.TotalDemand[temptime]>=b^.Quantity then
               p^.Company^.MRPtable.TotalDemand[temptime]:=
                  p^.Company^.MRPtable.TotalDemand[temptime]-b^.Quantity
            else
               p^.Company^.MRPtable.TotalDemand[temptime]:=0;
         end; {20}
         b:=b^.Next;
      end; {19}

      for i:=Today to SeasonLength do
      if p^.Company^.MRPTable.TotalDemand[i]>0 then
      begin {21}
         dur:=round(p^.Company^.MRPtable.TotalDemand[i]*p^.Company^.ProductionRate);
         if dur=0 then dur:=1;
         tempq:=p^.Company^.MRPTable.TotalDemand[i];
         if i-dur > Today then FromDate:=i-dur else FromDate:=Today+1;
         if FromDate>SeasonLength then FromDate:=SeasonLength;
         ToDate:=SeasonLength;
         if tempq>0 then
            for k:=FromDate to FromDate+dur-1 do
               if k<=SeasonLength then
               begin {22}
                  new(blocktmp);
                  blocktmp^.quant:=tempq;
                  blocktmp^.next:=p^.Company^.MRPTable.ProductionPlan[k];
                  p^.Company^.MRPTable.ProductionPlan[k]:=blocktmp;
               end; {22}
         p^.Company^.MRPTable.Orders[i]:=0;
         p^.Company^.MRPTable.TotalDemand[i]:=0;
      end; {21}

{This is where the TESTLOG file is generated in the manual simulation test:
assign(testlog,'c:\edi_sim\output\testlog.out');
rewrite(testlog);
for i:=1 to SeasonLength do
begin
   write(testlog,i:3,p^.Company^.MRPTable.Orders[i]:5,
                     p^.Company^.MRPTable.TotalDemand[i]:5,
                     p^.Company^.MRPTable.TotMatNeed[i]:5);
   q:=p^.Company^.MRPTable.ProductionPlan[i];
   while q<>nil do
   begin
      write(testlog,q^.quant:5);
      q:=q^.next;
   end;
   writeln(testlog);
end;
close(testlog);
}

{E. CALCULATE TOTAL MATERIALS NEED}

      {Calculate Materials EOQ based on realised and expected season production}
      totalproduction:=0;
      for i:=Today to SeasonLength do
      begin {23}
         totq:=0;
         q:=p^.Company^.MRPTable.ProductionPlan[i];
         while q<>nil do
         begin {24}
            totq:=totq+q^.quant;
```

```
            q:=q^.next;
         end; {24}
         totalproduction:=totalproduction+totq;
      end; {23}
      totalproduction:=totalproduction+p^.Company^.SeasonProduction;
      if totalproduction=0 then totalproduction:=1;
      if totalproduction<0 then
      begin {25}
         error('Negative Total Production!');
         halt;
      end; {25}
      CalculateEOQ(Materials,p^.Company,totalproduction);
      if Time=1 then {initialise materials inventory}
         p^.Company^.MaterialsInventory:=p^.Company^.MaterialsEOQ+
                                          p^.Company^.MaterialsReorderPoint;
      tempq:=p^.Company^.MaterialsInventory+p^.Company^.PendingOrdQ;
      for i:=Today to SeasonLength do
      begin {26}
         {calculate total production requirements for day i}
         totq:=0;
         q:=p^.Company^.MRPtable.ProductionPlan[i];
         while q<>nil do
         begin {27}
            totq:=totq+q^.quant;
            q:=q^.Next;
         end; {27}

         {if there is enough materials inventory to satisfy this requirement}
         if tempq>=totq then
         begin {28}
            tempq:=tempq-totq;
            p^.Company^.MRPtable.TotMatNeed[i]:=p^.Company^.MaterialsReorderPoint;
         end {28}
         else {if there is not enough inventory}
         begin {29}
            p^.Company^.MRPtable.TotMatNeed[i]:=totq-tempq+
                                             p^.Company^.MaterialsReorderPoint;
            tempq:=0;
         end {29}
      end; {26}

{This is where the TESTLOG2 file is generated in the manual simulation test
assign(testlog2,'c:\edi_sim\output\testlog2.out');
rewrite(testlog2);
for i:=1 to SeasonLength do
begin
   write(testlog2,i:3,p^.Company^.MRPTable.Orders[i]:5,
                     p^.Company^.MRPTable.TotalDemand[i]:5,
                     p^.Company^.MRPTable.TotMatNeed[i]:5);
   q:=p^.Company^.MRPTable.ProductionPlan[i];
   while q<>nil do
   begin
      write(testlog2,q^.quant:5);
      q:=q^.next;
   end;
   writeln(testlog2);
end;
close(testlog2);
}

{F. (IF USING EDI) PLACE ORDER PLANS TO TEXTILE COMPANIES}

      if p^.Company^.HasEDI then
      OrderPlanV(Today,SeasonLength,p^.Company^.MaterialsEOQ,
                 p^.Company^.MaterialsReorderPoint,p^.Company);

{This is where the TESTLOG3 file is generated in the manual simulation test
assign(testlog3,'c:\edi_sim\output\testlog3.out');
rewrite(testlog3);
pp:=p^.Company^.Suppliers;
for i:=1 to SeasonLength do
begin
   write(testlog3,i:3,pp^.Company^.MRPTable.Orders[i]:7,
                     pp^.Company^.MRPTable.TotalDemand[i]:7,
                     pp^.Company^.MRPTable.TotMatNeed[i]:7);
   q:=pp^.Company^.MRPTable.ProductionPlan[i];
   while q<>nil do
   begin
      write(testlog3,q^.quant:7);
      q:=q^.next;
   end;
   writeln(testlog3);
end;
close(testlog3);
}

{G. SUBMIT ACTUAL ORDERS TO TEXTILE COMPANIES}

      if (not p^.Company^.PendingOrder) and
         (p^.Company^.MaterialsInventory<=p^.Company^.MaterialsReorderPoint) then
      begin {30}
         Order(p^.Company,p^.Company^.MaterialsEOQ+p^.Company^.MaterialsReorderPoint-
               p^.Company^.MaterialsInventory);
         p^.Company^.PendingOrder:=true;
         p^.Company^.PendingOrdQ:=p^.Company^.PendingOrdQ+
                                  p^.Company^.MaterialsEOQ+
```

```
                                  p^.Company^.MaterialsReorderPoint-
                                  p^.Company^.MaterialsInventory
      end; {30}

      {go to the next company in the list}
      p:=p^.Next;

   end;{while ClothingCompanies} {1}


{FINALLY, WE MOVE TO TEXTILE COMPANIES WHO:
 A. INITIALISE VALUES (IF FIRST DAY IN THE SEASON)
 B. PERFORM SALES TO CLOTHING COMPANIES
 C. SCHEDULE PRODUCTION
 D. CALCULATE TOTAL EXPECTED DEMAND FOR PRODUCTION
}
   p:=TextileCompanies;
   while p<>nil do
   begin {1}

{A. INITIALISE VALUES (IF FIRST DAY IN THE SEASON)}

      if Today=1 then
      begin {2}
         p^.Company^.SeasonSales:=0;
         p^.Company^.LostSeasonSales:=0;
         p^.Company^.SeasonProduction:=0;
      end; {2}

{B. PERFORM SALES TO CLOTHING COMPANIES}

      {update outstanding orders list with last trail before performing sales}
      op:=p^.Company^.OutstandingOrders.Head;
      pop:=op;
      while op<>nil do {run through list, pop is the last node after this}
      begin {3}
         pop:=op;
         op:=op^.Next;
      end; {3}
      if pop<>nil then
         {connect list to last trail}
         pop^.Next:=p^.Company^.OutstandingOrders.LastTrail
      else {i.e. there were no outstanding orders}
         {last trail becomes the outstanding orders list}
         p^.Company^.OutstandingOrders.Head:=p^.Company^.OutstandingOrders.LastTrail;
      p^.Company^.OutstandingOrders.LastTrail:=nil;

      {run through the complete outstanding orders list and satisfy demand}
      Orders:=p^.Company^.OutstandingOrders.Head;
      while Orders<>nil do
      begin {4}
         if Orders^.Quantity <= p^.Company^.Inventory then
         begin {5}
            tempq:=Orders^.Quantity;
            FullDelivery:=true;
         end {5}
         else
         begin {6}
            tempq:=p^.Company^.Inventory;
            FullDelivery:=false;
         end; {6}
         if tempq=0 then
            Orders:=Orders^.Next
         else
         begin {7}
            {priority is given to older orders and, between orders of the same day,
             to larger ones - see also the Order and InsertOrder procedures}
            DeliverGoods(Orders^.Customer,tempq,Materials);
            p^.Company^.Inventory:=p^.Company^.Inventory-tempq;
            p^.Company^.SeasonSales:=p^.Company^.SeasonSales+tempq;
            p^.Company^.LostSeasonSales:=p^.Company^.LostSeasonSales+
                                        Orders^.Quantity-tempq;
            p^.Company^.OutstandingOrders.TotalQ:=
                         p^.Company^.OutstandingOrders.TotalQ-tempq;

            tempord:=Orders;
            if FullDelivery then
            begin {8}
               {update number of deliveries}
               Orders^.Customer^.Deliveries:=Orders^.Customer^.Deliveries+1;
               {signal when order is fully executed}
               if Orders^.Customer^.Deliveries = NoOfTextile then
               begin {9}
                  Orders^.Customer^.PendingOrder:=false;
                  Orders^.Customer^.Deliveries:=0;
               end; {9}
               if Orders=p^.Company^.OutstandingOrders.Head then
                  p^.Company^.OutstandingOrders.Head:=Orders^.Next;
               Orders:=Orders^.Next;
               dispose(tempord);
            end {8}
            else {if not FullDelivery}
            begin {10}
               Orders^.Quantity:=Orders^.Quantity-tempq;
               Orders:=Orders^.Next;
            end; {10}
```

```
        end; {7}
      end; {4}

      {record actual inventory level after satisfying demand}
      if Time>WarmupPeriod then
         writeln(invlog,Time,' ',p^.Company^.Name,' ',3{textile},' ',
                        p^.Company^.Inventory,' ',p^.Company^.EOQ);


{C. SCHEDULE PRODUCTION}

      q:=p^.Company^.MRPtable.ProductionPlan[Today];
      {run through the entire ProductionPlan list}
      while q<>nil do
      begin {11}
         prodsize:=q^.quant+p^.Company^.OutstandingOrders.TotalQ;
         ScheduleProduction(p^.Company,prodsize,
            round(prodsize*p^.Company^.ProductionRate),Today);
         p^.Company^.SeasonProduction:=p^.Company^.SeasonProduction+q^.quant;
         q:=q^.Next;
      end; {11}

{D. CALCULATE TOTAL EXPECTED DEMAND FOR PRODUCTION}

      {Calculate EOQ based on realised and expected season demand}
      totalorders:=0;
      for i:=Today to SeasonLength do
          totalorders:=totalorders+p^.Company^.MRPtable.Orders[i];
      totalorders:=totalorders+p^.Company^.SeasonSales+
                   p^.Company^.LostSeasonSales;
      if totalorders=0 then totalorders:=1;
      if totalorders<0 then
      begin {12}
         error('Negative sum of total orders - 2');
         halt;
      end; {12}
      CalculateEOQ(Product,p^.Company,totalorders);
      if Time=1 then {initialise inventory}
         p^.Company^.Inventory:=p^.Company^.EOQ+p^.Company^.ReorderPoint;
      {calculate daily production demand to satisfy orders}
      {Note:there is a supplement to the demand calculation later}
      totq:=p^.Company^.Inventory-p^.Company^.OutstandingOrders.TotalQ;
      for i:=Today to SeasonLength do
          if totq>=p^.company^.MRPtable.Orders[i] then
          begin {13}
             totq:=totq-p^.Company^.MRPtable.Orders[i];
             p^.Company^.MRPtable.TotalDemand[i]:=p^.Company^.ReorderPoint;
          end {13}
          else
          begin {14}
             p^.Company^.MRPtable.TotalDemand[i]:=p^.Company^.MRPtable.Orders[i]-totq+
                                                  p^.Company^.ReorderPoint;
             totq:=0;
          end; {14}

{This is where the TESTLOG4 file is generated in the manual simulation test
assign(testlog4,'c:\edi_sim\output\testlog4.out');
rewrite(testlog4);
for i:=1 to SeasonLength do
begin
   write(testlog4,i:3,p^.Company^.MRPTable.Orders[i]:7,
                      p^.Company^.MRPTable.TotalDemand[i]:7,
                      p^.Company^.MRPTable.TotMatNeed[i]:7);
   q:=p^.Company^.MRPTable.ProductionPlan[i];
   while q<>nil do
   begin
      write(testlog4,q^.quant:7);
      q:=q^.next;
   end;
   writeln(testlog4);
end;
close(testlog4);
}

      {delete production plan}
      for i:=1 to SeasonLength do
      begin {15}
         q:=p^.Company^.MRPtable.ProductionPlan[i];
         while q<>nil do
         begin {16}
            tq:=q;
            q:=q^.Next;
            dispose(tq);
         end; {16}
         p^.Company^.MRPtable.ProductionPlan[i]:=nil;
      end; {15}

      {supplement to the calculation of production demand}
      b:=BeventList;
      while b<>nil do
      begin {17}
         if b^.Company=p^.Company then
         begin {18}
            temptime:=b^.AtTime mod SeasonLength;
            if temptime=0 then temptime:=SeasonLength;
            if p^.Company^.MRPtable.TotalDemand[temptime]>=b^.Quantity then
```

```
                p^.Company^.MRPtable.TotalDemand[temptime]:=
                    p^.Company^.MRPtable.TotalDemand[temptime]-b^.Quantity
            else
                p^.Company^.MRPtable.TotalDemand[temptime]:=0;
        end; {18}
        b:=b^.Next;
    end; {17}

    for i:=Today to SeasonLength do
    if p^.Company^.MRPTable.TotalDemand[i]>0 then
    begin {19}
        dur:=round(p^.Company^.MRPtable.TotalDemand[i]*p^.Company^.ProductionRate);
        if dur=0 then dur:=1;
        tempq:=p^.Company^.MRPTable.TotalDemand[i];
        if i-dur > Today then FromDate:=i-dur else FromDate:=Today+1;
        if FromDate>SeasonLength then FromDate:=SeasonLength;
        ToDate:=SeasonLength;
        if tempq>0 then
            for k:=FromDate to FromDate+dur-1 do
                if k<=SeasonLength then
                begin {20}
                    new(blocktmp);
                    blocktmp^.quant:=tempq;
                    blocktmp^.next:=p^.Company^.MRPTable.ProductionPlan[k];
                    p^.Company^.MRPTable.ProductionPlan[k]:=blocktmp;
                end; {20}
        p^.Company^.MRPTable.Orders[i]:=0;
        p^.Company^.MRPTable.TotalDemand[i]:=0;
    end; {19}

{This is where the TESTLOG5 file is generated in the manual simulation test
assign(testlog5,'c:\edi_sim\output\testlog5.out');
rewrite(testlog5);
for i:=1 to SeasonLength do
begin
   write(testlog5,i:3,p^.Company^.MRPTable.Orders[i]:7,
                      p^.Company^.MRPTable.TotalDemand[i]:7,
                      p^.Company^.MRPTable.TotMatNeed[i]:7);
   q:=p^.Company^.MRPTable.ProductionPlan[i];
   while q<>nil do
   begin
      write(testlog5,q^.quant:7);
      q:=q^.next;
   end;
   writeln(testlog5);
end;
close(testlog5);
}
      {go to the next company in the list}
      p:=p^.Next;

   end;{TextileCompanies} {1}

              {===END OF MANUAL SIMULATION===}

end;{CurrentMeasurements}

                {************************************************}

procedure FinishingActions;
{Run through B-event list and finish events (basically release production)}
var
   temp:BeventPointer;
begin
   while (BeventList<>nil) and (BeventList^.AtTime<=Time) do
   begin
      BeventList^.Company^.Inventory:=BeventList^.Company^.Inventory+
                                      BeventList^.Quantity;
      temp:=BeventList;
      BeventList:=BeventList^.Next;
      dispose(temp);
   end;
end; {FinishingActions}

                {************************************************}

procedure IniCompanies;
{Initialise simulation data:
 A. INITIALISE RETAILERS' LIST
 B. INITIALISE CLOTHING COMPANIES' LIST
 C. INITIALISE TEXTILE COMPANIES' LIST
 D. CONNECT COMPANY LISTS}
var
   i,k:integer;
   temp:CompanyPointer;
   p:CompanyListType;
   tempredi,tempcedi,temptedi:integer;

begin

   {number of companies that use EDI}
   tempredi:=REDI;
   tempcedi:=CEDI;
   temptedi:=TEDI;

{A. INITIALISE RETAILERS' LIST}
```

```
   RetailCompanies:=nil;

   {the 'Retdata' file holds input data for Retailers}
   assign(Retdata,'c:\edi_sim\data\retdata.dat');
   reset(Retdata);

   {initialise the list of retailers}
   for i:=1 to NoOfRetail do
   begin
      new(temp);
      with temp^ do
      begin
         Name:=i;
         Sector:=Retail;
         Customers:=nil;
         Suppliers:=nil;
         OutstandingOrders.TotalQ:=0;
         OutstandingOrders.Head:=nil;
         OutstandingOrders.LastTrail:=nil;
         MShare:=100.0/NoOfRetail; {retailers have equal market shares}
         readln(Retdata, OrderCost, OrderCostEDI, InvHoldingCost, StockoutCost,
                          RandLeadTime, RandLeadTimeStd);
         EOQ:=0;
         ReorderPoint:=0;
         MaterialsEOQ:=0;
         MaterialsReorderPoint:=0;
         Inventory:=0;
         MaterialsInventory:=0;
         PendingOrder:=false;
         ProductionRate:=0;
         DemEstTime:=DemEstInterval;
         MatRandLeadTime:=0;
         MatRandLeadTimeStd:=0;
         ExpDemand:=0;
         SeasonSales:=0;
         LostSeasonSales:=0;
         SeasonProduction:=0;
         PendingOrdQ:=0;
         Deliveries:=0;

         if tempredi>0 then
         begin
            HasEDI:=true;
            tempredi:=tempredi-1;
         end
         else HasEDI:=false;

         {initialise MRP Table for retailers}
         with MRPtable do
         begin
            for k:=1 to SeasonLength do
            begin
               Orders[k]:=0;
               TotalDemand[k]:=0;
               ProductionPlan[k]:=nil;
               TotMatNeed[k]:=0;
            end;
         end;
      end;

      {insert the record in the retail companies list}
      Insert(temp,RetailCompanies);

   end {Retail Companies};
   close (Retdata);


{B. INITIALISE CLOTHING COMPANIES' LIST}

   ClothingCompanies:=nil;

   {the 'Clodata' file holds input data for Clothing companies}
   assign(Clodata,'c:\edi_sim\data\clodata.dat');
   reset(Clodata);
   for i:=1 to NoOfClothing do
   begin
      new(temp);
      with temp^ do
      begin
         Name:=i;
         Sector:=Clothing;
         Customers:=RetailCompanies;
         Suppliers:=nil;
         OutstandingOrders.TotalQ:=0;
         OutstandingOrders.Head:=nil;
         OutstandingOrders.LastTrail:=nil;
         readln(Clodata,MShare,OrderCost,OrderCostEDI,InvHoldingCost,
                         StockoutCost,ProductionRate,
                         RandLeadTime,RandLeadTimeStd,
                         MatRandLeadTime, MatRandLeadTimeStd);
         EOQ:=0;
         ReorderPoint:=0;
         MaterialsEOQ:=0;
         MaterialsReorderPoint:=0;
         Inventory:=0;
```

```
         MaterialsInventory:=0;
         PendingOrder:=false;
         DemEstTime:=DemEstInterval;
         ExpDemand:=0;
         SeasonSales:=0;
         LostSeasonSales:=0;
         SeasonProduction:=0;
         PendingOrdQ:=0;
         Deliveries:=0;

         if tempcedi>0 then
         begin
            HasEDI:=true;
            tempcedi:=tempcedi-1;
         end
            else HasEDI:=false;

         SeasonEstimates[1]:=0;
         SeasonEstimates[2]:=0;

         {initialise MRP Table for clothing companies}
         with MRPtable do
         begin
            for k:=1 to SeasonLength do
            begin
               Orders[k]:=0;
               TotalDemand[k]:=0;
               ProductionPlan[k]:=nil;
               TotMatNeed[k]:=0;
            end;
         end;
      end;

      Insert(temp,ClothingCompanies);

   end {Clothing Companies};
   close(Clodata);


{C. INITIALISE TEXTILE COMPANIES' LIST}

   TextileCompanies:=nil;

   {the 'Texdata' file holds input data for Textile companies}
   assign(Texdata,'c:\edi_sim\data\texdata.dat');
   reset(Texdata);
   for i:=1 to NoOfTextile do
   begin
      new(temp);
      with temp^ do
      begin
         Name:=i;
         Sector:=Textile;
         Customers:=ClothingCompanies;
         Suppliers:=nil;
         OutstandingOrders.TotalQ:=0;
         OutstandingOrders.Head:=nil;
         OutstandingOrders.LastTrail:=nil;
         readln(Texdata,MShare,OrderCost,OrderCostEDI,InvHoldingCost,
                        StockoutCost,ProductionRate,
                        RandLeadTime,RandLeadTimeStd,
                        MatRandLeadTime,MatRandLeadTimeStd);
         EOQ:=0;
         ReorderPoint:=0;
         MaterialsEOQ:=0;
         MaterialsReorderPoint:=0;
         Inventory:=0;
         MaterialsInventory:=0;
         PendingOrder:=false;
         DemEstTime:=0;
         ExpDemand:=0;
         SeasonSales:=0;
         LostSeasonSales:=0;
         SeasonProduction:=0;
         PendingOrdQ:=0;
         Deliveries:=0;

         if temptedi>0 then
         begin
            HasEDI:=true;
            temptedi:=temptedi-1;
         end
            else HasEDI:=false;

         SeasonEstimates[1]:=0;
         SeasonEstimates[2]:=0;

         {initialise MRP Table for textile companies}
         with MRPtable do
         begin
            for k:=1 to SeasonLength do
            begin
               Orders[k]:=0;
               TotalDemand[k]:=0;
               ProductionPlan[k]:=nil;
               TotMatNeed[k]:=0;
```

```
          end;
        end;
      end;

      Insert(temp,TextileCompanies);
    end {Textile Companies};
    close(Texdata);

{D. CONNECT COMPANY LISTS}

    p:=RetailCompanies;
    while p<>nil do
    begin
      p^.Company^.Suppliers:=ClothingCompanies;
      p:=p^.Next;
    end;

    p:=ClothingCompanies;
    while p<>nil do
    begin
      p^.Company^.Suppliers:=TextileCompanies;
      p:=p^.Next;
    end;

end;{IniCompanies}

                    {************************************************}

procedure Initialisation;
{Initialise simulation}
var
   i:integer;
begin

   randomize;

   {output files}
   assign(demlog,'c:\edi_sim\output\demand.out');
   rewrite(demlog);
   assign(invlog,'c:\edi_sim\output\inv.out');
   rewrite(invlog);
   assign(matinvlog,'c:\edi_sim\output\matinv.out');
   rewrite(matinvlog);

   {read Z distribution data}
   assign(Zdistr,'c:\edi_sim\data\zdistr.dat');
   reset(Zdistr);
   for i:=0 to 400 do readln(Zdistr,Zvalues[i,1],Zvalues[i,2]);
   close(Zdistr);

   {demand estimates for the first year are taken from historical data
    (subsequent years' demand is estimated from simulation data)}
   assign(Demand,concat('c:\edi_sim\data\demand.dat'));
   reset(Demand);
   for i:=1 to SeasonLength do
      readln(Demand,SeasonDemand[i,1],SeasonDemand[i,2],CumulSeasonDemand[i]);
   close(Demand);

   BeventList:=nil;
   Time:=1;
   Today:=1;

   {Initialise companies}
   IniCompanies;

end; {Initialisation}

                    {************************************************}

procedure CloseSystem;
{close input and output files}
begin
   close(demlog);
   close(invlog);
   close(matinvlog);
end;{CloseSystem}

{====================================MAIN PROGRAM=======================================}

Begin

   Initialisation;

   while Time<=EndOfTime do
   begin

      if Today=SeasonLength+1 then Today:=1;
      writeln('           Time: ',Time,'   ',Today);

      {end events}
      FinishingActions;

      {measurements and begin events}
      CurrentMeasurements;

      {advance time}
```

```
      Time:=Time+1;
      Today:=Today+1;

   end;

   CloseSystem;
   Writeln(chr(7),'OK');
   readln;

End.
```

APPENDIX C. ISSUE DEVELOPMENT AND TESTING

This Appendix will document the process of developing the ISSUE method discussed in Chapter 4 of the dissertation. ISSUE was developed based on an inductive approach of pattern identification (Kettinger et al 1997) against the four methodologies that constitute ISSUE's foundation. The Appendix also discusses the results of a reliability test conducted in the laboratory to assess the validity of the pattern identification and mapping approach.

C.1. ISSUE Development

As discussed in Chapter 4, ISSUE has been developed on the basis of the following methods:

d) Davenport's (1993) and Kettinger et al's (1997) frameworks for business process change.

e) The SDLC method of IS development.

f) Law and Kelton's (1991) generic methodology for simulation modelling used in the case study discussed in Chapter 3.

The combination of the above methodologies was expected to provide a sound foundation upon which a methodology of simulation-assisted IS evaluation could be developed. This approach was also expected to satisfy one of the basic design method issues identified in Chapter 4. This issue refers to the need of 'fitting' the design method within wider projects of process-based organisational design and/or IS development that are expected to be the 'umbrella' projects within which the design method would be employed in practice.

To develop the design method, each of the aforementioned four methods was analysed by the researcher in terms of the stages and activities it consists of. Based on this analysis, the five stages of ISSUE were developed. The reliability of the pattern identification and mapping process was tested in a laboratory-based test where 'judges' were asked to perform the same mapping independently of each other and of the researcher.

Because the reliability test was evaluated based on the PRL (Proportional Reduction in Loss) reliability measure proposed by Rust and Cooil (1994), we will begin our discussion by outlining the nature of the PRL.

C.2. The PRL Reliability Measure

Proportional Reduction in Loss (PRL) has been proposed as a measure for testing the reliability of inter-judge agreement on qualitative data. The method is applicable when a researcher wants to assess the consensus between judges that are asked to code a number of items into mutually exclusive qualitative categories.

The measure is founded on the premise that high inter-judge agreement indicates high reliability of the pattern identification results. Rust and Cooil (1994) have developed a model that demonstrates the explicit connection between agreement and reliability. Accordingly, the PRL measure is constructed as a reliability measure based on the average amount of 'loss' that the researcher is prepared to accept due to wrong judgements. PRL assumes values between zero and one, with higher values indicating higher data reliability. Rust and Cooil (1994) contend that a minimum of value of 0.7 (70%) is required to indicate acceptable reliability for exploratory research, while a more stringent threshold of 0.9 (90%) can be considered as the minimum acceptable PRL value for advanced practice.

C.3. ISSUE Reliability Test

Seven 'judges' participated in the test, all of them being academics and doctoral students knowledgeable in at least one of the reference disciplines of business engineering and/or in simulation modelling. The minimum number of judges needed for the test to produce valid results is dependent on the proportion of inter-judge agreement. In our case, assuming an inter-judge agreement of 0.5, we require (according to the statistical tables provided by Rust and Cooil 1994), at least three judges to ensure the minimum level of 70% reliability, or five judges to ensure the more stringent 90% reliability level. Even with inter-judge agreement being as low as 0.31, the same tables indicate that seven judges are adequate for reliable results.

Each judge was given an instruction and answer sheet as well as five additional sheets (four describing the foundational methodologies and one describing the ISSUE method). For each of the four foundational methodologies, the judges were asked to indicate which of the five stages of ISSUE better matched a particular stage of the tested methodology. The judges were instructed that the same ISSUE stage may be entered in multiple answers in the questionnaire and that no activity in the foundational methodologies should be left blank.

Table 25 illustrates the initial mapping of the ISSUE method to the four foundational methodologies. This mapping was not known to the judges at the time of the reliability test. It must be noted that the two final stages of Kettinger et al's (1997) framework, as well as the three final stages of the SDLC were not mapped to the ISSUE method, as they refer to development and post-implementation issues that were outside the scope of the design theory. The stages referred to in the Table are the respective stages of each foundational methodology, as they were described in Chapters 2 and 3 of the dissertation.

	Initiation	Simulation	Substantiation	Utilisation	Estimation
Davenport (1993)	1: Process Identification 2: Change Levers 3: Process Visions	4: Understanding Existing Processes		5: Designing and Prototyping the New Process	
Kettinger et al (1997)	1: Envision 2: Initiate	3: Diagnose		4: Redesign	
SDLC	1: Problem Identification	2: System Analysis		3: IS Requirements	4: IS Design
Law and Kelton (1991)	1: Problem Formulation 2: Data Collection 3: Conceptual Validation	4: Model Construction 5: Pilot Runs	6: Model Validation	7: Design Experiments 8: Production Runs	9: Output Analysis 10: Document Results

Table 25. Mapping of ISSUE to the Foundational Methodologies

Table 26 summarises the results of the PRL tests performed on the data provided by the judges. It is worth noting that the consensus of the judges (i.e. the majority of judgements for each stage of the foundational methodologies) coincides fully with the mapping shown in Table 25. Even when looked at their detail, the judgements are all considered as reliable according to the PRL measure. The PRL value for all stages of the foundational methodologies is greater than 70%, while in 20 out of 23 cases the RPL value is greater than 90%. It is worth noting that at the aggregate level of the foundational methodology itself, PRL values range between 95% and 99%, indicating extremely reliable mapping results.

	CONSENSUS	PAIRWISE AGREEMENTS	PAIRWISE DECISIONS	INTER-JUDGE AGREEMENT	PRL VALUE
Davenport (1993)					
Stage 1	Initiation	15	21	0.71	1.00
Stage 2	Initiation	10	21	0.48	0.94
Stage 3	Initiation	9	21	0.43	0.91
Stage 4	Simulation	9	21	0.43	0.91
Stage 5	Utilisation	9	21	0.43	0.91
TOTAL		**52**	**105**	**0.50**	**0.95**
Kettinger et al (1997)					
Stage 1	Initiation	21	21	1.00	1.00
Stage 2	Initiation	15	21	0.71	1.00
Stage 3	Simulation	11	21	0.52	0.96
Stage 4	Utilisation	7	21	0.33	0.77
TOTAL		**54**	**84**	**0.64**	**0.99**
SDLC					
Stage 1	Initiation	21	21	1.00	1.00
Stage 2	Simulation	9	21	0.43	0.91
Stage 3	Utilisation	7	21	0.33	0.77
Stage 4	Estimation	7	21	0.33	0.77
TOTAL		**44**	**84**	**0.52**	**0.96**
Law and Kelton (1991)					
Stage 1	Initiation	21	21	1.00	1.00
Stage 2	Initiation	11	21	0.52	0.96
Stage 3	Initiation	9	21	0.43	0.91
Stage 4	Simulation	11	21	0.52	0.96
Stage 5	Simulation	9	21	0.43	0.91
Stage 6	Substantiation	21	21	1.00	1.00
Stage 7	Utilisation	15	21	0.71	1.00
Stage 8	Utilisation	15	21	0.71	1.00
Stage 9	Estimation	15	21	0.71	1.00
Stage 10	Estimation	15	21	0.71	1.00
TOTAL		**142**	**210**	**0.68**	**0.99**

Table 26. Results of the PRL Tests

APPENDIX D. SUPPLEMENTARY DATA FOR CASE II

This Appendix contains a detailed description of the internal workings of the simulation model developed for the case study presented in Chapter 5 of the dissertation. The purpose of this description is twofold. Firstly, it will help defining the boundaries of the model and explaining in detail its relation to the real-world system (for example, which system elements are contained within or have been left out of the model). Secondly, it will provide further insight on the output analyses that were performed. These two elements are critical for the reader that wants to gain a thorough understanding of the simulation work carried out within the case study, but, due to space considerations, could not have been included in the main body of the thesis.

The Appendix also documents in detail the process of solution finding based on the analysis of the AS-IS model output that, again due to space considerations, is not addressed in detail in the main body of the dissertation.

However, before documenting the aforementioned issues in more detail, it is worth providing a short description and a critique of the software platform used for model development in the case study.

D.1. Process Charter

Process Charter is a basic-functionality business process simulator, focusing mainly on providing user-friendly constructs and facilities that allow modellers to build simulations quickly without requiring a great deal of expertise in simulation modelling. The basic model development process is very simple and straightforward: the modeller develops a flowchart depicting the system to be modelled using drag-and-drop icons from a 'palette' containing all standard flowchart symbols. Each node in the flowchart can then be calibrated with data needed to drive a dynamic execution of the model. Such data include duration of activities, priorities, routing options, input and output entities, resource requirements, and so on. All data can be entered using a simple graphical interface, while a *spreadsheet view* is also provided for more advanced uses. Five standard spreadsheets are included: *Activities*, *Resources*, *Assignments* (of resources to activities), *Key Values*, and *Flow Objects*. The *Key Values* feature is very useful as it directly relates to the notion of Key Performance Indicators (KPIs) discussed in the dissertation. Key values are under-defined parameters that are automatically stored for each simulation run to enable direct comparisons between critical parameters across different simulation scenarios. The *Flow Objects* spreadsheet allows the modeller to track the progress of every single temporary entity during the course of the simulation.

Process Charter provides only basic animation features, consisting only of flowchart nodes 'flashing' in different colours during the simulation run, depending on the state of each node (for example, busy, idle, or blocked). On the other hand, interaction features are more advanced, allowing for running the model at different speeds (even step-by-step) and monitoring the state of model parameters during execution.

Another very useful facility of Process Charter, as far as business process modelling is concerned, is *Calendars*. Calendars allow the modeller to specify work schedules that are later assigned to activities. For example, the modeller can specify the work shifts of employees, the time span of activities, and so on. Such a facility is extremely useful for modelling service systems as the modeller can directly specify such conditions as weekends, lunch breaks, holiday periods, etc., in a direct and very easy to use manner.

Process Charter also provides easy-to-use, automated output analyses of simulation runs. Numerical and graphical outputs for, amongst others, activities, resources, and queues, are automatically created for each simulation run and can be easily exported to other tools for further processing. Other facilities of the software include hierarchical decomposition of models, customisable system documentation, and so on.

On the minus side, all the aforementioned flexibility and ease-of-use come at a certain cost. Process Charter is not, strictly speaking, a 'real' simulator as the modeller cannot specify such important parameters as warm-up period, number of replications, and so on. Moreover, the package does not allow for using direct programming of any kind to depict complex logic that cannot be handled by the graphical interfaces. Also, despite the usefulness of the automated output analyses provided, the modeller is restricted to using *only* these data to assess model performance, as there is no provision for defining other output data to be collected during the simulation runs.

D.2. Simulation Model Activities

Based on the knowledge elicited through interviews, workshops, and direct data collection, a detailed textual description of the OFP was compiled. This description formed the basis for AS-IS simulation model development.

Both J&J and Ramma operate on an 8-hour shift (9.00-17.00) five days per week (this was modelled in Process Charter as the *Normal Shift* Calendar). Customers place approximately 20 orders per day on average without significant variations on order arrival patterns throughout the day. Therefore, in the model it has been assumed that the order inter-arrival time is exponentially distributed with a mean of 24 minutes. Roughly 40% of the customer orders are given to Ramma, 20% to J&J Thessaloniki, while the rest are collected directly by the salesmen. Almost half of the orders received by both J&J and Ramma are given over the phone while the rest are sent by fax.

The employee that handles order taking for Ramma (referred to as the *Ramma Ordering* employee) needs Normal (5,2) minutes to answer a customer phone, take the order, and key it in Ramma's order processing Information System. For a fax order, the employee time is limited to data entry and has been modelled as randomly distributed between two and three minutes. Ramma forward their orders in batch to J&J Thessaloniki for authorisation twice a day, at around 11.00 and 16.00 (*Send Orders* Calendar). All orders are forwarded by fax. The *Ramma Ordering* employee needs between two and three minutes per order to fax the orders to J&J.

Salesmen get orders from the customers they visit and deliver them to J&J Thessaloniki for authorisation when they visit the offices towards the end of their daily shift, after 16.00 every day (modelled as the *Salesman Order Delivery* Calendar).

J&J Thessaloniki do not have their own Information System, therefore they do not key-in the orders they receive. The corresponding employee (referred to as the *J&J Thessaloniki* employee) needs Normal(5,2) minutes to take a customer order by phone and note it on a pre-printed paper form. No time is spent for orders that arrive in J&J Thessaloniki by fax.

The *J&J Thessaloniki* employee is responsible for authorising all orders and needs between two and twenty minutes per order to do so (this time includes the time to fax the authorised order to Ramma). The time to authorise an order can be long as it may depend on details in the customer's contract.

When an authorised order is received, the *Ramma Ordering* employee needs to check the order for modifications (if it is an order that was initially received by Ramma) or key the order data in Ramma's order processing Information System (if it is an order initially received by J&J or a salesman). This activity takes between one and three minutes per order.

Each order is then taken by an employee at the Ramma warehouse (referred to in the model as the *Ramma Warehouse* employee). This employee checks the inventory levels for the products (an activity that lasts Normal (4,1) minutes) and issues the despatch note that has to accompany the products during delivery (an activity that takes between one and five minutes). Next, the same employee spends Normal (10,2) minutes picking the products, packing them, and scheduling their delivery.

Lorry drivers take the packed orders along with the despatch notes to deliver them to customers. Delivery schedules are different depending on the product destination. For orders that are delivered within the city of Thessaloniki (around half of the total orders), lorries leave Ramma twice a day at 09.30 and 14.30 approximately (modelled as the *Deliver Thes* Calendar). Delivery time for such products is normally distributed with a mean of 1 hour and a standard deviation of 15 minutes. For orders delivered to the rest of northern Greece, lorries leave Ramma only once a day at around 09.30 (modelled as the *Deliver Rest* Calendar). Delivery time is normally distributed with a mean of 4 hours and a standard deviation of 1 hour.

If a customer order cannot be fully executed due to stock shortages (which holds true for approximately 30% of the orders received in the AS-IS model), the *Ramma Warehouse* employee places a backorder for the missing items before issuing the despatch note for the part of the order that can be fulfilled. The creation of the backorder is done automatically by Ramma's warehouse management Information System and therefore the employee is only involved to double-check the backorder against the actual inventory level for possible mismatches (an activity that takes no more than one minute of the employee's time). Every Friday (modelled as the *Backorder Sending* Calendar), all backorders are merged into a single document (backorder list) that is sent by post to the J&J warehouse in

Mandra. The *Ramma Ordering* employee needs 10 minutes to create and send the backorder list, while the list needs two working days to reach the J&J warehouse in Mandra (modelled as the *Post* Calendar).

The backorder list is not processed as soon as it arrives at Mandra. Instead, it is placed in a queue along with similar lists sent by other J&J distributors. After a delay period that can last between two and eight hours, a warehouse employee (referred to as the *J&J Mandra* employee) processes the backorder list and schedules a shipment of products to Ramma. This activity takes approximately two hours, while the shipped products are sent along with the morning J&J deliveries. Lorries start every morning at around 10.00 (modelled as the *Replenishment Delivery* calendar) and need Normal (6,1) hours to reach the Ramma warehouse in Thessaloniki.

When the products arrive at Ramma, the *Ramma Warehouse* employee receives the products and sorts them in the warehouse. This activity takes Normal (30,5) minutes. Next, the same employee issues despatch notes and schedules deliveries for all pending backorders. This sub-process is the same as for normal order management.

Every two days (modelled as the *DN List Sending* Calendar) the *Ramma Ordering* employee prints out and sends to J&J a copy of all the despatch notes of the previous days. Preparing and sending out the despatch note list takes 10 minutes of the *Ramma Ordering* employee, while the list takes on average two working days to reach J&J (*Post* Calendar).

Similar to the backorder list, the DN list is not processed by J&J immediately upon arrival. Instead, it is placed in a queue along with similar lists sent by other J&J distributors where it stays for between two and eight hours. Afterwards, a J&J employee (modelled as the *J&J Athens* employee) keys-in all the information contained in the DN list into J&J's Information System. This activity takes between two and four minutes per despatch note. Invoices are then generated, printed, and sent to Ramma by post, needing again two working days on average to reach their destination (*Post* Calendar). When received, the *Ramma Ordering* employee sorts the invoices to be forwarded to customers (one minute per invoice approximately). Invoices are delivered to customers during the normal course of product deliveries (see above).

The following Tables depict the aforementioned process information as modelled in Process Charter. Table 27 contains the complete activity information contained in the simulation model. Table 28 describes how the various calendars that describe activity times and schedules were modelled. The columns in Table 27 contain the following information:

a) *Activity ID, Activity Name.* They refer to the activity labels in the flowchart of Chapter 5.
b) *Type.* In Process Charter an activity can be a *Starter* (when it has no inputs), an *Ender* (when it has no outputs), an *Interrupter* (when it can suspend lower priority activities to acquire resources it needs), or *Normal* (in all other cases).
c) *Inputs and Outputs.* In the Table, 'O' refers to orders, 'I' refers to invoices, and 'B' refers to backorders. When an asterisk is used (*), the activity will process all entities waiting in its input queue in a batch.
d) *Resources.* They are described in detail below.
e) *Duration.* Self-explanatory, as discussed above.
f) *Calendars.* They are explained in Table 28, and were also discussed above.
g) *Time Option.* In Process Charter an activity can have one of the following options to determine what will happen if the active time span (*calendar*) expires while the activity is running: *Suspend* (the activity will stop), *Finish Task* (the current work will finish and then the activity will stop), or *Finish All Inputs* (the activity will continue until all inputs have been processed).
h) *Run Limit.* In Process Charter an activity can have one of the following run limit settings: *Once Per Span* (the activity can be activated only once per active time span) or *None* (no limit is imposed on the number of activity runs per active span).

Activity ID	Activity Name	Type	Inputs	Outputs	Resources	Duration	Calendars	Time Option	Run Limit
1	Customer	Starter	---	O, I	---	(output interval) Expo (24) min	Normal Shift Calendar	Finish Task	None
2a	Ramma Receive Phone Order	Interrupter	O,I	O,I	Ramma Ordering	Normal(5,2) min	Normal Shift Calendar	Finish Task	None
2b	Ramma Receive Fax Order	Normal	O,I	O,I	Ramma Ordering	Random(2,3,1) min	Normal Shift Calendar	Finish Task	None
3a	J&J Receive Phone Order	Interrupter	O,I	O,I	J&J Thessaloniki	Normal(5,2) min	Normal Shift Calendar	Finish Task	None
3b	J&J Receive Fax Order	Normal	O,I	O,I	---	---	Normal Shift Calendar	Finish Task	None
4	Salesmen Receive Orders	Normal	O,I	O,I	---	---	Normal Shift Calendar	Finish Task	None
5	Send Orders for Authorisation	Normal	O,I*	O,I*	Ramma Ordering	Random(2,3,1) min / order	Send Orders	Finish All Inputs	Once per Span
6	Authorise & Forward Order	Normal	O,I	O,I	J&J Thessaloniki	Random(2,20,1) min	Normal Shift Calendar	Finish Task	None
7	Deliver Orders for Authorisation	Normal	O,I*	O,I*	---	---	Salesman Order Delivery	Finish All Inputs	None
8	Check & Key-in Order	Normal	O,I	O,I	Ramma Ordering	Random(1,3,1) min	Normal Shift Calendar	Finish Task	None
9	Check Inventory	Normal	O,I	O,I	Ramma Warehouse	Normal(4,1) min	Normal Shift Calendar	Finish Task	None
10	Issue Despatch Note (DN)	Normal	O,I	O,I	Ramma Warehouse	Random(1,5,1) min	Normal Shift Calendar	Finish Task	None
11	Pick, Pack & Schedule Shipment	Normal	O	O	Ramma Warehouse	Normal(10,2) min	Normal Shift Calendar	Finish Task	None
12a	Deliver (Thessaloniki)	Normal	O	O	---	Normal(60,15) min	Deliver Thes	Finish All Inputs	None
12b	Deliver (rest)	Normal	O	O	---	Normal(4,1) h	Deliver Rest	Finish All Inputs	None
13	Done	Ender	O	---	---	---	---	---	---
14	Create Backorder	Normal	O,I	O,I,B	Ramma Warehouse	1 min	Normal Shift Calendar	Finish Task	None
15	Create Backorder List	Normal	B,I*	B,I*	Ramma Ordering	10 min	Backorder Sending	Finish All Inputs	Once per Span
16	Send Backorder List	Normal	B,I*	B,I*	---	48 h	Post	Suspend	None
17	Wait to Process Backorder List	Normal	B,I*	B,I*	---	Random(2,8,1) h	Normal Shift Calendar	Suspend	None
18	Schedule Shipment	Normal	B,I*	B,I*	J&J Mandra	2 h	Normal Shift Calendar	Suspend	None
19	Send Shipment (Delivery)	Normal	B,I*	B,I*	---	Normal(6,1) h	Replenishment Delivery	Finish All Inputs	Once per Span
20	Receive Products & Update Inventory	Normal	B,I*	B,I*	Ramma Warehouse	Normal(30,5) min	Normal Shift Calendar	Finish All Inputs	None
21	Issue Despatch Note (DN)	Normal	B,I	B,I	Ramma Warehouse	Random(1,5,1) min	Normal Shift Calendar	Finish Task	None
22	Pick, Pack & Schedule Shipment	Normal	B	B	Ramma Warehouse	Normal(10,2) min	Normal Shift Calendar	Finish Task	None
23a	Deliver (Thessaloniki)	Normal	B	B	---	Normal(60,15) min	Deliver Thes	Finish All Inputs	None
23b	Deliver (rest)	Normal	B	B	---	Normal(4,1) h	Deliver Rest	Finish All Inputs	None
24	Done	Ender	B	---	---	---	---	---	---
25	Create DN List	Normal	I*	I*	Ramma Ordering	10 min	DN List Sending	Finish All Inputs	Once per Span
26	Send DN List	Normal	I*	I*	---	48 h	Post	Suspend	None
27	Wait to Process DN List	Normal	I*	I*	---	Random(2,8,1) h	Normal Shift Calendar	Suspend	None
28	Issue Invoices	Normal	I*	I*	J&J Athens	Random(2,4,1) min / invoice	Normal Shift Calendar	Suspend	None
29	Send Invoices	Normal	I*	I*	---	48 h	Post	Suspend	None
30	Receive Invoices & Schedule Shipment	Normal	I	I	Ramma Ordering	1 min / invoice	Normal Shift Calendar	Finish All Inputs	None
31a	Deliver Invoices (Thessaloniki)	Normal	I	I	---	Normal (60,15) min	Deliver Thes	Finish All Inputs	None
31b	Deliver Invoices (Rest)	Normal	I	I	---	Normal (4,1) h	Deliver Rest	Finish All Inputs	None
32	Done	Ender	I	---	---	---	---	---	---

Table 27. Detailed Activity Information

Calendar Name	Description
Normal Shift Calendar	Monday – Friday, 9.00 – 17.00
Send Orders	Twice a day @ 11.00 and 16.00
Salesman Order Delivery	Once a day @ 16.00
Deliver Thes	Twice a day @ 09.30 and 14.30
Deliver Rest	Once a day @ 09.30
Replenishment Delivery	Once a day @ 10.00
Backorder Sending	Every Friday @ 16.00
Post	24 hours, 6 days per week (no Sundays)
DN List Sending	Every Monday, Wednesday, and Friday @ 16.00

Table 28. Calendar Settings

D.3. Simulation Model Resources

The primary resources in the model are the employees of J&J and Ramma who carry out the various model activities.

Ramma employs nine people as follows:

a) One employee (modelled as the *Ramma Warehouse* employee) manages the warehouse-related operations, including inventory checking, creating backorders, and scheduling product shipments.

b) One employee (*Ramma Ordering* employee) manages customer orders, for example, answering phone calls and sending orders to J&J Thessaloniki for authorisation. The same employee manages the invoicing-related tasks as well as the communication with J&J Athens (for example, sending backorder lists).

c) One employee (not participating in the OFP, therefore not included in the simulation model) is a salesman responsible for acquiring new customers, visiting existing customers and maintaining relationships, providing feedback to Ramma about customers' perception of service levels, and so on.

d) Five employees are the lorry drivers. Delivery scheduling was not a consideration of the study, therefore the drivers are not explicitly modelled in the simulation.

e) Finally, Ramma's managing director (not directly influencing the OFP, therefore not included in the simulation model) is responsible for managing and overlooking the operation of Ramma, as well as managing the relationships with the customers, J&J, and other external bodies.

On the other hand, J&J employ in total more than 300 people in various locations. For the purposes of our study, only those employees that take part in the OFP were modelled:

a) One employee in J&J Thessaloniki (*J&J Thessaloniki*) who receives and authorises customer orders.
b) One employee in the Mandra warehouse (*J&J Mandra*) who manages all the warehouse operations related to Ramma.
c) One employee in the Athens headquarters (*J&J Athens*) who is responsible for handling invoices to Ramma customers.
d) A number of salesmen in Thessaloniki (not individually modelled in the simulation) who visit customers and, amongst others, get orders.

Table 29 presents the assignments of resources to activities and the priorities given to these activities. When two or more activities compete for a resource, the resource will be assigned to the activity with the lowest priority number. If the activities have equal priorities, they will alternate.

Resource	**Activity**	**Priority**
Ramma Ordering	2a. Ramma Receive Phone Order	2
	5. Send Orders for Authorisation	3
	15. Create Backorder List	3
	25. Create DN List	3
	2b. Ramma Receive Fax Order	4
	8. Check & Key-in Order	5
	30. Receive Invoices & Schedule Shipment	5
Ramma Warehouse	20. Receive Products & Update Inventory	4
	21. Issue Despatch Note (DN) (*backorders*)	4
	22. Pick, Pack & Schedule Shipment (*backorders*)	4
	9. Check Inventory	5
	10. Issue Despatch Note (DN) (*normal orders*)	5
	11. Pick, Pack & Schedule Shipment (*normal orders*)	5
	14. Create Backorder	5
J&J Thessaloniki	3a. J&J Receive Phone Order	4
	6. Authorise & Forward Order	5
J&J Mandra	18. Schedule Shipment	5
J&J Athens	28. Issue Invoices	5

Table 29. Resource Assignments and Priority Settings

D.4. Modelling Assumptions

The Order Fulfilment Process is defined to include J&J, Ramma, and the final customers. Therefore, the process is evaluated only in terms of the information and material flow between these parties. Any other parties that may be indirectly involved in the process, such as the J&J suppliers or other regional distributors, are not be taken into account as they do not influence the key performance indicators of the OFP.

As a consequence of the previous assumption, it is further assumed that the J&J warehouse in Mandra can always fulfil a backorder request received by Ramma. In other words, the replenishment of the J&J warehouse lies outside the scope of the model. This assumption is not expected to affect the validity of simulation results significantly as, according to J&J managers, the Mandra warehouse can directly fulfil backorders in the vast majority of cases.

Furthermore, the relationship and communication between J&J headquarters in Athens and J&J Thessaloniki is not modelled. Of course, there are communications between the two parties, but none of these concerns or affects the Order Fulfilment Process. The same applies to the communication between the J&J headquarters and the J&J warehouse.

Since individual product movements are not modelled, it was assumed that the existing lorry capacity in both the J&J warehouse and Ramma would always be enough to satisfy demand. In other words, the two companies never face a situation where products are ready for shipment but cannot be delivered due to a lack in transport facilities. The two companies have deliberately imposed a policy of all lorries starting their journeys at specified points in time, so that no such problems occur. In practice, all products that are ready to be shipped when the delivery schedule starts will be included in one of the lorry routes.

Finally, salesmen were also not modelled as individual entities but rather as a mechanism for delivering orders to the process. Again the reason for this assumption related to the unnecessary complexity that would be introduced to the model if salesmen were modelled individually. What concerns the particular study is the number and frequency of orders delivered by salesmen to the OFP rather than the utilisation rate of this resource. This rate would anyway be impossible to monitor since salesmen are concerned with a number of other activities, not related to the OFP.

Moreover, J&J Thessaloniki will always authorise all orders they receive and will not make any amendments to them. The first assumption reflects the fact that the number of orders modelled represents only the accepted orders, while the second represents a situation very close to actual reality (and can be further justified by the fact that individual products are not modelled anyway).

Most of the resources (Ramma and J&J employees) carry out various other duties, but only those duties that are related to the OFP are included in the model. Therefore, the utilisation of employees in the simulation does not depict their real workload conditions. Due to this, resource utilisation was not considered in the model output analyses.

D.5. Solution Finding

This section documents in detail the process of identifying potential solutions to the problems identified through the AS-IS model analysis in Chapter 5.

Information Exchange

As noted in Chapter 5, the information exchange problem relates basically to the exchange of backorder lists, despatch note lists, and invoices between J&J and Ramma. Potential solutions regarding backorders relate primarily to the *inventory replenishment policy* problem, therefore here we will be concerned only with invoices and despatch notes.

The main problem regarding the invoices in the current system refers to the high lead time for delivering invoices to customers. The major delay in the process stems from the fact that invoices have to be sent to Thessaloniki by post due to regulatory constraints (legal and taxation issues). A potential solution to overcome this problem would be for J&J Thessaloniki to issue invoices and forward them to Ramma. However, the problem then lies with the inadequate information and infrastructure the J&J office in Thessaloniki has, which would render invoice issuing problematic. Furthermore, J&J headquarters in Athens would lose valuable information regarding the payments they receive by customers.

In the light of the above, it was suggested that invoices continue to be issued by J&J Athens and be forwarded by post to Ramma. Therefore, an attempt to reduce the overall invoice lead time lies primarily with identifying mechanisms that would allow J&J Athens to issue invoices earlier.

J&J can issue invoices only after they have received the despatch notes that contain the necessary information. Despatch notes are currently being sent by post. However, there is no significant reason that would inhibit changing the means by which despatch notes are sent. In particular, despatch notes could be sent by EDI. Moreover, the need for despatch notes exchange can be eliminated altogether if an electronic connection is installed that will allow J&J to access directly the information contained in Ramma's Information System. Such a Remote Access System (RAS) would enable J&J to follow a more proactive strategy towards invoice issuing, as they could access Ramma's system to get the information needed for this activity without needing to wait for Ramma to initiate the process by sending the despatch notes.

For the purposes of benefits assessment, the EDI and RAS solutions will be considered as one, since they essentially represent different technological approaches to addressing the same KPIs in similar fashions. Therefore, it was decided that a more detailed discussion regarding the relative advantages of each solution could be postponed until after the simulation project established whether *any* of these proposals would qualify for implementation in general.

Inventory Replenishment Policy

It was suggested to abort the backorder list as a medium for informing J&J Mandra about backorders, and hence inventory shortages, in the Ramma warehouse. Instead it was proposed that backorders are sent to J&J Mandra as soon as they are created (a proposal that was deemed uneconomical) or, at least, at the end of each day.

The next question involved the means by which this information should be sent. As argued above, the use of postal services was deemed an extremely time-consuming process. Instead it was suggested that EDI/RAS adoption was examined in the TO-BE modelling phase to allow for similar changes as the ones discussed above regarding the despatch notes.

Discussions also focused on the time it takes J&J Mandra to process backorders. Under the existing situation, a backorder list that is received is placed at the end of a queue consisting of other similar lists sent to J&J by other regional distributors. However, this problem was considered to be out of scope for the particular project. Furthermore, it was believed that abolishing the backorder list would anyway help towards alleviating the problem and allow J&J Mandra to schedule replenishments more efficiently.

Another potential solution that was suggested, but was quickly rejected, was that J&J lorries do not deliver goods related to backorders to Ramma but directly to the customers. However, this would not be possible both due to practical problems (lorries starting from Athens would have to travel virtually across the country for very small deliveries) and due to the fact that Ramma would not have been able to monitor which backorders have been fulfilled.

However valid the aforementioned proposals for solutions may be they aim for the symptoms rather than the cause of the problem. Therefore, subsequent discussions with process owners focused on the root of the inventory replenishment problem, i.e. the fact that a relatively high number of backorders are created and have to be fulfilled. If the chance that Ramma is out of stock is reduced, then the need for backordering would be reduced and the overall problem would practically cease to exist.

Following that observation, further discussions were held aimed at reducing the possibility that Ramma is out of stock for products at any given time. Ramma may run out of stock for one or more of the following reasons:

a) J&J Mandra does not replenish Ramma's warehouse efficiently.
b) Ramma fail to inform J&J about their stock levels at frequent intervals or they report inaccurate levels of stock.
c) Ramma faces unusually high or seasonal demand patterns that cause them to run out of inventory.

A simple solution for the first problem would be for J&J to increase the overall levels of replenishing Ramma's warehouse. However, further to the well-known costs associated with excess inventory, it is believed that J&J do already follow a policy of rather generous replenishments. A second solution aiming simultaneously at the first and second problems above might be if J&J Mandra and Ramma share the same picture about existing Ramma stock levels. This would help J&J schedule replenishments in a more effective fashion and Ramma would not need to report its stock levels to J&J in the extant, error-prone, manner. Therefore, this solution would also enable J&J to follow a proactive approach to replenishment, without the need to wait for Ramma to report inventory problems. Such a solution might be facilitated if the companies are electronically interconnected to exchange information about stocks. This could be facilitated through some form of EDI/RAS communication that would enable J&J to have direct access to the stock picture maintained by Ramma. Such a solution would also couple with an overall approach to information exchange problems between the two companies (see above).

Data Inaccuracy

The problem of data inaccuracy, as stated above, relates primarily to the inability of J&J, under the current system, to have an accurate picture of the inventory held by Ramma in any given point in time. This problem can be solved if an electronic method of communication is established, for example the EDI or RAS system discussed above.

Work Duplication

Work duplication is essentially the same problem as data inaccuracy, in that most of the inaccuracies arise from re-typing/re-writing of information. If an EDI or RAS system is installed, J&J would not need to retype the information contained on the despatch notes (the major source of work duplication in the current system).

Order Authorisation Policy

The main problem seems to stem from the batch mode of order forwarding to J&J Thessaloniki from both Ramma and the salesmen. This results in an uneven spread of orders for J&J to deal with during the day. It was therefore initially proposed that Ramma forward orders to J&J Thessaloniki as soon as they receive them from customers. It was further examined whether J&J Thessaloniki and Ramma could be electronically linked to speed the process of exchanging orders before and after authorisation. However, this proposal was quickly ruled out due to the lack of appropriate IT infrastructure in J&J Thessaloniki. The cost of implementing and installing an electronic communication system was expected to outweigh the benefits of its intended use.

Another proposal involved automating the process of authorisation in J&J Thessaloniki. At the moment, this process is done manually by cross-checking an order against the customer's contract details. It was proposed that the contract information could be incorporated in a database in J&J Thessaloniki to speed up the authorisation process. This proposal however faced the same problems as the previous ones, i.e. the lack of appropriate infrastructure in J&J Thessaloniki and the unwillingness of the parent company to subsidise the regional office.

Another proposal aiming at the essence of the problem, involved empowering Ramma and the salesmen to authorise customer orders. Such a move would eliminate the need for forwarding every order to J&J Thessaloniki for authorisation and could thus contribute to reducing the overall order lead time. However, this proposal was also ruled out for three reasons. Firstly, it would necessitate that Ramma had access to confidential data contained in the customer contracts. Secondly, salesmen would need to acquire a means of sending the orders directly to Ramma (perhaps via a laptop and modem), a solution that was deemed not worth the cost, especially in view of the existing levels of workload. Finally, and perhaps most importantly, if J&J Thessaloniki did not have direct information about customer orders, they would lose out on the information required to update contract details for each customer.

However, a modified version of this scenario qualified for experimentation. This involves Ramma employees proceeding with the orders as soon as they receive them, while at the same time continuing to send them to J&J Thessaloniki for authorisation. This scenario was accepted because it does not present any of the problems discussed above, while at the same time allows Ramma to proceed with fulfilling an order without having to wait for authorisation. An additional reason for accepting this solution was the fact that the vast majority of orders are anyway authorised by J&J Thessaloniki without modifications.

The authorisation process is more concerned with giving J&J the information they need for contract monitoring rather than modifying or rejecting orders.

Finally, it was also examined whether customers could be encouraged to submit their orders to a single point (perhaps J&J Thessaloniki) instead of three. Such a solution was however not feasible due to business policy reasons: customers had mostly personal relationships with either a particular salesman or staff in Ramma. Both companies wanted to maintain this feeling of personal customer service as it was considered to be a source of additional revenue. For the same reasons, proposals that involved the customers sending their orders by electronic means were also quickly abolished.

Staff Inadequacies

After much discussion, it was agreed that what was initially perceived as a staffing problem in Ramma's warehouse could, at least partially, be due to problems in the *order authorisation policy* and the *inventory replenishment policy*. If the two policies are altered to regulate the workflow to the warehouse, the observed bottleneck within the warehouse may be reduced or even be eradicated. For this reason, it was decided that these two policies should be considered first, before tackling the staff inadequacy problem itself.

However, if the problem still persists after modifying the two policies, this may mean that the workload imposed on the Ramma warehouse employee may actually be too much for him to handle. In such a case, it was decided to experiment with two employees working in the Ramma warehouse.

LIST OF REFERENCES

Aalst, W.M.P van der and Hee, K.M. van (1996) Business Process Redesign: A Petri-net-Based Approach, *Computers in Industry, 29, 1*, pp. 15-26.

Ackoff, R.L. and Emery, F.E. (1972) *On Purposeful Systems*, Tavistock Publications, London.

Alstrom, P. and Madsen, P. (1992) Simulation of Inventory Control Systems, *International Journal of Production Economics, 26*, pp. 125-134.

Alter, S. (1996) *Information Systems: A Management Perspective*, 2nd edition, Benjamin Cummings Publishing, Menlo Park, CA.

Anvari, M. (1992) Electronic Data Interchange and Inventories, *International Journal of Production Economics, 26*, pp. 135-143.

Ardhaldjian, R. and Fahner, M. (1993) Using Simulation in the Business Process Reengineering Effort, *Industrial Engineering, 25, 4*, pp. 60-61.

Arthur, L.J. (1992) *Rapid Evolutionary Development: Requirements, Prototyping, and Software Creation*, Wiley, Chichester.

Avison, D.E. and Wood-Harper, A.T. (1990) *Multiview: An Exploration in Information Systems Development*, Blackwell Scientific Publications, Oxford.

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

Ba, S., Lang, K.R. and Whinston, A.B. (1997) Enterprise Decision Support Using Intranet Technology, *Decision Support Systems, 20, 2*, pp. 99-134.

Bacon, C.J. (1992) The Use of Decision Criteria in Selecting Information Systems/Information Technology Investments, *MIS Quarterly, 16, 3*, pp. 335-353.

Baily, M.N. and Chakrabarti, A. (1988) *Innovation and the Productivity Crisis*, Brookings Institution, Washington, DC.

Bakos, Y. (1998) The Emerging Role of Electronic Marketplaces on the Internet, *Communications of the ACM, 41, 8*, pp. 35-42.

Balci, O. (1994) Validation, Verification, and Testing Techniques Throughout the Life Cycle of a Simulation Study, *Annals of Operations Research, 53*, pp. 121-173.

Ballantine, J.A., Galliers, R.D. and Stray, S.J. (1994) Information System/Technology Investment Decisions: The Use of Capital Investment Appraisal Techniques in Organisations. In Brown, A. and Remenyi, D. (Eds.), *Proceedings of the 1st European Conference on IT Investment Evaluation*, Henley on Thames, England, September, pp. 148-166.

Banville, C. and Landry, M. (1989) Can the Field of MIS be Disciplined?, *Communications of the ACM, 32, 1*, pp. 48-60.

Barbeau, L.J.A. and Dececchi, T. (1997) A Framework for the Object-Oriented Design and Simulation of Information System Dynamics, *Simulation and Gaming, 28, 1*, pp. 44-64.

Barua, A. and Lee, B. (1997) An Economic Analysis of the Introduction of an Electronic Data Interchange System, *Information Systems Research, 8, 4*, pp. 398-422.

Bell, P.C., Anderson, C.K., Staples, D.S. and Elder, M. (1999) Decision-maker's Perceptions of the Value and Impact of Visual Interactive Modelling, *Omega, 27, 2*, pp. 155-165.

Bensabat, I., Goldstein, D.K. and Mead, M. (1987) The Case Research Strategy in Studies of Information Systems, *MIS Quarterly, 11, 3*, pp. 369-386.

Bergmann, B.R. (1990) A Microsimulated Model of Inventories in Interfirm Competition, *Journal of Economic Behaviour and Organisation, 14, 1*, pp. 65-77.

Beynon-Davies, P. (1995) Information Systems 'Failure': The Case of the London Ambulance Service's Computer Aided Despatch Project, *European Journal of Information Systems, 4, 3*, pp. 171-184.

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, FL, December, pp. 1206-1213.

Blacker, K. (1995) *The Basics of Business Process Re-engineering*, Edistone Books, Birmingham.

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

Boar, B.H. (1984) *Applications Prototyping: A Requirements Definition Strategy for the 80s*, Wiley, Chichester.

Boland, R.J., Jr. (1987) The Information in Information Systems. In Boland, R.J., Jr. and Hirschheim, R.A. (1987) *Critical Issues in Information Systems Research*, Wiley, Chichester.

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

Bots, P.W.G., Sol, H.G. and Verbraeck, A. (1994) Introduction to the 'Modelling the Dynamics of Organisations and Information Systems' Minitrack. In Nunamaker, J.F., Jr. and Sprague, R.H., Jr. (Eds.), *Proceedings of the 27th Hawaii*

International Conference on System Sciences, vol. IV, IEEE Computer Society Press, Los Alamitos, CA, pp. 632-634.

Bourland, K.E., Powell, S.G. and Pyke, D.F. (1996) Exploiting Timely Demand Information to Reduce Inventories, *European Journal of Operational Research, 92, 2*, pp. 239-253.

Brown, A. (1994) Appraising Intangible Benefits from Information Technology Investment. In Brown, A. and Remenyi, D. (Eds.), *Proceedings of the 1st European Conference on IT Investment Evaluation*, Henley on Thames, England, September, pp. 187-199.

Bruno, G., Briccarello, P. and Gavazzi, R. (1995) REBUS: A Dynamic Simulator for Business Process Reengineering. In Hamel, W.A. (Ed.), *Proceedings of the 13th Annual International Conference of the Association of Management*, Vancouver, Canada, August, pp. 237-249.

Brynjolfsson, E. (1993) The Productivity Paradox of Information Technology, *Communications of the ACM, 36, 12*, pp. 67-77.

Business Week (1987) Office Automation: Making it Pay Off, *Business Week, 12*, pp. 134-146.

Buzacott, J.A. (1996) Commonalities in Reengineered Business Processes: Models and Issues, *Management Science, 42, 5*, pp. 768-782.

Byrd, T.A. and Marshall, T.E. (1997) Relating Information Technology Investment to Organisational Performance: A Causal Model Analysis, *Omega, 25, 1*, pp. 43-56.

Carnall, C.A. (1995) *Managing Change in Organisations*, 2nd edition, Prentice Hall, Englewood Cliffs, NJ.

Carson, J.S. (1986) Convincing Users of Model's Validity is Challenging Aspect of Modeller's Job, *Industrial Engineering, 18, 4*, pp. 74-85.

Cash, J. and Konsynski, B.R. (1985) IS Redraws Competitive Boundaries, *Harvard Business Review, 63, 2*, pp. 134-142.

Castells, M. (1996) *The Rise of the Network Society*, Blackwell Publishers, Cambridge, MA.

Chandler, J.S. (1982) A Multiple Criteria Approach for Evaluating Information Systems, *MIS Quarterly, 6, 1*, pp. 61-74.

Checkland, P.B. (1981) *Systems Thinking, Systems Practice*, Wiley, Chichester.

Checkland, P.B. and Scholes, J. (1990) *Soft Systems Methodology in Action*, Wiley, Chichester.

Clemons, E.K. (1991) Evaluation of Strategic Investments in Information Technology, *Communications of the ACM, 34, 1*, pp. 22-36.

Cochran, W.J. and King, S.A. (1993) Using Symbolic Modelling in Business Re-engineering. In Evans, G.W., Mollaghasemi, M., Russell, E.C. and Biles, W.E. (Eds.), *Proceedings of the 1993 Winter Simulation Conference*, Los Angeles, CA, December, pp. 1177-1184.

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

Cox, B. and Ghoneim, S. (1996) Drivers and Barriers to Adopting EDI: A Sector Analysis of UK Industry, *European Journal of Information Systems, 5, 1*, pp.24-33.

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

Dalal, M.A., Erraguntla, M. and Benjamin, P. (1997) An Introduction to Using ProSim for Business Process Simulation and Analysis. In Andradottir, S., Healy, K.J., Withers, D.H. and Nelson, B.L. (Eds.), *Proceedings of the 1997 Winter Simulation Conference*, Atlanta, GA, pp. 718-724.

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

Davenport, T.H. (1993) *Process Innovation: Reengineering Work through Information Technology*, Harvard Business School Press, Boston, MA.

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

Davenport, T.H. (1998) Putting the Enterprise into the Enterprise System, *Harvard Business Review, 76, 4*, pp. 121-131.

Deloitte & Touche (1998) *1998 Global Chief Information Officers Survey*, available on request from: http://www.dtcg.com/home.html.

Denna, E.L., Perry, L.T. and Jasperson, J.S. (1995) Reengineering and REAL Business Process Modelling. In Grover, V. and Kettinger, W.J. (Eds.), *Business Process Change: Concepts, Methods and Technologies*, Idea Group Publishing, Harrisburg, PA, pp. 350-375.

Dickson, G.W., Leitheiser, R.C., Whetherbe, J.C. and Nechis, M. (1984) Key Information Systems Issues for the 1980s, *MIS Quarterly, 8, 3*, pp. 135-159.

Dijk, J.N. van, Jobing, M.J., Warren, J.R., Seeley, D. and Macri, R. (1996) Visual Interactive Modelling with SimView for Organisational Improvement, *Simulation, 67, 2*, pp. 106-120.

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

Doukidis, G.I., Mylonopoulos, N. and Lybereas, P. (1994) Information Systems Planning within Medium Environments: A Critique of Information Systems Growth Models, *International Transactions of Operational Research, 1, 3*, pp. 293-303.

Doukidis, G.I., Fragopoulou, A., Giaglis, G., Menounou, G., Mylonopoulos, N. and Pappas, J. (1995) *Sector Study for the Application of EDI in the Greek Textile/Clothing Sector* (in Greek), Research Centre, Athens University of Economics and Business, Athens.

Downs, E., Clare, P. and Coe, I. (1992) *Structured Systems Analysis Method: Application and Context*, 2nd edition, Prentice Hall, Englewood Cliffs, NJ.

Drucker, P.F. (1987) *Frontiers of Management: Where Tomorrow's Decisions are Being Shaped Today*, Heinemann, London.

Dur, R.C.J. and Bots, P.W.G. (1992) Dynamic Modelling of Organisations Using Task/Actor Simulation. In Sol, H.G. and Crosslin, R.L. (Eds.), *Dynamic Modelling of Information Systems II*, North-Holland, Amsterdam, pp. 49-74.

Earl, M.J. (1988) IT and Strategic Advantage: A Framework of Frameworks. In Earl, M.J. (Ed.), *Information Management: Its Strategic Dimension*, Clarendon Press, Oxford, pp. 33-53.

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

Eatock, J., Serrano, A., Giaglis, G.M. and Paul, R.J. (1999) A Case Study on Integrating Business and Network Simulation for Business Process Redesign. In Al-Dabass, D. and Cheng, R. (Eds.), *Proceedings of UKSIM'99: Conference of the United Kingdom Simulation Society*, Cambridge, April, pp. 114-118.

EDITEX (1993) *Report of Activities for the European EDI Project for the Textile/Clothing Sector*, EDITEX Europe Organisational Secretariat, Paris.

Eisenhardt, K.M. (1989) Building Theories from Case Study Research, *Academy of Management Review, 14, 4*, pp. 532-550.

Emmelhainz, M.A. (1993) *EDI: A Total Management Guide*, 2nd edition, Van Nostrand Reinhold, New York, NY.

Essex, D. (1995) Better Business Processes: Process Charter for Windows 1.0 from Scitor Corporation, *Byte, 20, June*, pp. 211-212.

Farbey, B., Land, F. and Targett, D. (1992) Evaluating Investments in IT, *Journal of Information Technology, 7, 2*, pp. 109-122.

Farbey, B., Land, F. and Targett, D. (1993) *How to Assess your IT Investment: A Study of Methods and Practice*, Butterworth-Heinmann, Oxford.

Farbey, B. Land, F. and Targett, D. (1998) Editorial, *European Journal of Information Systems, special issue on Information Systems Evaluation, 7, 3*, pp. 155-157.

Farhoomand, A.F. (1987) Scientific Progress of Management Information Systems, *Data Base, 18, 3*, pp. 48-56.

Fielder, K.D., Grover, V. and Teng, J.T.C. (1995) An Empirical Study of Information Technology Enabled Business Process Redesign and Corporate Competitive Strategy, *European Journal of Information Systems, 4, 1*, pp. 17-30.

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

Fuglseth, A.M. and Gronhaug, K. (1997) IT-Enabled Redesign of Complex and Dynamic Business Processes: The Case of Bank Credit Evaluation, *Omega, 25, 1*, pp. 93-106.

Furey, T.R. (1993) A Six-Step Guide to Process Reengineering, *Planning Review, 21, 2*, pp. 20-23.

Galliers, R. (Ed.) (1992a) *Information Systems Research: Issues, Methods and Practical Guidelines*, Blackwell Scientific Publications, Oxford.

Galliers, R.D. (1992b) Choosing Information Systems Research Approaches. In Galliers, R. (Ed.), *Information Systems Research: Issues, Methods and Practical Guidelines*, Blackwell Scientific Publications, Oxford, pp. 144-166.

Galliers, R.D. (1993) Towards a Flexible Information Architecture: Integrating Business Strategies, Information Systems Strategies, and Business Process Redesign, *Journal of Information Systems, 3, 3*, pp. 199-213.

Giaglis, G.M. (1996) Modelling Electronic Data Interchange Through Simulation: An Industry-Wide Perspective. In Bruzzone, A.G. and Kerckhoffs, E.J.H. (Eds.) *Proceedings of the 8th European Simulation Symposium, vol. I*, Genoa, Italy, SCS Publications, pp. 199-203.

Giaglis, G.M. and Paul, R.J. (1996) It's Time to Engineer Re-engineering: Investigating the Potential of Simulation Modelling in Business Process Redesign. In Scholz-Reiter, B. and Stickel, E. (Eds.), *Business Process Modelling*, Springer-Verlag, Berlin, pp. 313-332.

Giaglis, G.M., Paul, R.J. and Doukidis, G.I. (1997) Simulation for Intra- and Inter-Organisational Business Process Modelling, *Informatica, 21, 4*, pp. 613-620.

Giaglis, G.M. (1999) Modelling the Impact of Information Systems in Business Process Simulation Models. In Ades, M. (Ed.), *Proceedings of the 1999 Advanced Simulation Technologies Conference (Industrial and Business Simulation Symposium)*, San Diego, CA, April, pp. 172-177.

Giaglis, G.M., Mylonopoulos, N.A. and Doukidis, G.I. (1999a) The ISSUE Methodology for Quantifying Benefits from Information Systems, *Logistics Information Management, 12, 1-2*, pp. 50-62.

Giaglis, G.M., Paul, R.J. and O'Keefe, R.M. (1999b) Research Note: Integrating Business and Network Simulation Models for IT Investment Evaluation, *Logistics Information Management, 12, 1-2*, pp. 108-117.

Ginzberg, M.J. (1979) Improving MIS Project Selection, *Omega, 7, 6*, pp. 527-537.

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, FL, December, pp. 114-121.

Gradisar, M. and Pivk, A. (1993) Cost-Benefit Analysis of EDI: A Simulation Experiment. In the *Proceedings of the 6th International Conference on Electronic Data Interchange and Interorganisational Information Systems*, Bled, Slovenia, June, pp. 278-286.

Greasley, A. and Barlow, S. (1998) Using Simulation Modelling for BPR: Resource Allocation in a Police Custody Process, *International Journal of Operations and Production Management, 18, 9/10*, pp. 978-988.

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.

Gurbaxani, V. and Mendelson, H. (1990) An Integrated Model of Information Systems Spending Growth, *Information Systems Research, 1, 1*, pp. 23-46.

Hall, H. (1994) Information Strategy and Manufacturing Industry: Case Studies in the Scottish Textile Industry, *International Journal of Information Management, 14, 4*, pp. 281-294.

Hamilton, S. and Ives, B. (1982) MIS Research Strategies, *Information and Management, 5*, pp. 339-347.

Hammer, M. (1990) Re-Engineering Work: Don't Automate - Obliterate, *Harvard Business Review, 90, 4*, pp. 104-112.

Hammer, M. and Champy, J. (1993) *Reengineering the Corporation: A Manifesto for Business Revolution*, Harper Collins Publishers, New York, NY.

Hammond, J.H. (1991) Co-ordination in Textile and Apparel Channels: A Case for 'Virtual' Integration. In the *Proceedings of the 20th Annual Transportation and Logistics Educators Conference*, New Orleans, LA, pp. 113-141.

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

Harrel, C.R. and Field, K.C. (1996) Integrating Process Mapping and Simulation. In Charnes, J.M., Morrice, D.J., Brunner, D.T. and Swain, J.J. (Eds.), *Proceedings of the 1996 Winter Simulation Conference*, San Diego, CA, December, pp. 1292-1296.

Harrington, H.J. (1991) *Business Process Improvement: The Breakthrough Strategy for Total Quality, Productivity and Effectiveness*, McGraw-Hill, New York, NY.

Harrison, D.B. and Pratt, M.D. (1993) A Methodology for Reengineering Businesses, *Planning Review, 21, 2*, pp. 6-11.

Hayley, K., Plewa, J. and Watts, M. (1993) Reengineering Tops CIO Menu, *Datamation, 39, 8*, pp. 73-74.

Hedberg, S.R. (1996) AI Tools for Business Process Modelling, *IEEE Expert, 11, 4*, pp. 13-15.

Hirschheim, R.A. and Smithson, S. (1988) A Critical Analysis of Information Systems Evaluation. In Bjorn-Andersen, N. and Davis, G.B. (Eds.), *Information Systems Assessment: Issues and Challenges*, North Holland, Amsterdam, pp. 17-37.

Hirschheim, R.A. (1992) Information Systems Epistemology: An Historical Perspective. In Galliers, R. (Ed.), *Information Systems Research: Issues, Methods and Practical Guidelines*, Blackwell Scientific Publications, Oxford, pp. 28-60.

Hitt, L. and Brynjolfsson, E. (1994) The Three Faces of IT Value: Theory and Evidence. In the *Proceedings of the 15th International Conference on Information Systems*, Vancouver, Canada, pp. 263-277.

Hochstrasser, B. (1993) Quality Engineering: A New Framework Applied to Justifying and Prioritising IT Investments, *European Journal of Information Systems, 2, 3*, pp. 211-223.

Hollocks, B. (1992) A Well-Kept Secret? Simulation in Manufacturing Industry Review, *OR Insight, 5, 4*, pp. 12-17.

Hoogeweegen, M.R and Wagenaar, R.W. (1996) A Method to Assess Expected Net Benefits of EDI Investments, *International Journal of Electronic Commerce, 1, 1*, pp. 73-94.

Horn, R.L. van (1971) Validation of Simulation Results, *Management Science, 17, 5*, pp. 247-258.

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

Huber, G.P. (1984) The Nature and Design of Post-Industrial Organizations, *Management Science, 30, 8*, pp. 928-951.

Huber, G.P. and 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.

Hunt, K.L., Hansen, G.A., Madigan, E.F. and Phelps, R.A. (1997) Simulation Success Stories: Business Process Reengineering. In Andradottir, S., Healy, K.J., Withers, D.H. and Nelson, B.L. (Eds.), *Proceedings of the 1997 Winter Simulation Conference*, Atlanta, GA, December, pp. 1275-1279.

Hurrion, R.D. (1986) Visual Interactive Modelling, *European Journal of Operational Research, 23, 3*, pp. 281-287.

Iivari, J. (1988) Assessing IS Design Methodologies as Methods of IS Assessment. In Bjorn-Anderson, B. and Davies, G.B. (Eds.), *Information System Assessment: Issues and Challenges*, North Holland, Amsterdam, pp. 59-78.

Iyer, A.V. and Bergen, M.E. (1997) Quick Response in Manufacturing-Retailer Channels, *Management Science, 43, 4*, pp. 559-570.

Jackson, M. (1988) *System Development*, Prentice Hall, Englewood Cliffs, NJ.

Jarvenpaa, S.L. and Stoddard, D.B. (1998) Business Process Redesign: Radical and Evolutionary Change, *Journal of Business Research, 41, 1*, pp. 15-27.

Jelassi, T. and Figon, O. (1994) Competing through EDI at Brun Passot: Achievements in France and Ambitions for the Single European Market, *MIS Quarterly, 18, 4*, pp. 337-352.

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, Englewood Cliffs, NJ.

Jones, J. (1992) Business Process Re-engineering. In Swain, J.J., Goldsman, D., Crain, R.C. and Wilson, J.R. (Eds.), *Proceedings of the 1992 Winter Simulation Conference*, Arlington, VA, December, pp. 343-346.

Kalakota, R. and Whinston, A. (1996) *Frontiers of Electronic Commerce*, Addison-Wesley, Reading, MA.

Kasper, G.M. (1996) A Theory of Decision Support System Design for User Calibration, *Information Systems Research, 7, 2*, pp. 215-232.

Keen, P. (1991) *Shaping the Future: Business Design Through Information Technology*, Harvard Business School Press, Boston, MA.

Kekre, S. and Mukhopadhyay, T. (1992) Impact of Electronic Data Interchange Technology on Quality Improvement and Inventory Reduction Programs: A Field Study, *International Journal of Production Economics, 28, 3*, pp. 265-282.

Kettelhut, M.C. (1997) Using JAD for Strategic Initiative, *Information Systems Management, 14, 3*, pp. 29-36.

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.

Kim, H.W. and Kim, Y.G. (1997) Dynamic Process Modelling for BPR: A Computerised Simulation Approach, *Information and Management, 32, 1*, pp. 1-13.

King, W.R. and Epstein, B. (1976) Assessing the Value of Information, *Management Datamatics, 5, 4*, pp. 171-180.

King, W., Hufnagel, E. and Grover, V. (1988) Using Information Technology for Competitive Advantage. In Earl, M.J. (Ed.), *Information Management: Its Strategic Dimension*, Clarendon Press, Oxford, pp. 75-86.

Klein, M. (1994) Reengineering Methodologies and Tools, *Journal of Information Systems Management, 11, 2*, pp. 30-35.

Kuhn, T.S. (1970) *The Structure of Scientific Revolutions*, 2nd edition, University of Chicago Press, Chicago, IL.

Kumar, K. (1990) Post Implementation Evaluation of Computer-Based Information Systems: Current Practices, *Communications of the ACM, 33, 2*, pp. 203-212.

Land, F. (1992) The Information Systems Domain. In Galliers, R. (Ed.), *Information Systems Research: Issues, Methods and Practical Guidelines*, Blackwell Scientific Publications, Oxford, pp. 6-13.

Laudon, K.C. and Laudon, J.P. (1996) *Management Information Systems: Organisation and Technology*, 4th edition, Prentice Hall, Englewood Cliffs, NJ.

Law, A.M. (1991) The Many Uses of Animation and Graphics in Simulation, *Industrial Engineering, 23, 1*, pp. 20-21.

Law, A.M. and Kelton, D.W. (1991) *Simulation Modelling and Analysis*, 2nd edition, McGraw-Hill, New York, NY.

Lederer, A.L. and Prasad, J. (1993) Information Systems Software Cost Estimating: A Current Assessment, *Journal of Information Technology, 8, 1*, pp. 22-33.

Lee, A.S. (1989) A Scientific Methodology for MIS Case Studies, *MIS Quarterly, 13, 1*, pp. 33-50.

Lee, Y. and Elcan, A. (1996) Simulation Modeling for Process Reengineering in the Telecommunications Industry, *Interfaces, 26, 3*, pp. 1-9.

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

Leonard-Barton, D. (1987) The Case for Integrative Innovation: An Expert System at Digital, *Sloan Management Review, 29, 1*, pp. 7-19.

Lewis, J.F. (1993) Improving Business Using Simulation Analysis Techniques, *Industrial Engineering, 25, 2*, pp. 18-19.

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, CA, December, pp. 993-999.

Limayem, M. (1996) A Design Methodology for Embedding Decision Guidance into GDSS, *Group Decision and Negotiation, 5, 2*, pp. 143-164.

Lincoln, T. (1986) Do Computer Systems Really Pay Off?, *Information and Management, 11, 1*, pp. 25-34.

MacArthur, P.J., Crosslin, R.L. and 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.

Mahmood, M.A. (1993) Associating Organisational Strategic Performance with Information Technology Investment: An Exploratory Research, *European Journal of Information Systems, 2, 3*, pp. 185-200.

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

Mason, R. and Swanson, E. (1981) *Measurement for Management Decision*, Addison-Wesley, Reading, MA.

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.

Meel, J.W. van and Sol, H.G. (1996) Business Engineering: Dynamic Modeling Instruments for a Dynamic World, *Simulation and Gaming, 27, 4*, pp. 440-461.

Meier, J. and Sprague, R.H. (1991) The Evolution of Interorganisational Systems, *Journal of Information Technology, 6, 3-4*, pp. 184-191.

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

Mukhopadhyay, T., Kekre, S. and Kalathur, S. (1995) Business Value of Information Technology: A Study of Electronic Data Interchange, *MIS Quarterly, 19, 2*, pp. 137-156.

Mumford, E. and Weir, M. (1979) *Computer Systems in Work Design: The ETHICS Method*, Associated Business Press.

Mylonopoulos, N.A., Doukidis, G.I. and Giaglis, G.M. (1995a) Assessing the Expected Benefits of Electronic Data Interchange Through Simulation Modelling Techniques. In Doukidis, G., Galliers, R., Jelassi, T., Krcmar, H. and Land, F. (Eds.), *Proceedings of the Third European Conference on Information Systems*, Athens, Greece, pp. 931-943.

Mylonopoulos, N.A., Doukidis, G.I. and Giaglis, G.M. (1995b) Information Systems Investments Evaluation through Simulation: The Case of EDI. In Clarke, R., Gricar, J. and Navak, J. (Eds.) *Proceedings of the 8th International Conference on EDI and Interorganisational Systems*, Bled, Slovenia, pp. 12-26.

Naylor, T. H. (Ed.) (1979) *Simulation Models in Corporate Planning*, Praeger Publishers, New York, NY.

Ninios, P., Vlahos, K. and Bunn, D.W. (1995) Industry Simulation: System Modelling With an Object Oriented / DEVS Technology, *European Journal of Operational Research, 81, 3*, pp. 521-534.

Nissen, M.E. (1994) Valuing IT Through Virtual Process Measurement. In the *Proceedings of the 15th International Conference on Information Systems*, Vancouver, Canada, December, pp. 309-323.

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

Nygaard-Andersen, S. and Bjorn-Andersen, N. (1994) To Join or not to Join: A Framework for Evaluating Electronic Data Interchange Systems, *Journal of Strategic Information Systems, 3, 3*, pp. 191-210.

O'Brien, J. (1993) *Management Information Systems*, Irwin Publishers, Boston, MA.

OECD (1995) *OECD Economic Surveys: Greece 1995*, Organisation for Economic Co-operation and Development, Paris.

Opdahl, A.L. and Sindre, G. (1996) Towards an Integrated, Simulative Framework for Real-World Modelling. In Nunamaker, J.F., Jr. and Sprague, R.H., Jr. (Eds.), *Proceedings of the 29th Hawaii International Conference on System Sciences, vol. III*, IEEE Computer Society Press, Los Alamitos, CA, pp. 515-524.

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

Ould, M.A. (1995) *Business Processes: Modelling and Analysis for Re-engineering and Improvement*, Wiley, Chichester.

Oz, E. (1994) When Professional Standards are Lax: The CONFIRM Failure and its Lessons, *Communications of the ACM, 37, 10*, pp. 29-36.

Painter, M.K., Fernades, R., Padmanaban, N. and Mayer, R.J. (1996) A Methodology for Integrating Business Process and Information Infrastructure Models. In Charnes, J.M., Morrice, D.J., Brunner, D.T. and Swain, J.J. (Eds.), *Proceedings of the 1996 Winter Simulation Conference*, San Diego, CA, December, pp. 1305-1312.

Parker, M.M., Benson, R.J. and Trainor, H.E. (1988) *Information Economics: Linking Business Performance to Information Technology*, Prentice Hall, Englewood Cliffs, NJ.

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. (1993) Why Users Cannot 'Get What They Want', *ACM SIGOIS Bulletin, 14, 2*, pp. 8-12.

Paul, R.J. and Balmer, D.W. (1993) *Simulation Modelling*, Chartwell-Bratt Publishing, Lund, Sweden.

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.

Pidd, M. (1992) *Computer simulation in management science*, 3rd edition, Wiley, Chichester.

Polkinghorne, D. (1983) *Methodology for the Human Sciences: Systems of Inquiry*, State University of New York, New York, NY.

Popper, K.R. (1959) *The Logic of Scientific Discoveries*, Hutchinson Publishers, London.

Porter, M. (1985) *Competitive Advantage: Creating and Sustaining Superior Performance*, Free Press, New York, NY.

Powell, P. (1992) Information Technology Evaluation: Is it Different?, *Journal of the Operational Research Society, 43, 1*, pp. 29-42.

ProSci (1998) *Best Practices in Managing Change*, Loveland, CO.

Pruett, J.M. and Vasudev, V.K. (1990) MOSES: Manufacturing Organisation Simulation and Evaluation System, *Simulation, 54, 1*, pp. 37-45.

Purvis, R. and Sambamurthy, V. (1997) An Examination of Designer and User Perceptions of JAD and the Traditional IS Design Methodology, *Information and Management, 32, 3*, pp. 123-135.

Raymond, L., Pare, G. and Bergeron, F. (1995) Matching Information Technology and Organisational Structure: An Empirical Study with Implications for Performance, *European Journal of Information Systems, 4, 1*, pp. 3-16.

Reekers, N. (1994) Electronic Data Interchange Use in German and US Organisations, *International Journal of Information Management, 14, 5*, pp. 344-356.

Reekers, N. and Smithson, S. (1994) EDI in Germany and the UK: Strategic and Operational Use, *European Journal of Information Systems, 3, 3*, pp. 169-178.

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

Rhodes, E. and Carter, R. (1993) IT and Innovation in the Textile Supply Chain: Issues in the Introduction of Quick Response and Electronic Data Interchange Systems and their Gender and Skill Implications. In Gornostaev, J. and Thomas, R. (Eds.), *Proceedings of the 2nd International Conference on Information Technology and People, vol. I*, Moscow, May, pp. 164-180.

Riggins, F.J. and Mukhopadhyay, T. (1994) Interdependent Benefits from Interorganisational Systems: Opportunities for Business Partner Reengineering, *Journal of Management Information Systems, 11, 2*, pp. 37-57.

Rivard, E. and Kaiser, K. (1989) The Benefits of Quality IS, *Datamation, January*, pp. 53-58.

Roach, S.S. (1991) Services Under Siege: The Restructuring Imperative, *Harvard Business Review, 69, 5*, pp. 83-91.

Rockart, J.F. and Short, J.E. (1989) IT in the 90s: Managing Organizational Interdependence, *Sloan Management Review, 30, 4*, pp. 7-17.

Rust, R.T and Cooil, B. (1994) Reliability Measures for Qualitative Data: Theory and Implications, *Journal of Marketing Research, 31, 1*, pp. 1-14.

Sargent, R.G. (1994) Tutorial of Verification and Validation of Simulation Models. In Tew, J.D., Manivannan, S., Sadowski, D.A. and Seila, A.F. (Eds.) *Proceedings of the 1994 Winter Simulation Conference*, Lake Buena Vista, FL, pp. 77-87.

Sassone, P.G. (1987) Cost-Benefit Methodology for Office Systems, *ACM Transactions on Office Information Systems, 5, 3*, pp. 273-289.

Sauer, C.H. and MacNair, E.A. (1983) *Simulation of Computer Communication Systems*, Prentice Hall, Englewood Cliffs, NJ.

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

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

Scitor Corporation (1995) *Process Charter User Guide (Version 1.1)*, Scitor Corporation, Menlo Park, CA.

Scott-Morton, M.S. (Ed.) (1991) *The Corporation of the 1990s: Information Technology and Organisational Transformation*, Oxford University Press, New York, NY.

Shannon, R.E. (1975) *Systems Simulation: the art and the science*, Prentice Hall, Englewood Cliffs, NJ.

Simon, H. (1981) *Sciences of the Artificial*, 2nd edition, MIT Press, Cambridge, MA.

Skinner, R.C. (1992) Fashion Forecasting at Oxford Shirtings. In the *Proceedings of the Quick Response Conference*, Chicago, IL, March, pp. 90-107.

Smithson, S. and Hirschheim, R. (1998) Analysing Information Systems Evaluation: Another Look at an Old Problem, *European Journal of Information Systems, 7, 3*, pp. 158-174.

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

Sprague, R.H., Jr. and McNurlin, B.C. (1993) *Information Systems Management in Practice*, 3rd edition, Prentice Hall, Englewood Cliffs, NJ.

Srinivasan, K., Kekre, S. and Mukhopadhyay, T. (1994) Impact of Electronic Data Interchange on JIT Shipments, *Management Science, 40, 10*, pp. 1291-1304.

Stalk, G. and Hout, T.M. (1990) *Competing Against Time: How Time-based Competition is Reshaping Global Markets*, Free Press, New York, NY.

Stein, E.W. and Zwass, V. (1995) Actualising Organisational Memory with Information Systems, *Information Systems Research, 6, 2*, pp. 85-117.

Stoddard, D.B., Jarvenpaa, S.L. and Littlejohn, M. (1996) The Reality of Business Reengineering: Pacific Bell's Centrex Provisioning Process, *California Management Review, 38, 3*, pp. 57-76.

Strassman, P. (1985) *Information Payoff: The Transformation of Work in the Electronic Age*, Free Press, New York, NY.

Strassman, P. (1990) *The Business Value of Computers*, Information Economics Press, New Canaan, CN.

Sullivan, P. and Kang, J. (1999) Quick Response Adoption in the Apparel Manufacturing Industry: Competitive Advantage of Innovation, *Journal of Small Business Management, 37, 1*, pp. 1-13.

Swami, A. (1995) Building the Business Using Process Simulation. In Alexopoulos, C., Kang, K., Lilegdon, W.R. and Goldsman, D. (Eds.), *Proceedings of the 1995 Winter Simulation Conference*, Arlington, VA, pp. 1081-1086.

Talwar, R. (1993) Business Reengineering: A Strategy-Driven Approach, *Long Range Planning, 26, 6*, pp. 22-40.

Tardieu, H. (1992) Issues for Dynamic Modelling Through Recent Development in European Methods. In Sol, H.G. and Crosslin, R.L. (Eds.), *Dynamic Modelling of Information Systems II*, North-Holland, Amsterdam, pp. 3-24.

TEDIS (1993) *Trade EDI Systems Programme: Interim Report 1993*, Office for Official Publications of the European Communities, Luxembourg.

TEDIS (1996) *TEDIS Evaluation: Final Report*, European Commission, Brussels (confidential document prepared by Ernst & Young on behalf of the European Commission).

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

Thomasma, T. and Chen, Y. (1992) New Research Problems in Dynamic Modelling of Information Systems. In Sol, H.G. and Crosslin, R.L. (Eds.), *Dynamic Modelling of Information Systems II*, North-Holland, Amsterdam, pp. 399-406.

Tricker, R.I. (1992) The Management of Organizational Knowledge. In Galliers, R. (Ed.) *Information Systems Research: Issues, Methods and Practical Guidelines*, Blackwell Scientific Publications, Oxford, pp. 14-27.

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

Tsalgatidou, A., Louridas, P., Fesakis, G. and Schizas, T. (1997) Multilevel Petri Nets for Modeling and Simulating Organizational Dynamic Behavior, *Simulation and Gaming, 27, 4*, pp. 484-506.

Turban, E., McLean, E. and Wetherbe, J. (1996) *Information Technology for Management: Improving Quality and Productivity*, Wiley, Chichester.

Tushman, M.L. and 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.

Vedin, B.A. (Ed.) (1994) *Management of Change and Innovation*, Aldershot, Dartmouth.

Venkatraman, N. (1991) IT-induced Business Reconfiguration. In Scott-Morton, M.S. (Ed.), *The Corporation of the 1990s: Information Technology and Organisational Transformation*, Oxford University Press, New York, NY, pp. 122-158.

Venkatraman, N. (1994) IT-Enabled Business Transformation: From Automation to Business Scope Redefinition, *Sloan Management Review, 35, 2*, pp. 73-87.

Verbraeck, A. (1992) Dynamic Modelling of Information Systems: Refining the Research Agenda. In Sol, H.G. and Crosslin, R.L. (Eds.), *Dynamic Modelling of Information Systems II*, North-Holland, Amsterdam, pp. 407-411.

Vogel, D., de Vreede, G.J., Bots, P.W.G., Sol, H.G. and Verbraeck, A. (1996) Introduction to the 'Business Process Re-engineering and the Dynamics of Organisations and Information Systems' Minitrack. In Nunamaker, J.F., Jr. and Sprague, R.H., Jr. (Eds.), *Proceedings of the 29th Hawaii International Conference on System Sciences, vol. III*, IEEE Computer Society Press, Los Alamitos, CA, p. 450.

de Vreede, J.G., Vogel, D., Verbraeck, A. and Sol, H.G. (1997) Introduction to the 'Dynamics of Business Engineering' Minitrack. In Nunamaker, J.F., Jr. and

Sprague, R.H., Jr. (Eds.), *Proceedings of the 30th Hawaii International Conference on System Sciences, vol. II*, IEEE Computer Society Press, Los Alamitos, CA, p. 178.

de Vreede, J.G., Vogel, D., Verbraeck, A. and Sol, H.G. (1998) Introduction to the 'Dynamics of Business Engineering' Minitrack. In Nunamaker, J.F., Jr. (Ed.), *Proceedings of the 31st Hawaii International Conference on System Sciences, vol. I*, IEEE Computer Society Press, Los Alamitos, CA, p. 632.

de Vreede, J.G., Vogel, D., Qureshi, S., Verbraeck, A. and Sol, H.G. (1999) Introduction to the 'Engineering Organisational Processes and Systems' Minitrack. In Sprague, R., Jr. (Ed.), *Proceedings of the 32nd Hawaii International Conference on System Sciences*, IEEE Computer Society Press, Los Alamitos, CA.

Walls, J.G., Widmeyer, G.R. and El Sawy, O.A. (1992) Building an Information System Design Theory for Vigilant EIS, *Information Systems Research, 3, 1*, pp. 36-59.

Ward, J., Taylor, P. and Bond, P. (1996) Evaluation and Realisation of IS/IT Benefits: An Empirical Study of Current Practice, *European Journal of Information Systems, 4, 4*, pp. 214-225.

Warren, J.R. and Stott, J.W. (1992) CASE/Simulation: Making Performance Evaluation a Normal Part of Information Systems Development. In Sol, H.G. and Crosslin, R.L. (Eds.), *Dynamic Modelling of Information Systems, II*, North-Holland, Amsterdam, pp. 219-250.

Warren, J.R., MacArthur, P.J. and Crosslin, R.L. (1994) A Dynamic Modelling Toolkit to Add Rigor to Business Process Re-engineering. In Nunamaker, J.F., Jr. and Sprague, R.H., Jr. (Eds.), *Proceedings of the 27th Hawaii International Conference on System Sciences, vol. IV*, IEEE Computer Society Press, Los Alamitos, CA, pp. 683-692.

Warren, J.R. (1996) Guest Editorial: Simulation of Information Systems, *Simulation and Gaming, 27, 4*, pp. 438-439.

Warren, J.R., Dijk, J.N. van and Jobing, M.J. (1997) Human Factors in the Simulation of Information Systems, *Simulation and Gaming, 28, 1*, pp. 65-87.

Wastell, D.G., White, P. and Kawalek, P. (1994) A Methodology for Business Process Redesign: Experiences and Issues, *Journal of Strategic Information Systems, 3, 1*, pp. 23-40.

Watson, R.T. and Brancheau, J.C. (1991) Key Issues in Information Systems Management: An International Perspective, *Information and Management, 20*, pp. 213-233.

Weill, P. and Olson, M.H. (1989) Managing Investment in Information Technology: Mini Case Examples and Implications, *MIS Quarterly, 13, 1*, pp. 3-17.

Whiting, R.E., Davies, J. and Knul, M. (1993) Investment Appraisal for IT Systems, *BT Technology Journal, 11, 2*, pp. 193-211.

Willcocks, L. and Lester, S. (1991) Information Systems Investments: Evaluation at the Feasibility Stage of Projects, *Technovation, 11, 5*, pp. 283-302.

Willcocks, L. (1992a) IT Evaluation: Managing the Catch-22, *European Management Journal, 10, 2*, pp. 220-229.

Willcocks, L. (1992b) Evaluating Information Technology Investments: Research Findings and Reappraisal, *Journal of Information Systems, 2, 4*, pp. 243-268.

Willcocks, L. and Griffiths, C. (1994) Predicting Risk of Failure in Large-Scale Information Technology Projects, *Technological Forecasting and Social Change, 47, 2*, pp. 205-228.

Winston, W.L. (1987) *Operations Research: Applications and Algorithms*, PWS Publishers, Boston, MA.

Wiseman, D. (1992) Information Economics: A Practical Approach to Valuing Information Systems, *Journal of Information Technology, 7*, pp. 169-176.

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

Wood-Harper, A.T. (1992) Viewpoint: Action Research, *Journal of Information Systems, 2, 3*, pp. 235-236.

Yarden, S. (1997) Evaluating the Performances of Electronic Commerce Systems. In Andradottir, S., Healy, K.J., Withers, D.H. and Nelson, B.L. (Eds.), *Proceedings of the 1997 Winter Simulation Conference*, Atlanta, GA, December, pp. 1053-1056.

Yin, R.K. (1994) *Case Study Research: Design and Methods*, 2nd edition, SAGE Publications, Thousand Oaks, CA.

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

Yu, E.S.K., Mylopoulos, J. and Lesperance, Y. (1996) AI Models for Business Process Reengineering, *IEEE Expert, 11, 4*, pp. 16-23.