KNOWLEDGE REPRESENTATION WITHIN INFORMATION SYSTEMS IN MANUFACTURING ENVIRONMENTS

A thesis submitted for the degree of Doctor of Philosophy

By

Amir M. Sharif

Department of Information Systems and Computing, Brunel University

May 2004

Abstract

Representing knowledge as information content alone is insufficient in providing us with an understanding of the world around us. A combination of context as well as reasoning of the information content is fundamental to representing knowledge in an information system. Knowledge Representation is typically concerned with providing structures and theories that are used as a basis for intelligent reasoning. For this research however, the author defines an alternative meaning, which is related to how knowledge is used in a given context. Thus, this dissertation provides a contribution to the field of knowledge within information systems, in terms of the development of a *frame-of-reference* that will support the reader in navigating through the different forms of explicit and tacit knowledge use within the manufacturing industry. In doing so, the dissertation also presents the generation of a novel classification of three forms of knowledge (Structural, Interpretive and Evaluative forms); the development of a conceptual framework which highlights the drivers for knowledge transformation; and the development of a conceptual model which seeks to envelop both the content as well as the context of knowledge (Semiotic as well as Symbiotic factors). This is established through the use of an Empirical, Quantitative case study approach, that seeks to explore an interpretivist view of knowledge representation within two information systems contexts, within two UK manufacturing organisations. The first case study presents how *a-priori* knowledge assumptions are used in a computer aided engineering decision-making task within a high technology manufacturing company. The second case study shows how knowledge is used within the IT/IS investment evaluation decision making process, within a manufacturing SME. In doing so, both case studies attempt to elucidate the inherent, underlying relationship between explicit and tacit knowledge, via a frame-of-reference developed by the author which defines key drivers for knowledge transformation.

Keywords: Knowledge, Information Systems, Explicit and Tacit Knowledge, Case Study

Contents

List of Figures

List of Tables

Glossary of Terms

Term	Description
AI	Artificial Intelligence
CAE	Computer Aided Engineering
CBA	Cost Benefit Analysis
CNC	Computer Numerically Controlled
Company A	Case Study Participant Organisation, Chapter 5
Company B	Case Study Participant Organisation, Chapter 6
FC	Fuzzy Cognitive Map(ping)
FEA	Finite Element Analysis
FEM	Finite Element Method
FEMG	Finite Element Mesh Generation
FL	Fuzzy Logic
GA	Genetic Algorithm
IA	Information Architecture
IR	Information Retrieval
IS	Information System(s)
IT	Information Technology
KBES	Knowledge-Based Expert System
KM	Knowledge Management
KW	Knowledge Work
Manager M	Managing Director, Case Study Participant Individual, Chapter 5
Manager N	Production Manager, Case Study Participant Individual, Chapter 6
MPS	Master Production Schedule
MRPII	Manufacturing Resource Planning
NC	Numerically Controlled
NN	Neural Network(s)
NPV	Net Present Value
PCS	Production Control System
PPC	Production Planning and Control
SFD	Shop Floor Documentation
SME	Small and Medium-sized Enterprise (European Union definition, Chapter 3)
TQM	Total Quality Management
User X	Case Study Participant Individual, Chapter 5
Vendor V	Case Study Software Vendor, Chapter 6

Dedicated to my Parents and family

Acknowledgements

Any piece of written work requires commitment, long hours and lots of thinking (which can be painful at times). Sometimes, this task is just as difficult for those loved ones, family and friends alike, who share this journey perhaps unexpectedly, but with the same wishes and expectations that the work will one day be concluded. For me, this has truly been a long and difficult journey, taking the best part of 8 years of my life, within the course of which I have changed supervisors 3 times; secured and changed full-time employment twice; got married; become a father; and last but not not least, moved house as well! Needless to say that over the course of this time, the focus of the research has changed immensely, from a purely computational to a wholly Information Systems viewpoint (and I am glad for that change also).

I thank God for giving me insight where and when I needed it, and for giving me the chance to finish what I started way back in the autumn of 1995.

I would like to say a special thank you to my supervisor, Professor Zahir Irani, without whom I would not have been able to complete this mammoth task. The encouragement, support and motivation I have received within the last months of the PhD, were invaluable to me, and I doubt I would have had the impetus to finish the dissertation, without Zahir to support and guide me.

I would also like to thank my family for sticking by me in the days and nights that it took to finish these pages (in order of most recent suffering!): my wife, Faiza, and daughter, Noor; my mother and father; my sisters, brother and brothers-in-law. You never gave up on me, and your prayers, support and encouragement kept me going, even when I thought I wouldn't be able to make it.

And finally, many thanks to all those close friends too who kept on asking me to "Haven't you finished it yet? How much longer do you have to go?": thanks guys, truly great friends to have! Thank you one and all.

Amir Sharif

Publications arising from the Thesis

Sharif, A. (1997). "The Management of Intelligence-Assisted Finite Element Analysis Technology". In *Proc. Portland International Conference on Management of Engineering and Technology (PICMET'97)*, Portland, Oregon, July 27-31st 1997, Portland, OR : Portland State University / IEEE / Informs, pp.2550-2555.

Sharif, A., and Ettinger, R.D. (1997). "Finite Element Mesh Generation using Genetic Algorithms". In (Ed. J.R. Koza). *Proc. Late Breaking Papers, Genetic Programming 1997*, Stanford University, Stanford, USA, July 13-16th, 1997, Stanford, CA : Stanford University Bookshop, pp.219-223.

Irani, Z., and **Sharif, A.** (1997). "Genetic Algorithm Optimisation of Investment Justification Theory". In (Ed. J.R. Koza). *Proc. Late Breaking Papers, Genetic Programming 1997*, Stanford University, Stanford, USA, July 13-16th, 1997, Stanford, CA : Stanford University Bookshop, pp. 88-91.

Sharif, A.M., and Barrett, A.N. (1998). "Utilising knowledge for optimum mesh design". *IEE Colloquium on Knowledge Discovery and Data Mining*, IEE, London, 7-8 May 1998. Digest No. 98/310, London : IEE, pp.4/1-4/5.

Sharif, A.M., and Barrett, A.N. (1998). "Seeding a genetic population for mesh optimisation and evaluation". In (Ed. J.R. Koza). *Proc. Late Breaking Papers, Genetic Programming 1998*, University of Wisconsin, Madison, USA, July 22-25th, 1998, WI, Omni Press, pp.195-201.

Irani, Z., and **Sharif, A. M.** (1998). "A revised perspective on the evaluation of IT/IS Investments using an Evolutionary approach". In (Ed. J.R. Koza). *Proc. Late Breaking Papers, Genetic Programming 1998*, University of Wisconsin, Madison, USA, July 22-25th, 1998, WI, Omni Press, pp.77-84.

Sharif, A.M. (1999). "Neural and Evolutionary Computing in Finite Element Analysis". *Journal of Computing and Information Technology*, **7** (1), pp.105-119.

Sharif, A.M. (1999). "Harnessing agile concepts for the development of Intelligent Systems". *New Generation Computing*, **17** (4) : 369-380.

Sharif, A.M., and Irani, Z. (1999). "Research note : Theoretical Optimisation of IT/IS Investments". *Logistics Information Management,* **12** (2) : 189 - 196.

Irani, Z., **Sharif, A.M.**, and Love, P.E.D. (2001). "Transforming Failure into Success through Organizational Learning: An analysis of a Manufacturing Information System". *European Journal of Information Systems*, **10** (1) : 55-66.

Irani, Z. **Sharif, A. M.**, Love, P.E.D., and Kahraman, C. (2002). "Applying Concepts of Fuzzy Cognitive Mapping to model IT/IS Investment Evaluation". *International Journal of Production Economics*, **75** (1) : 199-211.

Badii, A., and **Sharif, A.M.** (2003). "Integrating Information and Knowledge for Enterprise Innovation". *Logistics Information Management*, **16** (2) : 145 - 155.

CHAPTER 1

Introduction

This opening chapter provides the background to the thesis in terms of the need to investigate the relationship between information, knowledge, and how it is represented, codified and used. In providing a context for understanding the dissertation topic, the author considers the manner in which knowledge is used within knowledge-intensive information systems and environments, such as those found within manufacturing, in order to assist in decision making processes. Subsequently, a case is then made for investigating the relationship between explicit (content-based) and tacit (context-based) knowledge, via an empirical, qualitative case study research approach. In doing so, an outline of the dissertation is provided, with regards to the overall research objectives, research methodology, research design and focal theory which is to be used in order to synthesise and develop a frame of reference for knowledge representation within the context of manufacturing IS environments.

Introduction

The existence and creation of this planet occurred many millions of years ago. Human beings have been on Earth for only a fraction of this period, and in this time have tried to find ways in which to try to appreciate and understand their relationship with the real world. Religion has brought mankind reasons for its existence and art has brought it a method for expressing its emotions. But, it is science and technology that has brought mankind its greatest advances, and has helped to supplant human knowledge through the fundamental processes of conjecture, theory and experiment.

This combination of both subjective abstraction of thought and creative insight, has given many mathematicians, scientists, philosophers and artists the impetus to develop representations of physical, as well as man-made phenomena in the world around us. Using behavioural observation, researchers in psychology as well as computer science have over the last 25 years, attempted to model the manner in which knowledge and information is processed and represented. As such, the boundaries between Information Technology (IT), which encompasses hardware, software and peripheral devices, and Information Systems (IS), which encompass the socio-technological aspects of IT usage, have increasingly blurred. Where the distinction between IT and IS occurs, is in the way in which IS typically refers to environments which support the flow of information between human stakeholders, in order for that information to be processed. Once processed, this information is then utilisable in such a way as to be useful for other information flow tasks (such as decision making, problem solving and the like). Thus, and as Gupta (1996) states, an IS is a system which predominantly creates, processes, stores and retrieves information. As a result, the development and evolution of computers from their humble beginnings as purely computational devices, to information processing tools, has led to the emergence of the sub-disciplines within computing relating to knowledge processes. With the continual increase in computer performance, and the manner in which computers are utilised to assist in information-intensive tasks, the importance of understanding what constitutes information and knowledge in this context, is increasingly important.

The flexibility and ease with which information and knowledge can be stored and represented within computer systems, has lead to an exponential increase in the volume of information that is stored within computerised information systems.

Perversely, this has also subsequently led to an increase in the complexity of the knowledge contained therein, and the related consumption of that knowledge. Indeed, as has been found as a result of the literature review within Chapter 2 of this dissertation, the increased availability of information to the masses, has led to quite literally led to information overload. The complexity of managing and representing knowledge in its most effective form thus becomes paramount. Lyman and Varian (2000) in their on-going research to measure how much information is produced in the world each year, report that as a planet, approximately up to 2 Exabytes of information (i.e. 100 billion Gigabytes, 100 million Terabytes or 1 x 10^{18} bytes) are produced in terms of paper, film, optical and magnetic media. This equates to 250 megabytes for every man, woman and child on Earth, *per year*. To give an indication of the enormity of this information, it should be considered that 1 Terabyte is equal to the textual content of 1 million books. Simply the fact that our consumption and appetite for information has grown to such levels and continues to grow at a rate of 50% or more each year, and also the fact that according to Lyman and Varian, every individual will be able to access virtually all recorded information ever, is a sobering indicator of the need to make sense information. In 1999 alone, it is estimated that over 90% of all information produced globally was in digital format (i.e. that which was originally sourced and encoded within and using information technology formats and processes).

Whilst this can be seen as a purely computational matter in some respects, there is a clear need to not only understand the process of creating, storing and disseminating information within an information system (i.e. the codification), but also to understand the manner by which such information is both presented and used in relation to individuals (i.e. the sublimation of information into useful data, or knowledge). As Sorensen and Kakihara (2002) note,

> *'It is important that we recognise the need for a symmetrical debate between the ways in which technologies construct us and the ways in which we construct technologies.'*

(Sorensen and Kakihara 2002, pp.8)

This further elucidates the contingent differences between IT and IS, and seeks to highlight the fact that purely encoding data in itself does not provide a context for using information and harnessing knowledge effectively.

Thus, the aim of this thesis is to investigate and postulate the dynamic interplay between both explicit (formalised) and tacit (intuitive) knowledge, by observing participants with regard to two particular information systems within the manufacturing sector. Through analysing the nature of computer aided engineering (CAE) as well as manufacturing resource planning (MRP) tasks, the research seeks to provide a frame-of-reference for the effective representation of knowledge in these specific terms cases.

The remainder of this chapter serves as a basis for placing the dissertation within a research context, through defining the research focus, research aims and objectives and thesis structure.

Research Focus

The focus of this dissertation will be to develop a frame-of-reference, to assist in the understanding of the nature of knowledge embedded within these particular cases. Subsequently, the goal of the research herein, is to provide key *characteristics of the representation of knowledge, in the context of information systems within manufacturing environments*. For clarity, in this thesis the term 'representation', is defined in terms of the literal exposition and of knowledge. As such the term 'knowledge representation', in this light, is not meant to signify the semantic structure of knowledge as is generally defined in the field of Artificial Intelligence, such as through Natural Language Processing (Genesereth and Nilsson, 1987).

Rather, this dissertation is focused on those aspects of knowledge which are dependent upon human processes and tasks, and not based upon a set of representations which are defined in computational or algorithmic structures. Furthermore, the term 'environment', relates the information system in question to its stakeholders and their related working practices, which are required in order to carry out business process tasks. This can also be viewed in the terms of Checkland's view of IT/IS with respect to the fact that IT/IS should not just be viewed as a means to an end (i.e. the provision of computers or technology), but rather in terms of how an organisation or individual conceptualises and realises technology within a given context of process and stakeholder relationships (Checkland, 1981). Through an empirical analysis of two case studies in the area, the thesis attempts to provide an insight into how knowledge is represented and handled, via both positivist and interpretivist stances.

The first study investigates the nature of a typical problem-solving / creative task, which is heavily dependent upon *a-priori* knowledge of some kind. In particular, the study highlights information dependencies relating to computer aided engineering tasks within the design and analysis of electromagnetic waveguiding devices, by an electrical engineer. These minute components are built into lasers, telecommunications networks and other such switching devices. The essential operation of a waveguide relies upon a beam of light passing through it. Since the speed of light is far in excess of that of electrical impulses, waveguides have the potential of being the basis of the next generation of computers. In order to model and analyse such devices effectively, a combination of both theoretical grounded scientific knowledge is required.

This knowledge can be said to be "hard" or explicit, with respect to the enforceability of hermeneutic rules and concepts within the science of physics. However, there is also a certain degree of "soft" or tacit empirical knowledge that is required in order to provide assistance with the decision making task relating to putting the "hard" scientific knowledge in context. Thus, there is a clear relationship between not only the content, but also the usage of information in the right manner.

The second case study, involves a similar information process task, but taken from the aspect of observing how "hard" knowledge is used in order to rationalise and contextualise "soft" knowledge.

Through witnessing the decision making task of IT/IS cost evaluation within a medium-sized manufacturing company, this latter interpretivist view, seeks to also show the inherent link between the content and context of knowledge once again.

Research Aim and objectives

As such, the aim of the research within this dissertation is to develop a frame-of-reference in order to distinguish between different forms of knowledge within two manufacturing IT/IS scenarios. This should provide an outline of the boundaries between hard (explicit) and soft (tacit) knowledge, and the relationship between knowledge context and content within decision-making tasks. Based upon the definition of this research aim, the objectives of this research are:

- To carry out a critique and review of the literature within the area and thenceforth to produce a taxonomy of views of knowledge representation within Information Systems, in order to provide a background to the research;

- Generate focal theory which is the genesis of the thesis, based around the concepts of knowledge – specifically, organisations within the manufacturing sector which have a dependency or inherent requirement to utilise Information Systems;

- Develop a research methodology that is able to capture and generate data to test the focal theory, via a specific research design;

- Use empirical evidence to analyse and test the data collected in comparison to the focal theory generated;

- To develop a frame-of-reference for knowledge representation within manufacturing information systems environments, which involve knowledge required within decision-making tasks.

In striving to achieve these objectives, the thesis aims to highlight the importance of the way in which knowledge is viewed and used for particular decision-making and process intensive tasks, by modelling the relationship between the information consumer the knowledge itself.

Study scope and Thesis

In their book on knowledge creating companies, Nonaka and Takeuchi (1995) explain the different kinds of knowledge by talking about tacit and explicit knowledge. Polanyi (1966) also mentions the tacit dimension based on the fact that *"we can know more than we can tell"* (Polanyi 1966). He recognises that the tacit dimension forms an indispensable part of human knowledge, although we might not always be aware of having this knowledge.

Knowledge is not always strictly objective and possible to separate from the individual. Nonaka and Takeuchi build on the ideas of Polanyi and they view the tacit knowledge as encompassing all knowledge we have, which we find difficult to communicate in plain words. They define explicit knowledge as that part of what we know that can be explained. They use this to explain the differences between Japanese and Western companies by showing how the Japanese recognise a tacit dimension to knowledge and how it might be worked upon and transformed into explicit knowledge, which can easily be shared within the organisation. By accepting the fact that individuals posses knowledge, which they cannot fully express, Nonaka and Takeuchi claim that Japanese companies have learned to draw not only on the hard knowledge of their workers, but also to create forums for sharing tacit knowledge.

Whilst it is not the remit to explicitly verify the explicit-tacit hypothesis in this regard, the argument put forward is that an interaction between explicit and tacit knowledge forms exist, which engenders a relationship between both information content and information context. In these terms, it is pre-supposed that representing knowledge as information content alone, is insufficient given the increasing demands of information management, retrieval and storage and the alignment between processes and technology (in terms of IT and IS) required within an organisational setting.

Knowledge therefore, cannot simply be defined as the understanding of information within a given context. Rather knowledge is a multidimensional quantity, which encompasses the many facets of content and context of information. Two important themes, or threads, which serve as the backdrop to the remainder of the research run throughout this thesis, based upon sociological as well as assumption-based premises.

Firstly, given that a relationship may exist between both tacit and explicit knowledge types, the author attempts to highlight the socio-psychological relationship between these knowledge forms. This is in terms of knowledge which is required for decision-making tasks, such as in the evaluation of a manufacturing resource planning information system. Secondly, if such a relationship does tend to exist between both tacit and explicit forms of knowledge, what other dependencies and inter-relationships might exist?

For example, modelling products to be manufactured using a CAE information system, requires the user of such a system to have expert knowledge of not only the system and product in question but also requires a certain level of decision-making and design innovation capability. Thus, combining both of the socio-psychological and behavioural case threads together, defines a thesis which states that the representation of knowledge within both the CAE and ISE tasks within manufacturing IS, involves heuristic and organisational culture influences.

In this conjecture, the idea is put forward that through an examination of both the semiotic (structure of meanings) as well as symbiotic (relationship with the environment) of knowledge, a frame-of-reference can be discerned to allow navigation between different forms of knowledge. The combination of context as well as reasoning of the information content is therefore fundamental.

As such the goal of this thesis is to observe the two given cases in which such an interplay between both semiotic and symbiotic concepts, are likely to occur, within the manufacturing sector. These were chosen due to the fact that as they are typically knowledge-intensive tasks, and hence were good candidates for investigation.

Dissertation structure and research methodology

The dissertation takes an empirical and interpretivist viewpoint towards understanding the nature of knowledge, via two particular manufacturing information system environments. This is achieved by adopting a case study approach, as proposed by Mumford (1993), Walsham (1993) and Yin (1994) which uses semi-structured interviews as well as observational techniques to gather empirical evidence relating to both explicit as well as tacit knowledge types. The structure of the following chapters reflects this overall approach and complements the methodology proposed by Phillips and Pugh (1994), which comprises of background, focal and data theory to support the development of a novel contribution. Figure 0.1 shows an outline of the dissertation structure in this regard, details of which are now outlined in the sections below.

Background Theory: Understanding knowledge

In order to develop suitable hypotheses relating to the observation of knowledge work, a survey of the literature that describes each of the factors relating to the representation of knowledge within information systems is discussed in Chapter 2. This essentially describes the background theory of the research presented herein and identifies the main components of the research. Knowledge is therefore discussed in the light of three pertinent forms: Structural, Interpretive and Evaluative knowledge.

In the first sense, knowledge is defined as that which is based wholly upon structural or semantic forms. This can mean that knowledge which is derived from interpretive experience (say as in the example of searching and data gathering tasks) or evaluative experience (as in continuous learning and optimisation of knowledge dependent, decision-making tasks). The second sense of knowledge is regarded as being at an interpretive level – that is to say, through the usage of and acquirement of information, such as in the task of information retrieval and information filtering. In this sense, knowledge is created as a by-product of information usage tasks, and tends to be relevant only in the context of that task (for example, when involved in searching and filtering tasks, such as looking up information within libraries and other data sources).

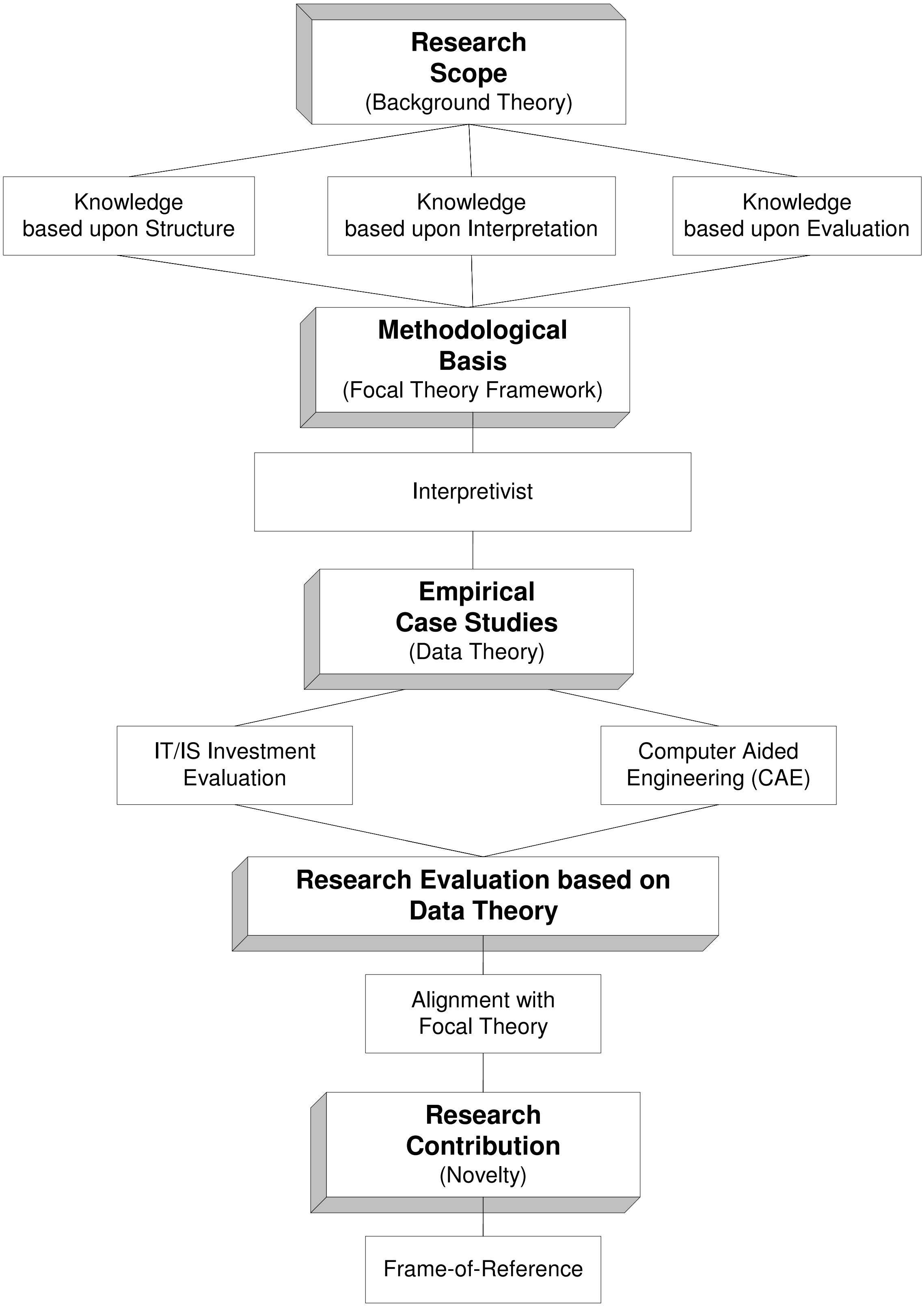


Figure 0.1 Thesis Roadmap

The third sense of knowledge is defined as a by-product of the use of data and information, principally through the implementation of so-called knowledge "management" processes and techniques. Such approaches attempt to define and ascribe techniques for managing knowledge on both the organisational and individual levels. This is begun to be equivalent to a broad range of organisational learning approaches also, where "corporate memory" is the sum of employee knowledge relating to processes, people and technology.

As such, the remit of such forms of representation, is via the use of policies, strategies and procedures which seek to validate experiential information via ordered ontologies and taxonomies. By highlighting those factors affecting the phenomenon being researched, issues such as developments, limitations, controversies and breakthroughs are addressed and included within the background theory. Hence, the background theory attempts to demonstrate a clear and concise "grasp" of the area under investigation, by identifying the problem domain.

Focal theory: Methodology and Thesis

The second element in the form of a doctoral dissertation is the focal theory. It is here that the area of research is identified and the nature of the issues under investigation described, and a process of their analysis begins. This is presented in Chapter 3. The focal theory of the research is described in terms of key information systems methodologies which relate and have some bearing on the concept of knowledge in general. The research methodology and research design used within this dissertation is thenceforth described in Chapter 4. The principal approach used, is based upon the well-known case study approach (Yin, 1994), and as such involves observing the knowledge intensive tasks relating to computer aided engineering and information systems evaluation, within two separate manufacturing organisation. Noting that in the traditional sense of case study research, the observed phenomenon in question is analysed in an interpretivist as opposed to positivist sense, this research takes the view that the complexity and informal manner by which knowledge is represented and used, requires a hybrid solution. As such, the overriding methodology and context of analysis, is couched in both interpretivist and positivist terms. This is due to the fact that each case observed, there are specific aspects of each of these philosophical concepts exhibited. In outlining and suggesting these methodological viewpoints, the generation of conceptual models and hypotheses, to push forward the academic discussion, are therefore formed within Chapter 4. A narrow sense of research is described, which provides a clear "story line" to the thesis, and identifies the need to support any theoretical conjectures with data.

Data theory: Empirical Investigation

Data theory needs to address issues such as: (i) the conditions affecting the choice of research strategy; (ii) the most appropriate epistemological stance to adopt; and, (iii) the development of suitable research method(s). As a result, appropriate and reliable lines of enquiry are established, and data gathering research methodologies developed. As such, Chapter 4 also covers in some part, the third constituent element of a doctoral dissertation which is the data theory. This essentially justifies the relevance and validity of the material that supports the thesis. The empirical data is therefore presented in Chapter 5 and 6, in the form of observed knowledge tasks and processes, within two manufacturing organisations. These organisations utilise knowledge in separate ways, although they exhibit qualities of evaluative, interpretive and structural knowledge, which exists as a background to the overall discussion within this dissertation.

During the development of the data theory, decisions justifying the use of a multiple case strategy are made, together with the development of qualitative research methods that provide interpretivist views of knowledge on the one hand; and the development of positivist views on the other. Such constructs then form part of the empirical research methodology that is used to guide the research process. The constructs of the data theory essentially consists of: (i) a research design; (ii) case study data collection methods; and, (iii) a case study data analysis process.

Presenting the novel contribution

The final element of the doctoral dissertation is concerned with aligning the thesis, to the background theory, methodological basis and the discipline being researched. Hence, within Chapter 7, the contribution that the thesis makes is discussed, along with limitations of the research identified, and suggestions for further work. Essentially, this section of the dissertation discusses why, and in what way, the background theory and the focal theory are now different, as a result of the research. Through an analysis of the case study material, aligned with the methodological stance offered in earlier chapters, a frame-of-reference for discerning knowledge representation within manufacturing information systems is therefore developed. Finally, Chapter 8 summarises the research findings, evaluates the data theory and presents the aspects of novelty claimed in the dissertation, before discussing proposals for further work. Within this final chapter, emphasis is placed in the manner by which the concept of knowledge representation within manufacturing IT/IS environments has been developed from the literature and the empirical case study research.

Summary

This chapter has described and defined the nature and importance of both information and knowledge. In doing so, a distinction was made between information technology (IT) and information systems (IS), the types of knowledge that are inherent in the latter. By recognising the fact that information-intensive tasks within manufacturing IS environments involve a degree of both explicit and tacit knowledge, the case is made for the resulting thesis. A quantitative, assumption-based view of these aspects, pre-supposes that explicit scientific knowledge is supplemented with tacit decision-making knowledge, in order to drive computer-aided design and analysis tasks. Whereas, a qualitative, or socio-psychological observation of causal inter-relationships which exist within the tacit decision-making task of IT/IS cost evaluation, implicitly relies upon explicit knowledge relating to stakeholders of the IS involved in the task.

Hence, representing knowledge as information content alone is insufficient, in terms of providing an understanding of that knowledge also. A combination of context as well as reasoning of the information content is fundamental to representing knowledge in an information system. Through empirically observing and investigating the manner in which knowledge is used as well as represented, the resulting dissertation will attempt to define a frame-of-reference for the epistemological and causal approaches to knowledge representation, within manufacturing IS environments.

In doing so, both observed case studies seek to provide an interpretivist reasoning of the knowledge being represented. As such, an appropriate IS methodology grounded in terms of the well-known case study approach, is key to both understanding the qualitative and quantitative nature of knowledge (i.e. tacit and explicit knowledge).

Hence, this thesis attempts to provide a novel approach in this regard, through proposing a frame-of-reference for knowledge representation within two specific manufacturing information systems environments, through the definition of a relationship between content (semiotic) as well as context (symbiotic) information.

CHAPTER 2

BACKGROUND THEORY

This chapter provides a context to the thesis by reviewing the published literature on pertinent aspects of knowledge, its definition, forms and application within Information Systems. In particular, this chapter investigates and defines the nature and meaning of knowledge and how various schools of thought differ on the implementation and application of it. Furthermore, additional background detail is given on knowledge requirements within decision-making tasks relating to within manufacturing IS environments. As a result of a review of the literature, a novel taxonomy of the extant literature in the field is proposed, based on the characteristics of each definition of knowledge. The establishment of this taxonomy highlights the fact that there are many different forms of knowledge representation, which complicates the understanding of knowledge usage within information system environments. This serves to provide a context to the observed cases and their resulting analyses, in later sections of the dissertation. The chapter concludes by setting the basis for the generation of the focal theory and research hypotheses in Chapter 3, through highlighting the contingent differences and complexities with respect to the definition of knowledge currently within IS.

Background Theory

The purpose of this chapter is to provide a context for the research, in terms of presenting and discussing previously published research, in terms of the representation of knowledge and its usage within manufacturing IS environments. The chapter begins by defining the nature of knowledge, and how various researchers have defined this concept in the light of information systems. In order to develop a taxonomy of the literature in the field, a discussion of the main schools of thought in terms of representing and managing knowledge within information systems, is presented. These approaches are Structural, Interpretive and Evaluative and are methods for identifying and working with knowledge. The latter three terms are throughout the dissertation in order to ground the research thesis and to distinguish between the various forms of knowledge. Furthermore, as the research presented within this dissertation is in the form of two empirical case studies, relating to both computer aided engineering and investment evaluation of an IS respectively, the chapter continues with further definitions from the literature of the contextual knowledge requirements and issues, in these particular cases also.

As a result, those aspects that pertain to the representation of knowledge within these spheres of application are identified via a taxonomy of the core published literature on the subject. The chapter concludes with a summary of the key literature review findings.

The evolution of Knowledge

Knowledge has not always been recognised as a key asset and critical success factor within organisations and business. Indeed for many organisations, knowledge has become to be a given: an implicit, hidden, though very valuable component of an enterprise (Drucker, 1999; Stewart, 1997). The growth and spread of the concept of knowledge, can be largely attributed to the integration of management concepts within the field of information systems. This has been in part due to the evolution and emergence of the information era.

As Alvin Toffler notes, the arrival of the industrial age within the Western world, heralded the dawn of an era that would liberate civilisation from the reliance upon agriculture and craft-based industry, to a world of machines and devices that would be able to mass-produce all manner of products and services for the populace. The zenith of this age has undoubtedly been the latter half of the 20th century, where the commoditisation of goods such as steel, oil, automobile and more recently, consumer electronics, had become the most significant aspect of the industrial revolution (Toffler, 1980). However, as this commoditisation reached its peak, the reliance upon information to support the development, marketing and sales of manufactured goods and services has became increasingly important. The evolution and progression of cheaply available computing power, has meant that almost all manufactured products and / or services, are dependent upon information resources. In many cases, information itself is becoming the product being sold (Järvenpää and Immonen, 1998).

The continuing natural progression of this commoditisation, has now led to the emergence of the knowledge age or the "knowledge economy". That is, a period within which the usage and contextualisation of information services and goods, is the main driver, and without which it is difficult to engage in any business or enterprise (Tapscott *et al.*, 1998). The nature of knowledge, as will be shown from the review of the published literature, means that the implied usage of information is now of primary importance, especially in terms of the economic benefits that knowledge itself can bring (United Nations, 2001). Management theorists such as Drucker (1993, 1999) and Porter (1985), who typically presage emerging trends and opportunities within business management, also noted the importance of knowledge within an organisation, as being the driver for building and sustaining competitive advantage. In particular, Porter mentions that making the best use of knowledge is management responsibility, which requires a systematic and organised approach (Porter, 1985).

Thus, the importance of knowledge and the manner in which it is managed and applied throughout an organisation, adds value, especially when it supports business processes and the strategic direction of the company (Quinn, 1992). In many cases, the importance and value of knowledge, now rivals the material assets of an organisation, via the concept of an organisational or "corporate memory" (Handy, 1990) and builds upon the Schumpterian notion of knowledge being created as a result of individual and collective experiences (Schumpeter, 1934). As such, many multinational organisations, such as Microsoft, Hewlett Packard, Ernst and Young, Volvo and others, have recognised the impact of knowledge upon all business processes – including strategic planning, business process improvement, IT/IS implementation, best practice management and innovation (Kucza and Komi-Sirvio, 2001; McCampbell *et al.*, 1999 ; Rimmel, 2001).

Furthermore, the concept of "knowledge work", or work that utilises knowledge in creating value has gained momentum within companies and firms who now value knowledge as a particular asset in itself – which is called intellectual capital (Stewart, 1997; Winslow and Bramer, 1994). A central tenet within this definition and belief is that through the exchange and interpretation of information between individuals within an organisation, allows knowledge to be created and maintained. Over the last decade, researchers such as Nonaka and Takeuchi (1995), Svensen (1998), Seufert *et al.*, (1999) and King *et al.* (2002) have all separately noted that the management of such organisational knowledge in all its forms, needs to be critically balanced and controlled in order for it to be maximised to its potential. Hence it can be seen that whilst on the one hand knowledge is a conceptual, if not almost an ethereal concept, the realisation that its existence has an impact upon organisational effectiveness cannot be doubted.Before proceeding with the remainder of the dissertation, it is also important to outline some other key definitions that underpin the work which is to follow. As such, a detailed inspection of the many different meanings of knowledge now follows.

Roots and definitions of knowledge

It has been noted from the previous section that knowledge in itself is a by-product of information. As such, from an information systems viewpoint, Knowledge is based upon the refinement of the concept of data and information. In order to define knowledge, it is important to define both data and information as separate but related entities.

Data can be described as being unstructured facts (Avison and Fitzgerald, 1998). Further, it can also be said that data can be a specific, discrete and / or finite quantity which can describe the specific state or being of something. For example, it can be said that the data which describes the temperature on a given day, is the specific reading on a thermometer, say 15 degrees celcius. Information, on the other hand, is the interpretation of data. This is in the sense that information is a refinement on the context of a set of data, which as a whole implies some specific meaning. Hence, a collection of temperatures (temperature data such as 15, 20, 25 degrees celcius), can be classified as being climate-related information.

That is, certain data which is related to each other within a specific context and for a particular meaning. Figure 0.1 shows how data, information and knowledge are related, but also differ from one another in this respect.

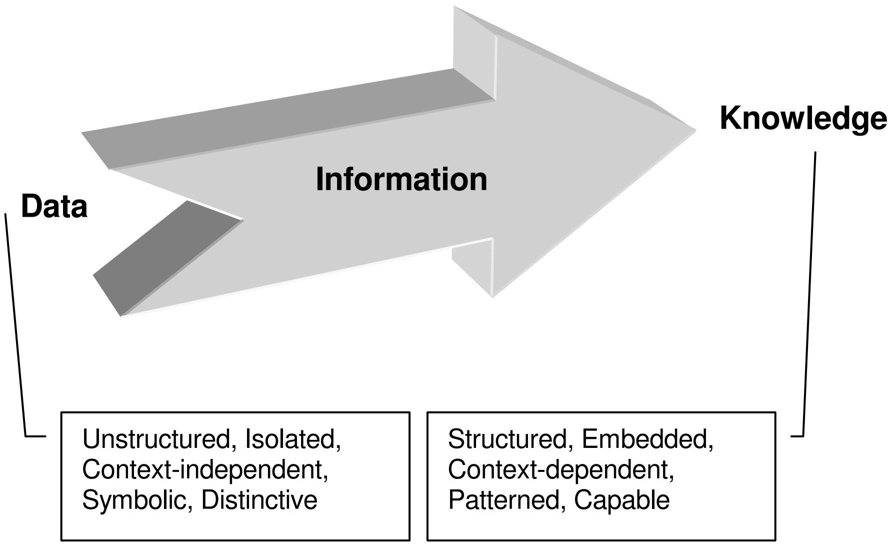


Figure 0.1 Data, Information and Knowledge (from Probst, Raum and Romhardt, 2001)

As can be seen, Knowledge exists at the other end of this data and information continuum. In its simplest sense, knowledge is the natural outcome of *understanding* and *using* information within a particular context. Since knowledge is based upon the refinement of both of these concepts, there can exist many definitions of knowledge. Probst, Raub and Romhardt (1994), give one such definition of as:

> '*…the whole body of cognitions and skills that individuals use in order to solve problems…*'

(Probst *et al.* 1994, pp.24)

In this case, the authors view knowledge as pertaining specifically to decision-making tasks which require the applicable usage of context-specific information. Another view of knowledge is given by Davenport and Prusak (1998), who suggest that knowledge is more of a collection of experiences and values, which provides the individual or organisation with the ability to evaluate and incorporate new ideas and information (Davenport and Prusack, 1998). This can also be the basis for an even more philosophical stance, in that knowledge can also represent higher order concepts such as insight, action, wisdom, and resolve, much in the light of the ideas of Wittgenstein (1953). Indeed, Polanyi has famously stated that knowledge is such a thing, that it is impossible to define fully, as 'we know more than we can tell' (Polanyi, 1966). Staying within this philosophical context, knowledge can also been described as a set of ontological commitments, which prescribes how we view the world around us (Davis, Shrobe and Szolovits, 1993). Through this lens of understanding, knowledge can therefore also be regarded as being the accumulation and cultivation of information and data over time (Leonard-Barton, 1995).

Given the multitude of definitions of knowledge, from management science through to the latter philosophical stance, it is perplexing to see that there is no overall theory of knowledge *per se*, as each theory of knowledge is grounded within specific situational or organisational, contexts (Diedrich and Targama, 2000; Wiig, 1999). Thus, the common problem encountered with attempting to understand and "manage" knowledge, is in how it is principally defined.

However, there is a common theme which runs through most of the literature concerning knowledge, in that it can be segmented into direct or *explicit* knowledge or indirect, implicit or *tacit* knowledge (Nonaka and Takeuchi, 1995; Polanyi, 1962; Sveiby, 1997). Explicit knowledge can be said to be knowledge which is objective, theoretical, and can be asserted via formal logical and systematic arguments. Such knowledge is easily communicable and exchangeable, through many forms of media – documents, audiovisual equipment, computerised records, etc, etc. Thus, explicit knowledge can be said to be part of the *world*, i.e. relates to some object. Tacit knowledge on the other hand, is regarded as being knowledge which is in the most part, subjective, practical and personal. Hence, it can be said to be part of a *person*, i.e. relates to some subject and this is why it is difficult to formalise and communicate to others. As such, tacit knowledge is deeply rooted in the behaviours and actions of individuals, who have a commitment to a specific context (such as a particular area of expertise or series of work practices). Given these points, it can be seen that these are just a few out of the many definitions of knowledge which exist, each with their own specific connotations and theoretical grounding. As Syed has shown, the implementation of knowledge within computing and information systems is indeed vast, as shown in Figure 0.2 (derived by the author from Syed, 1998).

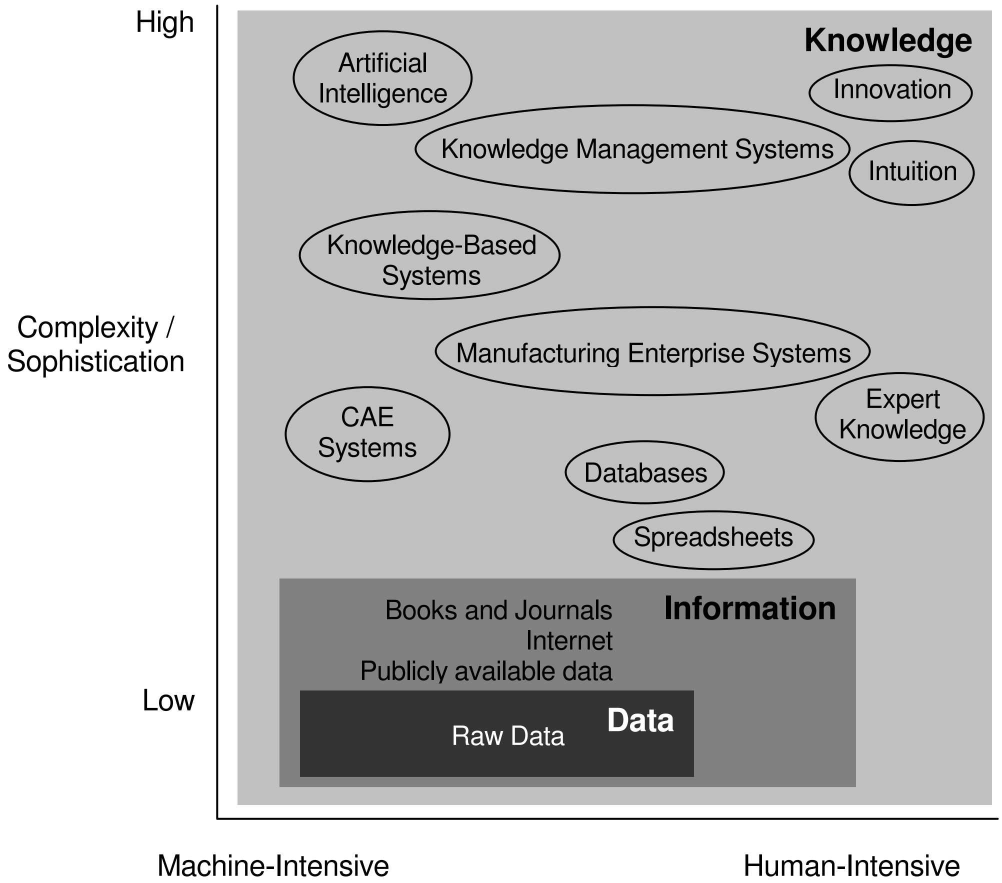


Figure 0.2 The knowledge landscape within IS (modified from Syed, 1998)

In Syed's diagram, specific tools and technologies are situated within a range of low to high complexity, from textbooks all the way up to systems which exhibit emergent behaviour. Sorensen and Kakihara (2002), also define knowledge within an IS setting, in terms of four "discourses": knowledge as an object (in order to support information distribution); as an interpretation (in order to filter information); as a process (to coordinate and collaborate across information structures); and lastly, as a relationship (in order to provide interaction between individuals and systems).

For the purposes of this research, the focus is therefore given to define methods and constructs which can be segmented along the lines of Nonaka and Takeuchi's explicit and tacit forms of knowledge, and also aligned to Sorensen and Kakihara's first three discourses (object, interpretation and process). In other words, those forms of knowledge which begin from purely data / information based knowledge (structural), through to informational context knowledge (interpretive), and finally through to a higher level of usable knowledge (evaluative). As such, these knowledge forms are now investigated and defined, in the sections that follow.

Forms of Knowledge

The variety of definitions which makes a general understanding of how and what knowledge is, can now be seen to be a complex affair. In order to understand these points of view, the following sections will now highlight three key forms which are characterisable in terms of the way in which they are implemented in practice. As such, the surveyed literature given in the remainder of this section will be delineated along the lines of Structural, Interpretive and Evaluative forms of knowledge respectively. This is shown graphically in Figure 0.3 below. This is a novel representation derived by the author, which defines the key aspects of knowledge representation, i.e. the method and manner by which knowledge manifests itself, within information system environments. Effectively, these 'pillars' build upon and therefore support a general definition of knowledge, and as such are both independent of yet intrinsically linked to the *representation* and usage of knowledge itself.

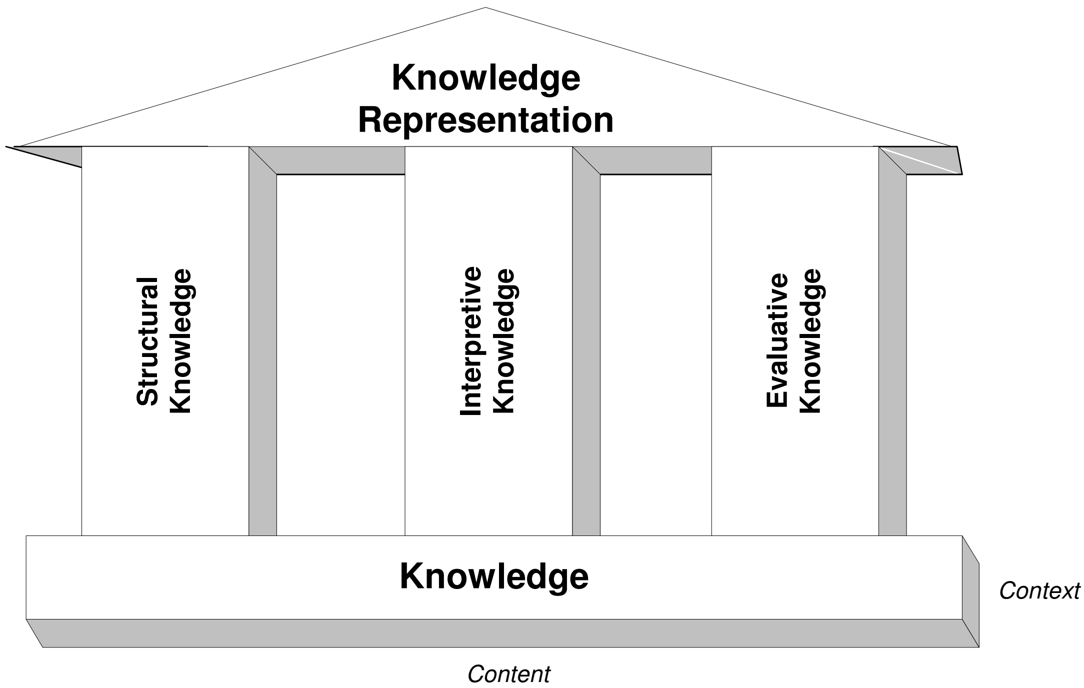


Figure 0.3 Pillars of knowledge

This is terms of aspects of content and context. The only recently referenceable material in the same light as this diagram, is that model offered by Orange and Onions (2002), who define the "3 K's" of knowledge: the Known (facts and truths); the Knower (viewpoint and context of knowledge); and the Knowing (processes associated with knowing what is known). As such, Orange and Onions limit their model to both ontological and epistemological points of view, which engender a combination of philosophical stances alongside processes for understanding knowledge. The focus of this research is however clearer in the sense of attempting to delineate specific *forms* of knowledge so that each form of knowledge can be attributed to a wider set of decision-making tasks within manufacturing IS environments. The remainder of the thesis therefore attempts to highlight and explore the interplay between each of the constituent parts of knowledge in this regard.

Structural Knowledge

One method of providing a view on the context of knowledge, is through a research area which centers on the notion of mapping knowledge in some data-centric or computable (algorithmic) form. Of the two approaches, some researchers such as Galliers and Newell (2000), have even suggested that knowledge in itself should only be relevant where the data that defines it, is relevant and accurate. A much less radical approach in this light, is instead to focus on how knowledge can be structured and represented, in terms of language and logic. This is field is known more generally, as Knowledge Representation and is an important sub-field of Artificial Intelligence (AI) research. This specifically concerns itself with defining constructs which define a series of logical assertions (Genesereth and Nilson, 1987). In John Sowa's words, knowledge representation applies theories and techniques from the fields of logic, ontology and computation in order to represent some *thing* in the real world (Sowa, 2000). In this sense, the representational view of knowledge is purely structural: knowledge which is embodied via the use of semantic and logical propositions (Davis, Shrobe and Szolovits, 1993).

Although it is outside of the scope of this thesis to discuss aspects of AI in detail, it is important however to discuss some pertinent aspects of this type of knowledge. The ultimate goal of any knowledge representation, in this sense, is to allow information to be efficiently structured, modified, and reasoned with. As the basis of knowledge representation is from a purely computational basis, it is therefore fitting to view this approach as being based upon a series of *structural* components. That is, a series of models and concepts which require knowledge to be abstracted in a particular manner. Some of the better known approaches in this light include semantic networks, frame systems, predicate logic and the use of formal ontologies.

Foundations of Knowledge Representation

Briefly, a semantic net, is a graphical method of representing real-world concepts via nodes in a directed graph (Quillian, 1967). Knowledge and meaning between concepts, is implied through the interconnection between each concept. By reading this directed graph, a language or semantic structure of the knowledge can be formed and hence can be abstracted through a computer language. Such methods have been used successfully to model knowledge which is well defined, as in classification problems, as shown in Figure 0.4, and in applications such as in medical prognosis (Genesereth and Nilsson, 1987).

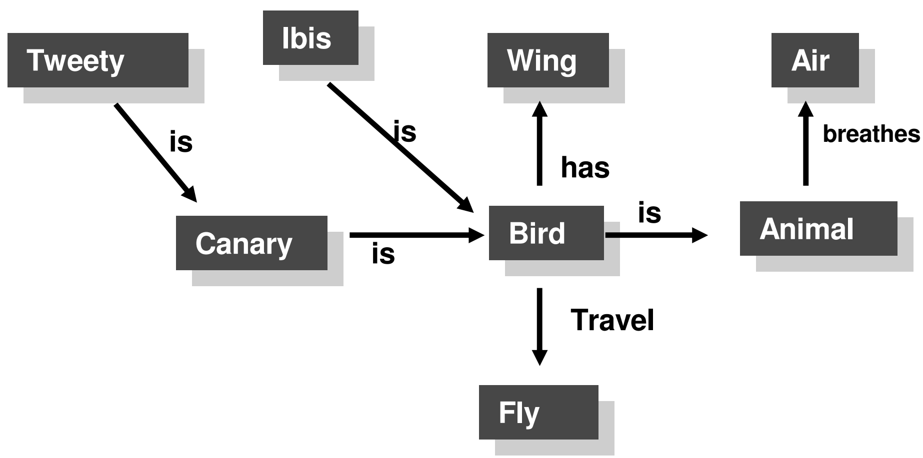


Figure 0.4 Semantic net representation of the classification of types of bird

Frame systems were introduced by Minsky (1975), as a means to structuralise a semantic network in order to describe specific instances of an occurrence. Here, a frame is a named piece of data, which exhibits particular attributes (known as a slot). Due to the fact that each frame has certain properties, more complex knowledge structures can be inferred by artificially replicating and inheriting semantic node attributes. Frames are useful for representing a large amount of context-dependent knowledge, which can be proved via logical assertions.

As such, frames are typically used as a method for reasoning with a given amount of knowledge as in the example of fault diagnosis example shown in Figure 0.5. A more rigorous approach to formalising knowledge, is through the use of First-order logic (FOL), or predicate logic / calculus.

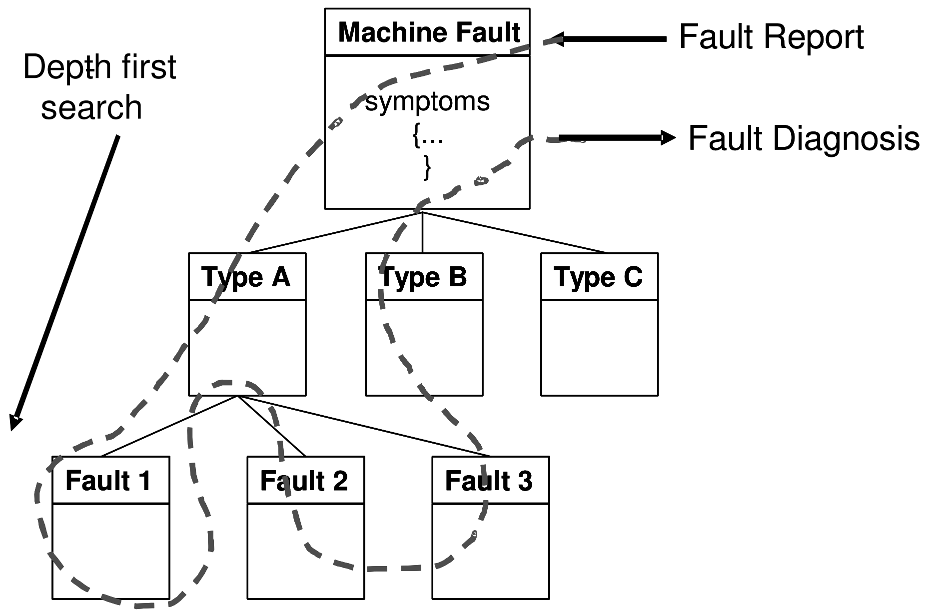


Figure 0.5 Fault diagnosis using Frame-based reasoning

In this method, a series of logical assertions are made about each component of knowledge, from which an overall bounding set of knowledge can be inferred. For example, in order to provide knowledge about fruit apples, it could be stated that "all apples are fruit", and "some apples are green and some are red".

From these two assertions, it can be further inferred that "green apples are fruit" and "red apples are fruit" also. This implication through a low-level relationship between objects that exist in some epistemological sense, makes this a very powerful method. As such, the abstraction of knowledge through this approach has led to the development of a standard for interchanging knowledge structures, such as the Knowledge Interchange Format (KIF) (Genesereth and Fikes, 1992). However, in order for information from different sources to be integrated, there needs to be a shared understanding of the relevant domain. This is where many knowledge representation formalisms break, due to the inflexibility of the methods for sharing both structured and unstructured knowledge (i.e. knowledge based upon known and / or uncertain information). Therefore, the use of ontological structures has been greatly welcomed in the area. Ontology is the philosophical study of the nature and organisation of reality (or of a conceptualisation, as noted by Gruber, 1993). But even this definition is vague. As Guarino and Giaretta (1995) note, an ontology should provide terms for representing all possible states of affairs with respect to a given domain of knowledge. Hence, a key problem with this structural form of knowledge is that when a conceptualisation of the world is attempted, some simplifying assumptions must be made about its structure. This limitation can be inhibited somewhat by the use of contextual logic, which involves defining specific assertions about knowledge within a given context (Guha, 1991; McCarthy, 1993). This is also further compounded when abstracting these ideas via programming languages, in order to produce programs which exhibit some knowledge-seeking behaviour.

Importance of Ontology

In his work, Sowa presents a very detailed view of the ontological nature of knowledge in his books on knowledge engineering (Sowa, 1994; Sowa, 2000). This stance remains true to the argument that knowledge which is to be represented, must be in a form which is computable, at some level. This is chiefly through a model which provides the definition of knowledge via a combination of physical objects, events, processes, and their distinctive place in space and time. This highly philosophical set of conjectures, ultimately provide the basis for suggesting that knowledge can only be described as a consequence of these factors (as shown by the author in Figure 0.6).

Heylighen upholds the ontological stance within the knowledge representation paradigm, by extending the notion of a Correspondence Epistemology: knowledge is a reflection of the external world (Heylighen, 2001). For example, it can be said that the sky is blue because the colour of the sky and its relationship to the fact that the climatological makeup of the Earth, makes the sky appear to be blue.

However, when such simplistic sources of knowledge are mapped onto a computer system, the ontological premise provided by the abstraction of this knowledge, is also implemented.

That is to say, the programmer or analyst directly influences the structural representation of the knowledge they are attempting to provide.

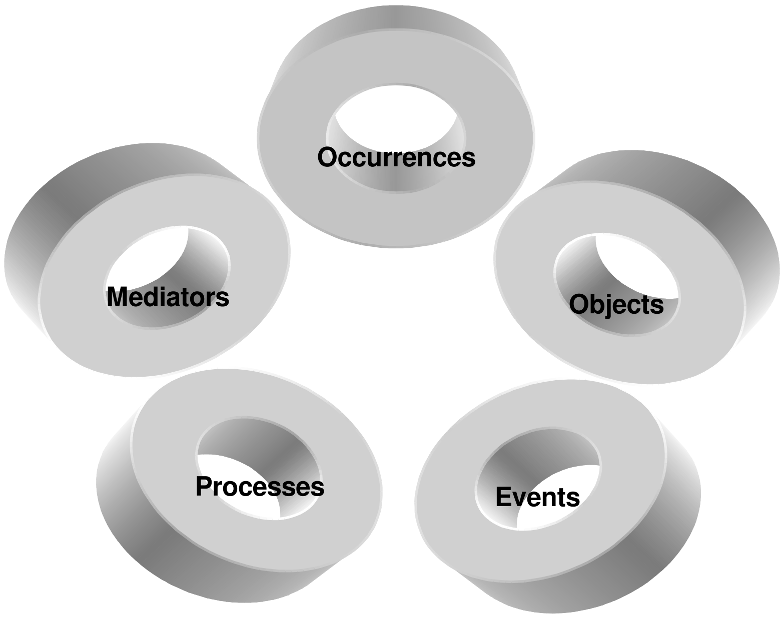


Figure 0.6 Ontological aspects of knowledge (adapted from the work of Sowa)

As such, Heylighen proposes that to counteract this bias, is to "bootstrap" or facilitate each knowledge structure by creating inter-relationships. He provides the following model - assuming there are two models which describe some type of knowledge, model A and model B:

> *'…model A can be used to help construct model B, while B is used to help construct A … The net effect is that more (complexity, meaning, quality, etc.) is produced out of less.'*
>
> (Heylighen 2001, pp.695)

Furthermore, such considerations can be represented as purely graphical, semantic structures, known as entailment meshes. As an example, Figure 0.7 shows the entailment mesh and the semantic net for the interrelationships between 5 objects: pen, paper, writing, table and chair. When structured through the bootstrapping method, each concept is relatable to any other by its contextual significance (i.e. the semantic net or set of interdependent concepts, Brachman, 1977). In this example, the act of writing is dependent upon having a pen and paper (which is a known pre-requisite in order to write). The contextual modifiers of a table and chair also mean that a location (a chair, table or some other seating arrangement) is required, in order to write on paper.

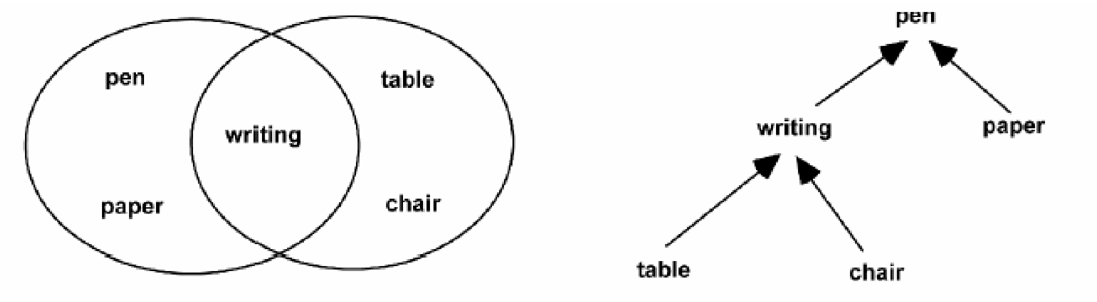


Figure 0.7 An entailment mesh and semantic net defining the concept of "writing" (from Heylighen, 1999)

Hence, our knowledge of the act of writing is dependent upon the close interrelationships between each of these semantic nodes as shown. A refinement of this representational concept, is presented by Merali (2002), who suggests that information (and hence knowledge) also exists through self-organising behaviour, in an autopoeitic manner. Autopoeisis is the process of continuous generation and self-production, which occurs in many biological systems. Merali contends that in the case of knowledge representation across organisational boundaries, embedded organisational knowledge is a true ontological reflection of the world that the company operates in. And the autopoeitic effect that occurs in the representation of organisational knowledge, is a direct result of the manner by which the company *interfaces* with the outside world. This is carried out through the a structure known as the Cognitive Congruence Framework, which defines a collection of beliefs and relationships (schema); an identity (self-concept); a set of rules and premises that bound the knowledge (relationship script); and the manner by which such knowledge relationships are enabled (relationship enactment) - shown in Figure 0.8.

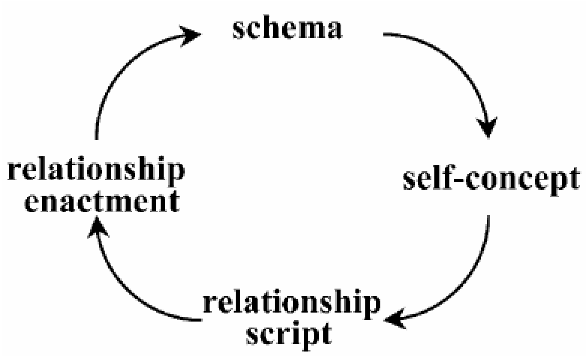


Figure 0.8 The Cognitive Congruence Framework (from Merali, 2001)

The epistemological stance taken by Merali then, overcomes many of the abstract arguments raised by Sowa and other AI researchers, through suggesting that knowledge can be represented best when all the components of that knowledge, somehow reinforce their interrelationships by not only their existence but also by the level of their interaction. Going back to the pen semantic network presented by Heylighen earlier, it can be inferred that the task of writing can only be known when an instrument for writing (a pen), available materials (paper) and a place to write (desk and chair) are available. This inclusive relationship model, provides perhaps the best and most understandable example of the representational school of thought. However, a key issue with knowledge representation is the fact that ambiguity can quickly arise when attempting to make knowledge conform to some specific contextual structure. This is described by Heylighen (1999), when he notes that knowledge can be represented as either in an inviolate logical state (e.g. all pens must be related to all forms of paper, in order for someone to be able to write) or that knowledge must represent some specific model which reflects the real world (e.g. the model of a "writer" is someone who uses a pen to write a novel, whilst sitting at a desk on a chair). These notions of form, existence and relational behaviour are presented by the author in a summary of this particular literature, within Table 0-1.

Table 0-1 Fundamental models of Structural Knowledge

Author(s)	***Structural Knowledge Model***
Logical	
Quillian (1967)	Frames
Minsky (1975)	Semantic Nets
Brachman (1977)	Frames, Semantic Nets
Genesereth and Nilson (1987)	Natural Language Processing, Predicate Logic
Davis *et al.* (1993)	Predicate / First Order Logic
Galliers and Newell (2000)	Contextual Logic

Ontological	
Simon (1969)	Contextual Logic
Guha (1991)	Correspondence Epistemology
Genesereth and Fikes (1992)	Cognitive Congruence
Gruber (1993)	Ontological reasoning
McCarthy (1993)	Contextual Logic
Sowa (1994)	Semantics
Guarino and Giaretta (1995)	Contextual Logic
Heylighen (1999)	Ontological reasoning
Sowa (2000)	Ontological reasoning
Heylighen (2001)	Ontological reasoning
Merali (2002)	Autopoeitic Behaviour

The reviewed literature presented within Table 0-1, is a novel structuring and classification of the representative published work which relates to the semantic and / or algorithmic representation of knowledge (i.e. Structural Knowledge). The resulting grouping of the representative literature by the author, has been carried out in order to delineate specific philosophical stances taken by the given researchers, in defining knowledge. As such, the author suggests that these stances fall into two categories, namely Logical and Ontological approaches. In the former, knowledge is viewed in terms of the semantic mathematical structure of propositions and statements (i.e. in terms of a calculus, Genesereth and Nilson, 1987). Within this approach, knowledge itself is a by-product of the process of induction (an inference from a particular instance) or deduction (an inference from a set of truths or facts), of information and data. In the latter case, knowledge is viewed in terms of a particular contextual relationship between the observer, or consumer of, knowledge and the environment around them (i.e. in terms of a set or flow of processes that support the capture and subsequent reasoning of knowledge, from the observer's environment, Merali, 2002).

As can be seen through these examples, the abstraction of innocuous ontological relationships, can become obscure and confusing – as a result of stating a set of logical or propositional arguments which attempt to define logical relationships between information / data . In order to keep this ambiguity within some form of context, such knowledge must be in relation to a recipient or user of the said knowledge. This can therefore be said to be a form of interpretive knowledge, and is explained in the next section in further detail.

Interpretive Knowledge

A second form of knowledge, is that which has evolved from, knowledge representation paradigms discussed in the previous section. The concept of Information Retrieval (IR), relies upon the existence of a representation of knowledge. Without a given representation, or method of relating information to a recipient, knowledge cannot be produced from merely information alone (Capurro, 1985). This idea is rooted within the discipline of Library and Information Science, where the goal is to be able to search and filter information in order to provide knowledge about it. The central problem of IR is the analysis and measurement of the relevance of the stored information, i.e. the relation between requested information and retrieved information. Furthermore, it is concerned with the impact of information on the receiver, where such a receiver (or user) requires information to solve problems and make decisions (Capurro, 1992). IR techniques are therefore in some sense, interpretive, in the sense that knowledge which is inferred from an information search is based upon some hermeneutic or pre-understanding of the knowledge, as shown in Figure 0.9. For the purposes of this dissertation, some generic concepts relating to IR will be presented, in order to assist with the formation of suitable hypotheses later on this work, and are not meant to be an exhaustive set of definitions of the subject area, but serve to provide some general insight into the area.

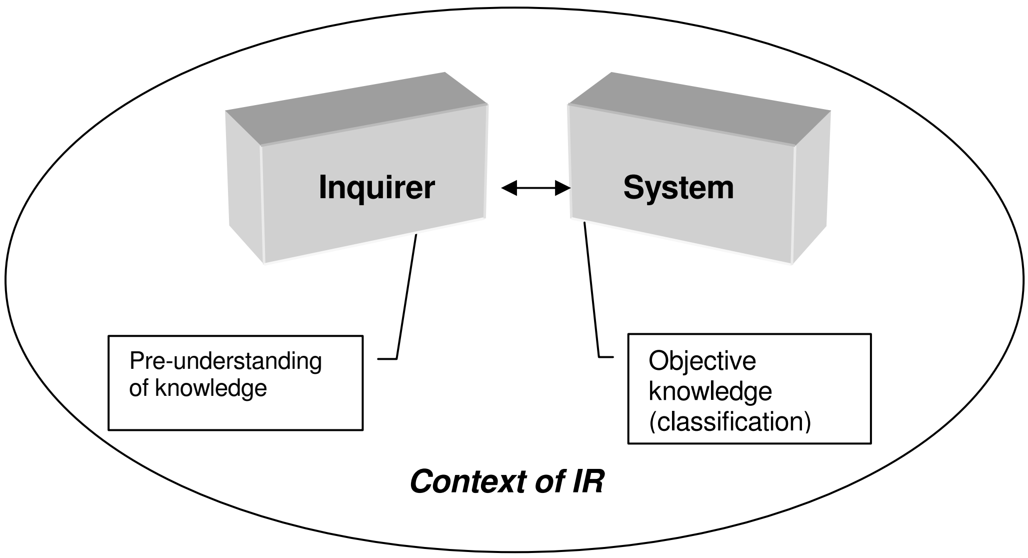


Figure 0.9 A pre-understanding view of Information Retrieval (IR) – adapted from Capurro (2000)

Foundations of Information Retrieval

The typical process within IR, is to select a query, and carry out a search for information based upon this. The outcome of any information retrieval task, is to return a set of documents (or embedded knowledge), in response to an information query. As such, the strength of the retrieval relies upon the amount and the context of queries that are used, as well as techniques for filtering the results (known as indexing and abstracting).

A good example of a retrieval search in a modern day setting, is via the internet using a web page search engine (such as Google.com). As more detail is provided to the search engine, the greater the chance of finding an exact match to the query (searching for "Craters of the Moon" should retrieve more detailed information than simply searching for "Moon"). Moens (2000) describes the use of IR models which are based upon matching the query exactly (Boolean model); finding frequencies of a word occurrence (Vector model); finding frequencies of the matching query and the retrieved occurrence (Probabilistic model); and comparing queries and retrieved results across multiple representations (Network model). Information retrieval therefore requires some intermediary to carry out the information search task. It is then reliant upon the requestor of that information to deduce or infer the required knowledge, in order to support problem solving or decision-making tasks.

Hjorlund advocates that information science itself, provides a mix of concepts from across linguistics, psychology and sociology. Thus, eleven key components of knowledge domain analysis, include aspects of psycho-sociological, as well as systemic, importance within IR tasks (Hjorlund, 2002). Furner also describes the importance of the sociological aspect of information science, as prescribed by the pioneers of library science, Shera, Otlet and Rubakin (Furner, 2002). These models base the inquirer after information and knowledge, at the centre of the information retrieval task. This inquirer essentially exists in order to not only justify the existence of the information itself, but also in order to provide an interface and some context or interpretation to the retrieved information. Several models of this form of behaviour are now presented, which are based upon these and associated notions of document search and retrieval.

Models of IR

The first type of model for IR is that which can be defined as being situational or purely context-sensitive. In this model, the information search, is only relevant to the context of the knowledge which is required. Several researchers have articulated this, through various approaches, such as by Dervin (1999), Wilson (1981) and Saracevic (1996). All of these models are essentially based upon integrating information, interface to a computational representation engine, query formation, retrieval from a knowledge source and interaction with the real / external world. As such, the emphasis given to this approach of interpretive knowledge, is heavily reliant upon processes and systems which encode and provide access to information (Hirscheim and Klein, 1998). This is shown best by Saracevic's Stratified Model for IR, in Figure 0.10.

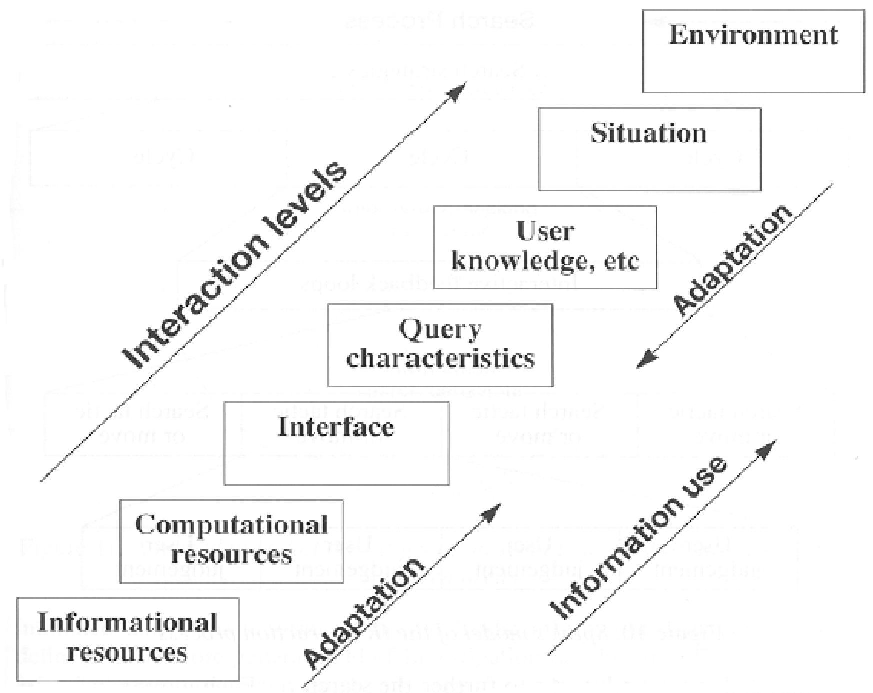


Figure 0.10 The situational IR model (Saracevic, 1986)

As can be seen from Figure 0.10, this representation of the information retrieval or interpretive form of knowledge, encapsulates three key aspects: an information resource, a query / search for knowledge required, and a situational context. These are driven by computational resources, an interface to an information system, and the environment that the information system exists in respectively. A key limitation of this approach, is that once the situational knowledge requirement becomes complex, the information need also becomes ill defined. This has an impact on the information search behaviour, and as such further contextual input is required, in the form of cognitive or the causal *relevance* of the knowledge which is found. However, as Ferneley *et al.* (2002) note, the usage of particular IR retrieval models such as those which are mostly situational and use algebraic search to infer a particular set of knowledge, do not provide insight into the *context* of a document.

Rather the emphasis is placed upon how the knowledge will be stored or presented, as opposed to what the knowledge actually means. Hence, there is a discrepancy between how information is found and how that information is turned into knowledge and used in the real world. Any form of IR and information science must be able to provide additional context from the information found, in order for the receiver or user of the information to make decisions (Hayes, 1991).

This decision-making capability, is what distinguishes information from knowledge at the lowest level, as has been noted in earlier sections. Thus, the second model for IR, is largely based upon the work of Belkin (1980), Belkin and Kwasnik (1986), Kuhlthau (1991), Ingwersen (1996) and Vakkari (2000), who postulate the importance of recognising the psychological context of the information inquirer through a *cognitive* (mental) aspect. Belkin in his seminal work on the subject (Belkin, 1980), concentrates on the need to understand that the user and inquirer after information, requires knowledge in order to reduce their own personal uncertainty relating to their decision making task. Again, the typical processes of IR are included (query, interface, search and retrieval), with the focus being on the so-called anomalous states of Knowledge (ASK) based upon the inquirer's level of uncertainty. Kuhlthau also focuses on these feelings, as the user deals with the initiation, selection, exploration, formulation, collection and presentation of their information search. The primary focus of the knowledge task, in this case, is based upon the user's *behaviour* relating to how they deal with uncertainty and finding a successful fit to their information needs.

In both these cases, the importance of the cognitive model is paramount, in that the representation of knowledge must be effective at representing the *inquirer's knowledge*, rather than describing the information itself. Both Ingwersen and Vakkari base their work closely on Belkin and Kuhlthau's, again with more of an emphasis on the impact on information systems given. In these particular models, the emphasis is placed more on the enquirer rather than on the information system *per se.* Whilst Ingwersen (1996) remains true to the work of Belkin, in the sense of modelling the uncertainty of knowledge through interfacing with an information system, he does however focus on this latter aspect more than on the former. Vakkari (2000), on the other hand, extends these concepts further and includes weighting factors, in the form of relevance criteria.

These criteria weight particular aspects of knowledge in terms of an assessment of the information search, conducted through a combination of an information system and / or an intermediary. Hence, throughout the published literature on the subject of IR, researchers have found that the task of information retrieval and information seeking in order to extract and utilise knowledge, is fraught with complexity. This complexity is due to the high variability of human behaviour and the manner by which inquirers after information, affect the relevance of the knowledge that is interpreted, as highlighted by the author in a summary of this particular literature, as shown within Table 0-2.

Table 0-2 Fundamental Information Retrieval models

Author	*Information Retrieval Model*
Interaction with the Information System	
Wilson (1981)	Computational Resources, Query Interface
Capurro (1992)	Information Resources
Saracevic (1996)	Computational Resources, Query Interface
Hirscheim and Klein (1998)	Computational Resources
Dervin (1999)	Computational Resources, Query Interface
Capurro (2000)	Computational Resources
Moens (2000)	Query Interface
Vakkari (2000)	Information Resources
Furner (2002)	Information Resources
Hjorlund (2002)	Information Resources
Interaction with the Information Inquirer / User	
Belkin (1980)	Cognitive / Uncertainty skills
Belkin and Kwasnik (1986)	Cognitive / Uncertainty skills
Hayes (1991)	User Knowledge, Cognitive / Uncertainty skills
Kuhlthau (1991)	Cognitive / Uncertainty skills
Capurro (1992)	User Knowledge
Ingwersen (1996)	Cognitive / Uncertainty skills
Capurro (2000)	User Interpretation of the environment
Ferneley *et al.* (2002)	User Interpretation of the environment
Furner (2002)	User Knowledge, User Interpretation of the environment , Cognitive / Uncertainty skills
Hjorlund (2002)	User Knowledge, User Interpretation of the environment

Table 0-2 is a novel structuring and classification of the representative published work, which relates to the relationship between the consumer or user of requested and retrieved information from an information system (i.e. Interpretive Knowledge). The author primarily based this classification of the literature, upon Saracevic's model shown earlier in Figure 0.10. As such, the resulting grouping of the literature presented, has been carried out by the author in order to delineate that published research which concentrates on defining the interaction with a given information system (i.e. a purely IT or computational stance); or in defining the interaction of the consumer of information, in order to harness knowledge (i.e. an IS or user-centric stance). For example, Wilson (1981), Saracevic (1996) and Dervin (1999) are particular about specifying those computational or IT-specific resources which should complement the information consumer's request for information. Whilst Belkin (1980), Kuhlthau (1991), Ingwersen (1996), and Capurro (2000) all suggest that it is the cognitive or psycho-physiological contextual aspect of the information consumer, which drives the information retrieval process (almost independently of the information system used).

Hence, IR models are more biased towards and dependent upon the cognitive and socio-cultural state of the inquirer. This view fits with many other IR researchers as highlighted earlier, and suggests that in order to overcome issues of uncertainty, linguistic complexity and relevance criteria, the effective usage or *evaluation* of the represented and retrieved information, needs to be taken into account, as cited by Brajnik (1999). Hence, the natural progression of interpretive models of knowledge, pre-supposes a third school of thought relating to the usage of knowledge within information systems, and is defined in the next section.

Evaluative Knowledge

Both structural and interpretive forms of knowledge are largely concerned with effectively representing knowledge, with a limited regard to providing context to it. This is understandable, given the fact that these methods have evolved from fundamental computer science precepts which have been predominantly rooted in computation. And thus to a certain degree, have inherent biases relating to the modelling and programmatic assumptions which have been in the hands of such systems designers. Hence a third form of knowledge has emerged over the years, which relies upon those aspects of the discipline of IS research, whereupon the process or *evaluative* nature of knowledge is considered. The most visible and prominent manifestation of this approach, has been through the development of management science related theories, which have blended with IS theories, to form the subject of Knowledge Management.

This evaluative form of knowledge, which involves not only the representative but also the interpretive aspects of knowledge, consists of a series of processes and policies for creating, managing and disseminating knowledge. Further details of these aspects are given in the following sections.

Foundations of Knowledge Management

The history and application of the concept of Knowledge Management (KM), has principally occurred because of the need within business organisations, to capture and codify knowledge through some means or another. Computer science techniques assisted greatly with this effort, and at the zenith of AI research and development through the 1980s and into the early 1990's, the usage of knowledge engineering techniques grew rapidly (Coats, 1991; Sveiby, 1997). This was principally based upon largely structural as well as interpretive forms of knowledge, as has been cited in previous sections, culminating in the development of knowledge-based expert systems (Jackson, 1990), an example of which is shown in Figure 0.11.

This form of information system, can be thought of as an automated reasoning tool based upon a pre-defined domain of knowledge (the *knowledge base* / long term data memory), which can provide a reasoning path (the context / *chain of inference* / short term data memory) via a question/answer facility based upon the knowledge domain (the *inference mechanism*). Such a system works through a user-friendly interface, which employs mostly real-world linguistic questioning techniques. This helps in the development and justification for an answer found from the results to each 'fired' question from the inference engine (Jackson, 1990). Expert systems emulate and use the knowledge of experts and ask pertinent questions about the given problem and provide relevant explanations for those questions and conclusions.

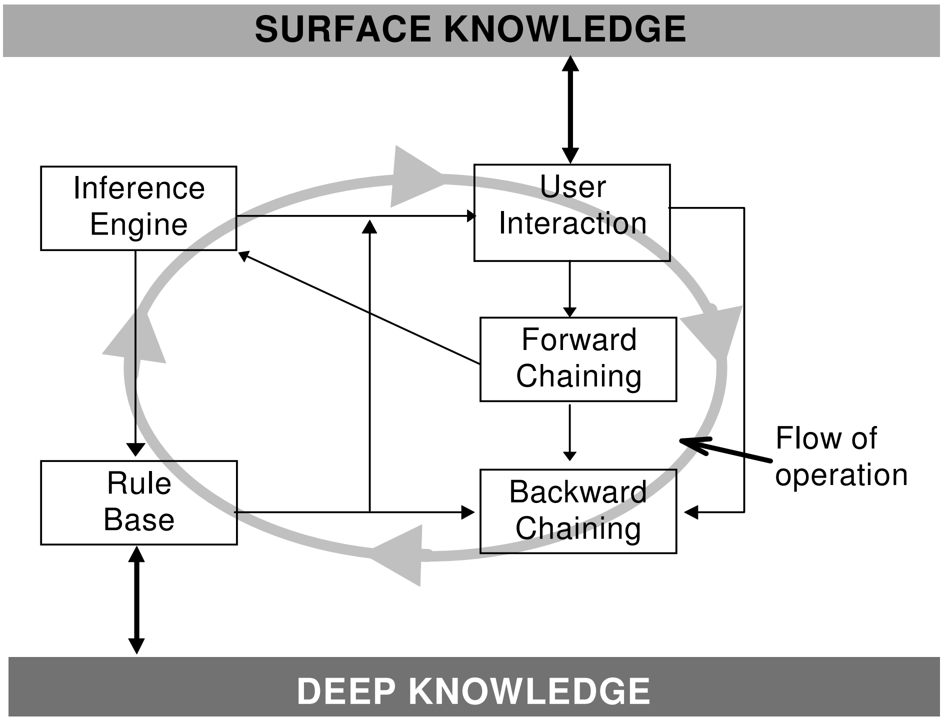


Figure 0.11 An expert system

In broad terms, an expert system is a large database of known theoretical knowledge ('Deep' knowledge) or acquired / heuristic knowledge ('Surface' knowledge). Expert knowledge bases can be combined together in order to apply different heuristics (intuitive rules of thumb) to solving difficult problems. Although expert systems became highly fashionable during this period, there was still a high degree of dependence upon the underlying assumptions, or *a-priori* knowledge required to drive the inference engine. Structured knowledge modelling techniques, such as KADS (Wielinga *et al.*, 1993), Protégé 2000 (and to a lesser extent the Unified Modelling Language, UML) were developed in order to create the specification and implementation of rules for knowledge systems based upon expert knowledge (Abdullah *et al.*, 2002). At the same time, the field of management was also becoming increasingly interested in the role and importance of organisational learning and its impact on organisational performance (Drucker, 1993; Earl, 1995; KPMG, 1998; Porter, 1985). Through the continued development of information systems design (Olesen and Myers, 1999), and the advocacy of leading management thinkers such as Davenport (1996), Prahalad and Hamel (1990), and the ubiquitous work of Hammer and Champy (1993), this then led to the formation of the concept of knowledge management, as is currently understood. A loose definition of KM based upon Wiig (1985), can be said to be a set of techniques, and tools which help an organisation to discover, organise and integrate new and existing knowledge into the business, and to help control the flow of paperwork, as Lethbridge (1994) notes:

> *'the process of acquiring, representing, storing and manipulating, categorisations of things and their relationships…'*
>
> (Lethbridge 1994, pp.2)

Whilst Probst, Raub and Romhardt (1994) suggest that knowledge management is:

> *'…an integrated set of interventions which take advantage of opportunities to shape the knowledge base'*
>
> (Probst, Raub and Romhardt 1994, pp.25)

Further, Maki *et al.* (2002), state that knowledge management :

> *'…refers to organisations' attempts to introduce tools, technologies, and procedures to utilise available knowledge and intellectual capital in order to learn, create new knowledge, and make the most of the knowledge potential.'*
>
> (Maki *et al.* 2002, pp.1)

Whichever definition of this evaluative form of knowledge is used, it is well understood that this concept essentially covers aspects of both the process of *capturing* as well as *using* knowledge, and aligning this with *tools* to facilitate this. The breadth and scale of the representation of these concepts, is truly immense and an exhaustive bibliography and review of this form of knowledge, is well beyond the scope of this dissertation. However, Huber (1991), Holsapple and Joshi (1999), Lai and Chu (2000) and Chauvel and Despres (2002), provide excellent overviews of some key KM frameworks. These frameworks can be said to be based on both Broad and / or Specific models. The former models encompass core organisational principles required for managing knowledge (phenomena and actions), whilst the latter models deal with issues of knowledge usage for particular organisational needs (knowledge as an asset, intellectual capital, knowledge technology tools and knowledge transfer).

A traditional outcome of these frameworks and models, focuses on three key aspects: people, process and technology (Davenport and Prusack, 1998; Leonard-Barton, 1995). The People component, deals ostensibly with organisational, individual and cultural aspects of the use and implementation of knowledge. This is in terms of those key stakeholders whose day-to-day work relies heavily upon the transfer and usage of (Stewart, 1997) – so-called “knowledge workers”. The Process component, suggests methods and techniques for managing the flow of knowledge within an organisation. This can be via the implementation of strategies and policies to identify where and how knowledge exists within the enterprise. Finally, the Technology component, deals with those particular tools and infrastructure within an organisation which assist in providing access to and the exchange of information. The use of repositories of information, such as corporate networks, file systems, intranets and more recently, portals (Tapscott *et al.*, 1998), has greatly enhanced this aspect of knowledge management also (Ruggles, 1997). These stages are typically defined by researchers in the field, via differing terminology, although the relevance and argument is essentially the same (Kluge *et al.*, 2001; Probst *et al.*, 2001; Ruggles, 1997; Wiig, 1995). Essentially, these components can be crystallised into more specific processes such as collection, storage, dissemination and creation (Davenport *et al.*, 1996; Maki *et al.*, 2001) - a simplified view of this, is shown in Figure 0.12.

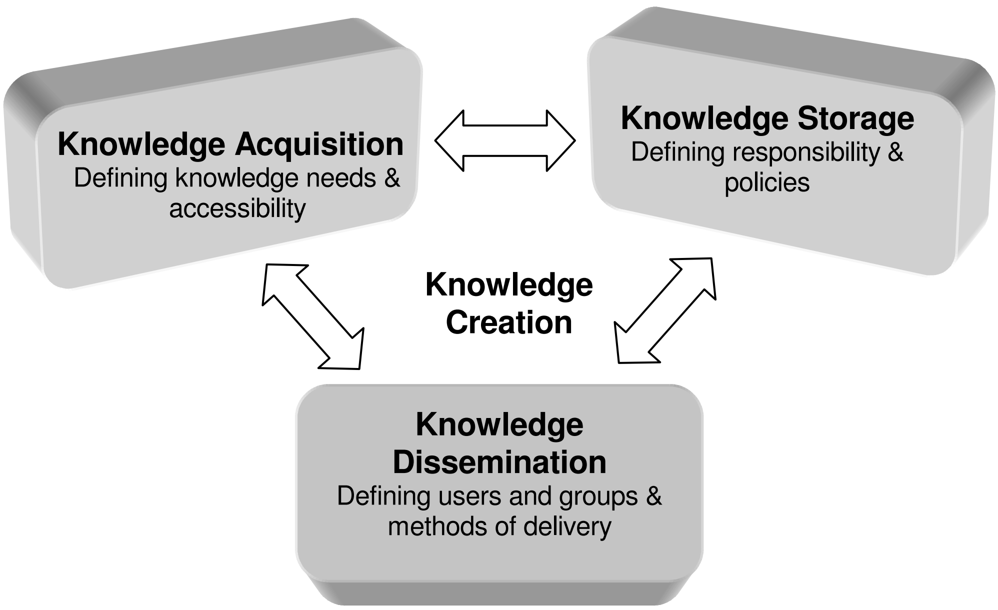
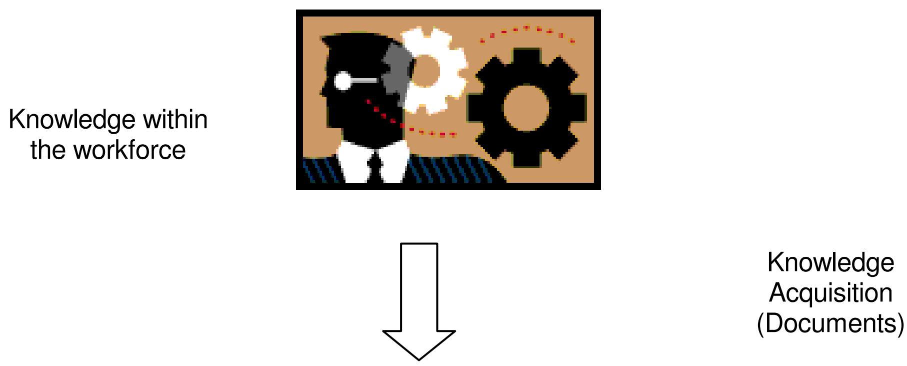


Figure 0.12 Knowledge processes as defined by Maki *et al.* (2001).

Perhaps of all of the researchers to define the nature and importance of knowledge transfer between the 3 stages shown in the diagram overleaf, Nonaka and Takeuchi (1995), in their landmark work outlined the tacit to explicit knowledge dynamic. This approach to viewing knowledge, relies upon the notion that different levels of knowledge are required in order to carry out a task: explicit knowledge in the form of information and data; and tacit knowledge in the form of intuition and an individual's personal viewpoint. Within the corporate enterprise context, Bennett (1998) and Smith (2001) further highlight the importance of both of these forms of knowledge existing, in terms of strategic decision-making and organisational culture contexts respectively. An overview of these facets of the knowledge management process has therefore been distilled and summarised by the author into Figure 0.13. This diagram shows a simplification of the many knowledge management models which are present today, based upon the literature reviewed so far.

Predominantly, these are equivalent to the four organisational learning constructs attributed to Huber (1991) : knowledge acquisition, information distribution, information interpretation, and organisational memory; the four stages of conceptualise, reflect, act and retrospect as noted by Van der Spek and Spijkervet (1997); the phases of creation, retention and transfer as noted by Newman and Conrad (1999); and also the encoding, comparison, response-selection and response-execution processes as discussed by Carlson and Sorderberg (2001). The process of capturing knowledge is first and foremost based upon the definition of the extant knowledge within the organisation, relating the users of that knowledge. Following on from this, there is a stage of codification, whereupon knowledge that has been defined is gathered and represented in some manner, relevant to the users and organisation. Schulz and Jobe (2001) suggest that knowledge codification in itself, needs to be carried out carefully, in order to represent the correct information most effectively. This is since not all knowledge is convertible into an explicit, representable form.



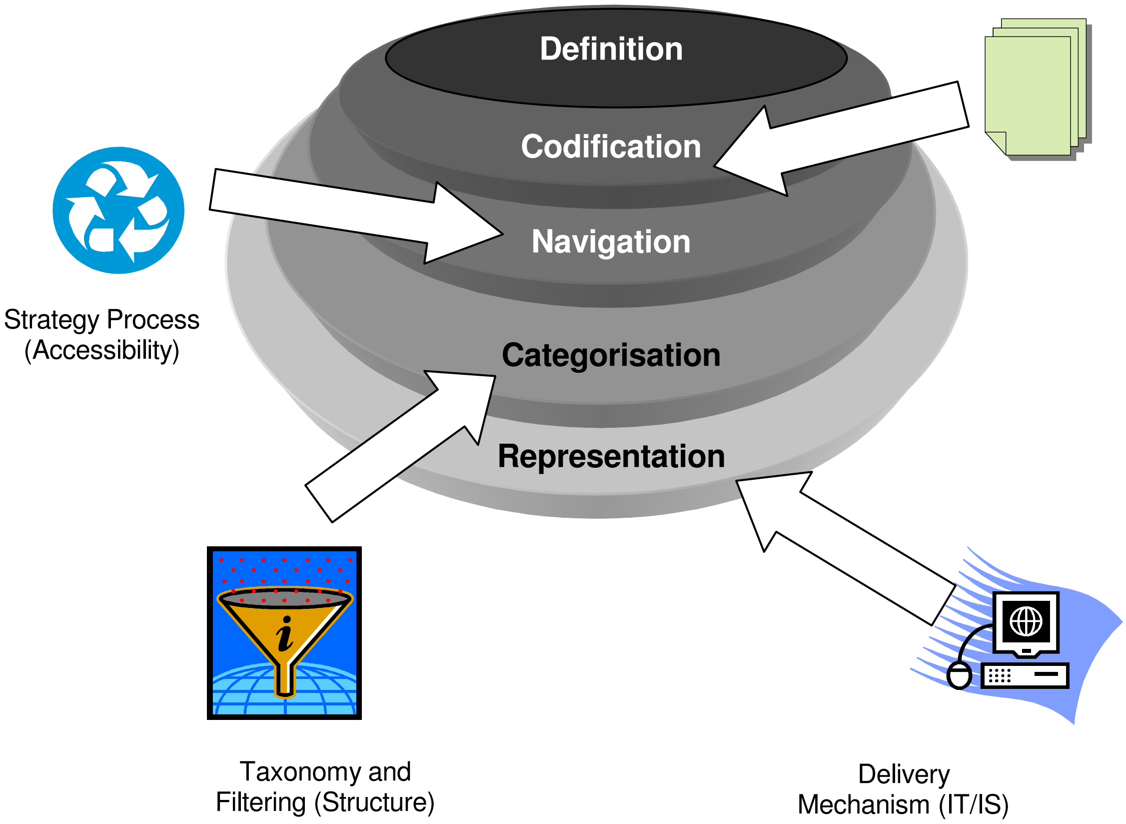


Figure 0.13 Typical Knowledge Management activities

Once this has been achieved, and some would say prematurely achieved, the manner by which useful work can be made, is mapped via some level of navigation. This is more commonly understood as being a strategic process which identifies gaps in the complete knowledge resolution process (King *et al.*, 2002). In order to align this process with the given knowledge, a method for structuring the content is required, through a process of taxonomical categorisation. This would be in the form of highlighting, the information architecture (Rosenfeld and Morville, 2002): that is information topics; document types; accessibility and availability levels; structure of information (i.e. a schema); a common vocabulary for the information (i.e. a thesauri and / or a lexicon). Finally, the implementation of any knowledge management approach, needs to deal with the delivery / execution mechanism in order to represent the knowledge structured in this way. Thus, evaluative knowledge in the guise of the paradigm of knowledge management, is yet another method of knowledge which is characterisable through the process-oriented view of knowledge usage and representation. Some of these evaluative knowledge models and theories reviewed, have been summarised by the author and are shown within Table 0-3.

Table 0-3 Fundamental Evaluative Knowledge Management models

Author	***Evaluative Knowledge Model***
Generic / Epistemological	
Huber (1991)	Knowledge activities, Strategic implementation
Nonaka and Takuechi (1995)	Knowledge activities
Ruggles (1997)	Knowledge Process
Van der Spek and SpijKervet (1997)	Knowledge Process
Wiig (1997)	Knowledge activities, Knowledge Process
Davenport and Prusack (1998)	Strategic implementation
Bennett (1998)	Strategic implementation
Tapscott *et al.* (1998)	Organisational Capabilities, Strategic implementation
Newman and Conrad (1999)	Knowledge Process
Wiig (1999)	Knowledge activities, Knowledge Process
Kluge *et al.* (2000)	Strategic implementation, Knowledge Process
Probst *et al.* (2001)	Strategic implementation, Knowledge Process
Carlson and Sorderberg (2001)	Knowledge activities, Knowledge Process
King *et al.* (2001)	Knowledge Process
Maki *et al.* (2001)	Organisational Capabilities
Schulz and Jobe (2001)	Knowledge Process
Smith (2001)	Strategic implementation
Contextual / Phenomenological	
Nonaka and Takuechi (1995)	Knowledge Transfer
Leonard-Barton (1995)	Organisational Structure
Stewart (1997)	Intellectual Capital, Organisational Structure
Bennett (1998)	Knowledge Transfer
Syed (1998)	Knowledge Transfer
Maki *et al.* (2001)	Organisational Structure
Smith (2001)	Knowledge Transfer

The Evaluative knowledge models shown in Table 0-3, have also been structured by the author in a similar novel manner, to the review of Structural and Interpretive knowledge literature shown in Table 0-1 and Table 0-2 earlier. As such, Table 0-3 is a representative collection of the published work in the field, which relates to a series of processes and policies for creating, managing and disseminating knowledge (i.e. Evaluative Knowledge). Again, the resulting grouping of this literature by the author, has been carried out in order to highlight specific philosophical stances taken by the given researchers in defining this form of knowledge. As such, the author has denoted each approach as being either Generic / Epistemological or Specific / Phenomenological in nature.

In the former, knowledge is viewed in terms of processes and techniques for capturing, codifying, storing and disseminating knowledge amongst individuals and teams within organizations (as highlighted by Davenport and Prusack, 1998; King *et al.*, 2001; Maki *et al.*, 2001; Ruggles, 1997; Wiig, 1997). That is relative to the relationship that information and knowledge consumers have with the source and nature of knowledge itself – i.e. an epistemological basis. Whilst in the latter case, knowledge is viewed in terms of the manner in which such knowledge is used and transformed between individuals in terms of specific human behavioural or environmental activities, such as collaborative team-based design (for example as exemplified by Nonaka and Takeuchi, 1995) or in terms of decision-making processes (as in the case of Bennet, 1998; Smith, 2001). Thus, in this case, this relates to the observed or experienced interaction between individuals and knowledge – i.e. a phenomenological basis.

Given these preceding definitions of the three key forms of knowledge, Structural, Interpretive and Evaluative, the author now presents a novel taxonomy of this reviewed literature within the context of the dissertation, in the next section.

Taxonomy of Knowledge forms

As has been shown in the preceding sections, the author has attempted to classify and thenceforth to present representative literature in terms of three distinct forms of knowledge pertinent to this dissertation (Structural, Interpretive and Evaluative). In doing so, the author has shown that in each case, the respective researchers within set of reviewed literature take a particular stance, with respect to the knowledge form involved. Hence, in Table 0-1, Table 0-2 and Table 0-3, the author has shown that there are specific points of view about each knowledge form. In the case of Structural knowledge, these are the logical and ontological stances; for Interpretive knowledge, these are the interaction relationship with information system and the information inquirer, respectively; and for Evaluative knowledge these are Generic / Epistemological and Specific / Phenomenological.

The author now wishes to place these forms of knowledge in terms of the overall context of the development of the concept of knowledge, as it relates to the field of Information Systems as a whole. In doing so, the author presents a fishbone diagram in Figure 0.14 which shows the key schools of thought which have affected and caused the development of concept of knowledge within IS. As such, this diagram shows the relevance and contingent relationship between each form of knowledge discussed thus far, and how the reviewed literature relates to the rest of the dissertation, in terms of the concept of knowledge representation. The author has deliberately used a fishbone diagram for the taxonomy in Figure 0.14, to show the highly constrained and localised development of the understanding of knowledge as a result of the influences of the different disciplines of philosophy and economics; computer science, information science; and business management. This is an important diagram and visualisation, as in the literature there is minimal contextualisation of the contingent differences and subtleties of what exactly constitutues knowledge.

Once again, these views of knowledge representation, in the sense of the manifestation of experiences, intellectual tasks and processes, proceeding from the left hand side of the diagram towards the right hand side, can be split up into : (i) root definitions and causes based upon theories arising from the fields of philosophy, economics and management

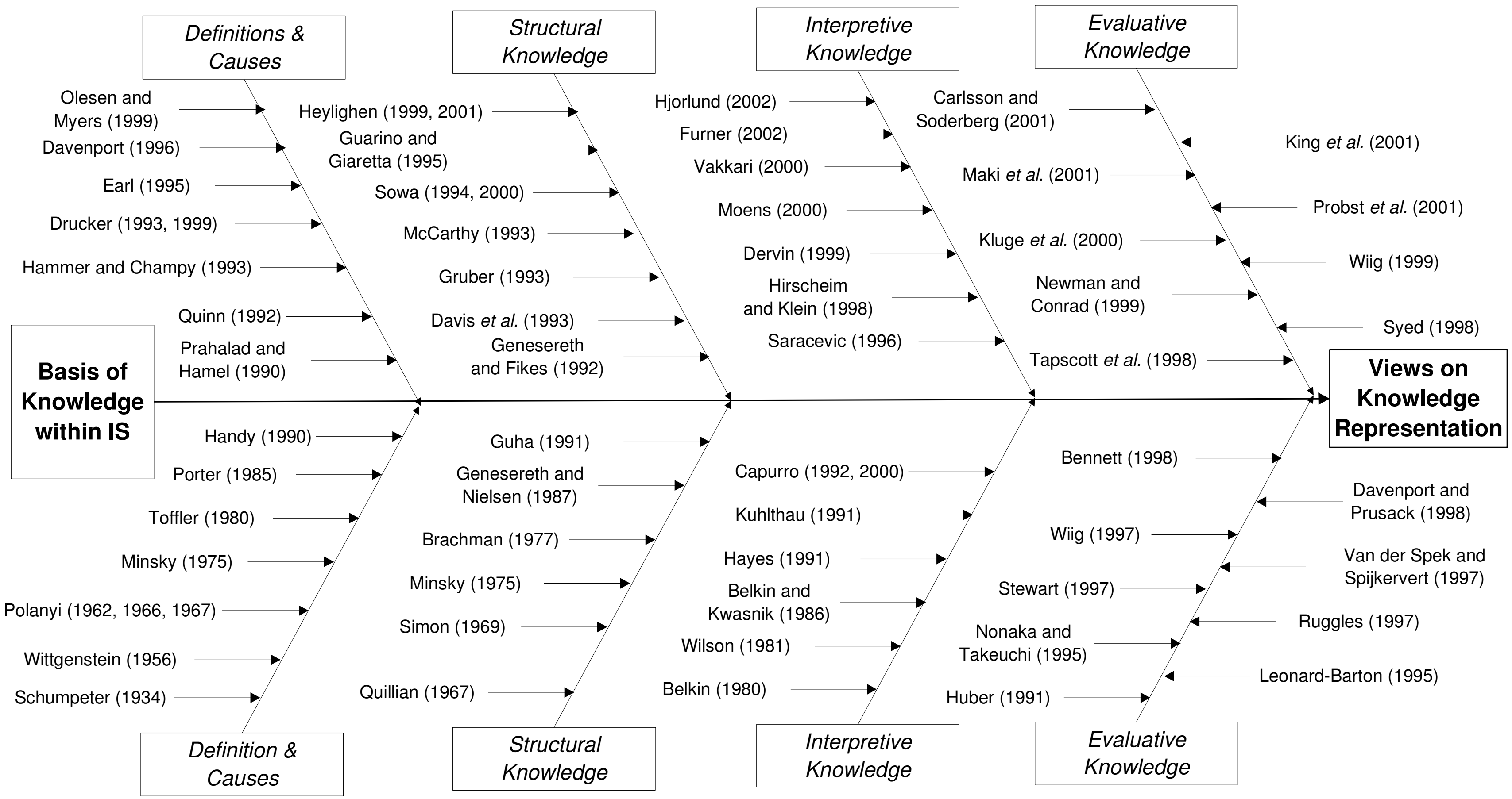


Figure 0.14 Taxonomy of knowledge forms derived from the literature review

science; (ii) Structural knowledge which is based upon strictly logical and ontological assertions; (iii) Interpretive knowledge which is based upon concepts of information science in terms of the retrieval and manipulation of information search queries; and lastly, (iv) Evaluative Knowledge, which concerns itself with the stakeholder aspects of managing and codifying knowledge within an organisational setting. Principally, this shows the manner by which theories based within social and behavioural sciences have affected the evolution and understanding of knowledge as a concept (Blackler, 1995), towards a specific realisation of the term within the realm of Information Systems.

The novel taxonomy presented by the author of the published research within the area of knowledge within information systems, shows that each strand within the diagram essentially underpins and highlights the fact that there has always been a continual need to harness and qualify knowledge, in order to achieve some greater goal.

In terms of the root causes and definitions, the literature points to the usefulness of *knowledge as a resource* which can supplant creativity (i.e. innovation and entrepreneurial efforts within the business domain). At the same time, the development and evolution of computer science as a discipline, led to the need to quantify information in terms of low-level data. This has been principally to define knowledge in terms of its semantic and logical content, and to allow *knowledge to be quantified*, *i.e.* the Structural knowledge view. Coupled with this, has been the requisite desire to make sense of information, thus to use *knowledge in decision-making processes*, i.e. the Interpretive knowledge view. Lastly, and more specifically more recently, it has become increasingly important to situate knowledge in terms of tasks and systems, which either an individual or organisation, can control and manage, in order to that *knowledge can be oriented within a process lifecycle*, i.e. the Evaluative knowledge view.

The review of the published literature in the field, relating to all of these forms of knowledge, shows that the roots of knowledge are far removed from the information systems view of it. The definitions of knowledge are heavily rooted in many seminal articles and treatise within the fields of economics, philosophy and business management. Even within these separate views of what constitutes knowledge, there has been a repeated attempt by researchers to put knowledge in a particular context. As such, knowledge was primarily seen as being a purely metaphysical concept, in terms of feelings and emotions relating to being aware or understanding one's surroundings – hence, knowledge can only be shown through experience and behaviour (Wittgenstein, 1956). Indeed Polanyi (1966) and to a certain extent Minsky

(1975) and Toffler (1985) expanded upon this thinking, in terms of attempting to distill the very essence of knowledge as it relates to specific human events and thought processes.

However, the lines of metaphysical and psychological enquiry, although pertinent and interesting to practitioners in economics, business management and computer science, were largely left to be dealt with by psychologists and behavioural scientists (Quinn, 1992). From the early 1960's then, practitioners in these fields sought to define and contextualise knowledge themselves, and this in the view of the author, is where the potential complexity about the understanding of knowledge has arisen from. Apart from the concerted effort by researchers within the field of Artificial Intelligence such as Quillian (1967), Minsky (1975) and even Sowa (1994), there has been little cross-pollination and sharing of ideas between both the psychological and applicational schools of thought, relating to knowledge. By this it is meant that to a greater or lesser extent, the development and understanding of what knowledge is and how it can be used by individuals within decision-making tasks, has not been consistent in terms of the way in which the concept of knowledge has been derived from the metaphysical (abstraction of knowledge) to the physical (realisation of knowledge). Improvements in computing technology over the period 1960 – 1980 meant that many researchers and interested parties in the field of computer science, were primarily concerned with the codification and fundamental representation of data and information (and rightly so). However, in the view of the author, this focus on codification extended the notion of knowledge as a resource, as opposed to extending the understanding of knowledge within a specific context (such as decision-making tasks). As such, the Artificial Intelligence research, is still struggling to imbibe knowledge into systems, due to a specific focus on principles of logical structuralisation (algorithmic representation), which do not necessarily encompass the metaphysical nuances of the feeling or emotional aspects of knowledge (as even Guarino and Giaretta, 1995, Heylighen, 2001 and Sowa, 2000, acknowledge). Hence, the schism or split between the abstract and applicational view of knowledge is most apparent when the differences between the Structural and Interpretive forms of knowledge are considered.

As has been discussed, the published work in terms of Interpretive knowledge focuses on the relationship between inquirers after information and information sources. The work of Belkin (1980) and Wilson (1981) was significant in terms of this thesis and the focus on knowledge representation, because they were able to state quite clearly, the contingent difference between certainty and uncertainty of knowledge how to deal with information. Belkin's Anomalous State of Knowing (ASK) model, clearly poses questions about how we view and understand knowledge and information that is represented to us. Belkin does not encourage or even is concerned with the structuralisation of information and knowledge. Rather, Belkin sets the tone for the field of information science in terms of returning in some respect, to the metaphysical or psychological aspects of what constitutes knowledge. In this respect, Belkin and others (most notably Capurro, Dervin and Furner) are more closer to the Wittgensteinian and Polanyian concepts of "showing" and "knowing" the reality around us. Indeed authors such as Hayes (1991) and perhaps the best example of all, Saracevic (1996), have shown that their view of understanding information and knowledge is strictly limited to an altruistic stance. Information science is purely concerned with the context of information retrieval, in terms of understanding information presented to an individual. It is inflexible with regards to decision-making and other creative thought processes. So, once again, this is a different and exclusive view of knowledge.

The difficulty in attempting to represent knowledge and its associated processes within information systems then, has been due to these largely independent schools of thought, amongst which there has been little overlap. The one school of thought which has managed to bring the philosophical view of knowledge back has been that centred around business management (i.e. Evaluative knowledge). Although this is once again, another interpretation of what and how knowledge is, researchers within business and management have sought to harness both advances in psychology, economics and computer science in order to address organisational and business enterprise needs. The modern day world, has in effect, been responsible for making knowledge an important asset once again (Stewart, 1997), and has forced researchers and practitioners alike to combine their thinking (such as highlighted by Davenport and Prusack, 1998; Leonard-Barton, 1995; Newman and Conrad, 1999). As such, the concept of knowledge management has been a vibrant growth area within enterprise IT/IS over the period 1990 – 2001, where many researchers and practitioners have been attempting to realise the nuances of not only semantically structuring knowledge (Wiig, 1997), but also relating knowledge to its abstract, metaphysical state (Huber, 1991; Nonaka and Takeuchi, 1995; Van der Spek and Spijkervert, 1997) and to a series of processes (Davenport and Prusack, 1998; King *et al.*, 2001; Kluge *et al.*, 2000; Ruggles, 1997). Whilst these approaches have been somewhat successful as compared to the purely Structural and Interpretive forms of knowledge, there is still a need to understand the context of how knowledge is used, specifically for human decision-making tasks (which almost always inevitably involve an abstract or tacit dependence upon a meaning or understanding of the observable world).

The dissertation therefore attempts to address this aspect of how knowledge is used and represented, in terms of the underlying, fundamental nature of knowledge – the relationship between the metaphysical, abstract or tacit dimension and its explicit form. Without relating the context of a piece of knowledge within an associated information system (or process related to thereof), the author contends that it is difficult to effectively represent that knowledge for use in decision-making tasks. Rather, as Wiig (1999) notes, knowledge itself may become meaningless with an appropriate understanding of its context as well as its content. A possible reason for this impasse and the continuing complexity relating to the understanding of knowledge, may be due to the fact that there is a scarcity of longitudinal research and empirical work on knowledge creation and its effect within organisations, to progress and enhance these ideas (Chauval and Despres, 2002 ; Soo *et al.*, 2002a). Even though it is understood that the objective of knowledge management, is to eliminate the obstacles of knowledge flow, there have been few attempts to analyse, systematically, how different variables affect the flow and utilisation of knowledge, within a knowledge intensive organisation also (Maki *et al.,* 2002).

Thus, this novel taxonomy structured by the author as a result of the reviewed literature within this chapter, attempts to show the identified forms of knowledge concept, classified in terms of an identification of their respective characteristics, in order to progress the thesis towards the research aims within this dissertation. The generation of this taxonomy provides the author with a basis for establishing the scope and limitations of each definition of knowledge, through a deeper understanding of the dependent stances in each knowledge form.

Summary

The chapter started by observing the increasing importance of knowledge within organisations, as a factor of the evolution of the industrial age. The emergence of the so-called information or "knowledge economy" has meant that the relevance and usage of knowledge has increased dramatically to such an extent that it is now recognised as an essential component of an organisation. Following on from this, some key definitions of data, information and knowledge were provided. This was in order to ground the survey of the extant literature which followed.

Through reviewing some generic descriptions and definitions of knowledge within the organisational context, a novel conceptualisation of three forms of knowledge was presented in terms of dimensions of content and context: Structural, Interpretive and Evaluative. These forms were then further detailed in terms of published literature in the fields of knowledge representation, information retrieval and knowledge management respectively. Subsequently, the author presented novel categorisations of the reviewed literature in terms of logical and ontological (in terms of Structural Knowledge); the interaction relationship with information system and the information inquirer (in terms of Interpretive Knowledge); and for Generic / Epistemological and Specific / Phenomenological stances (in terms of Evaluative Knowledge).

A resulting novel taxonomy of these areas was then presented, based on the characteristics of each definition of knowledge (Structural, Interpretive, Evaluative). Through highlighting the fact that definitions and the understanding of knowledge within an organisational context has its roots in the philosophical, economics and management sciences, the progression towards representing knowledge within information systems is therefore complicated by these multiple points of view of knowledge. As a result, it was highlighted, that the taxonomy therefore extends the notion of knowledge as a resource, as a quantifiable and verifiable structure, as an aid to decision-making processes, and as a constituent part of a series of value-adding processes. In doing so, the author also noted that the contingent differences between each form of knowledge thus reviewed so far, highlights the fact that a relevant and necessary relationship between both the content as well as context of knowledge is required, in order for knowledge to be useful for human decision-making tasks.

CHAPTER 3

KNOWLEDGE IN MANUFACTURING IS

Following on from the formation of the context of the thesis in the previous chapter, this chapter develops lines of inquiry which provide a focus to the research undertaken. This involves the generation of a proposition which builds upon the *reviewed literature by discussing those factors which have an influence on the usage of evaluative knowledge, within manufacturing IS. As such, a detailed interpretation of both explicit and tacit knowledge is given, in order to show the interrelationship between both these forms within the CAE and ISE tasks. By the concurrent themes of socio-psychological interaction and assumption-based knowledge via a classification of Nonaka and Takeuchi's four key knowledge aspects, a conceptual framework for how knowledge is transformed within manufacturing IS environments is then proposed.*

Knowledge in Manufacturing IS

Following the review of literature in the previous chapter, it should now be clear that there are numerous ways to create, extract, codify and represent knowledge. Many of these approaches were highlighted as being constituents of artificial intelligence (knowledge representation in terms of semantic structures), information science and knowledge management.

The purpose of this chapter is to define the focal theory of the research and propose a premise from which suitable lines of research inquiry are suggested, based upon the review of the literature defined in the background theory. This is in the sense of defining further, the Evaluative form of knowledge, in terms of what exactly constitutes explicit and tacit knowledge forms. The chapter begins by identifying types of IS which are typically encountered within manufacturing IS. This is in terms of those IS which are typically knowledge-centric in nature. Furthermore, the author discusses what is meant exactly by knowledge representation, and following on from this, the selection of the given manufacturing scenarios, henceforth known as *IS environments*. Within manufacturing there are specific cases where the effective use of represented knowledge is unclear or indeed requires clarification. These two areas are namely decision flow within CAE tasks, and the IT/IS investment evaluation of manufacturing systems. A detailed analysis of the importance of explicit and tacit knowledge is given, in terms of the sociological and psychological influences occurring. Thus the chapter continues, by attempting to address two issues: firstly how is explicit and / or tacit knowledge used in decision making tasks within product design and IT/IS evaluation, and secondly, as such, which particular factors drive and are the basis for, the representation of these phases within the manufacturing cycle? These factors are based upon Nonaka and Takeuchi's four aspects of knowledge creation and transfer: socialisation, externalisation, combination and internalisation.

In concluding the chapter, a conceptual framework is presented which outlines the influencing factors of both socio-psychological and *a-priori* assumption-based dimensions of explicit and tacit knowledge, within the manufacturing IS environment context.

Information Systems within Manufacturing Environments

In order to begin to refine and focus the thesis within this dissertation, the author now defines both the type of IS and knowledge which is relevant to the thesis, within the coming chapters. For the purposes of this research, attention will be given to considering those types of IS within manufacturing organizations (both large and SME alike), which involve the use of knowledge directly in order to execute tasks. In terms of this dissertation, the definition of an SME (Small and Medium-sized Enterprise) relates to the European Commission definition (upto 250 employees, and an annual turnover not exceeding 40 Million Euros; Commission of the European Communities, 1996). As such, the types of IS which are applicable to this research are those which require knowledge or sustained intellectual input, i.e. business processes which are inherently knowledge-centric.

Therefore, the author wishes to concentrate solely on those types of IS which encompass the remit of the dissertation, namely Management Information Systems (MIS) / Decision Support Systems (DSS) and Knowledge Work Systems (KWS). By definition, MIS are designed to provide information and support relating to the monitoring, controlling, decision-making, and administrative activities of middle managers. MIS provide managers with reports relating to the organisations current performance and historical records. Typically these systems focus entirely on internal events, providing the information for short-term planning and decision making. Materials Resource Planning (MRPII) and other such resource planning systems such as Enterprise Resource Planning (ERP, Rao, 2000) are typical examples of such MIS within manufacturing.

These types of information systems, allow organisations to integrate data and information across a range of business processes and tasks, in order to provide an accurate and realistic view of the current operational state of the organisation. Such implementations have been focussed around the implementation of production planning or materials management modules and components of ERP systems, such as in the case of the SAP R/3 product (Al-Mashari and Zairi, 2000). Such modules typically integrate information relating to the scheduling of man, machine and material costs and resources, with the potential to integrate and control production plant machinery as well (such as via automated or flexible manufacturing cells, which control Computer Numerically Controlled lathes and milling machines). In other cases, such systems support non-routine decision-making tasks, which focus on less-structured decisions for which information requirements are not always clear. This can also in the form of simple spreadsheet-based applications, which can be used for estimating and forecasting tasks (Coats, 1991).

As a form of MIS, DSS tend to provide information and knowledge to managers, in order make decisions that are semi-structured, unique, or rapidly changing, though not easily specified in advance. They can use internal information from MIS, but can also use information from external sources too (such as from inter-organisational systems such as human resources and / or payroll). DSS can also provide far greater analytical power than other forms of IS, through incorporating modelling, data mining, aggregation and analysis tools, in order to "what-if" scenarios. As such they are also seen to be similar to scheduling or work-package balancing systems, which take as input a number of key process variables. DSS typically provide user-friendly, interactive tools, although the output of such systems is to drive key decision-making tasks, relating to tactical or strategic aspects of the business. A good example of such a DSS, is in the implementation of balanced scorecard or organisational performance, which allow key process indicators (KPI) of the company to be monitored and tracked by senior management (Kaplan and Norton, 1992). Within the manufacturing context, DSS may be most visible as being a part of the bill of materials (BOM) and operational planning modules within an ERP system. Through balancing information and data relating to scheduled production runs, supply of materials, labour and machine cost and time to delivery (i.e. time-fence estimates), DSS in these forms can provide production managers with accurate "dashboard" style assistance.

At the other end of the spectrum, KWS systems, support knowledge and data workers within the organisation. This type of system is a relatively recent introduction to the field of information systems, and has become to be a class of system by itself, mainly through the recognition and understanding of the concept of knowledge work (as described in chapter 2 in detail). To recap, knowledge workers typically have as their main responsibility, the relevant skills to transform information into knowledge, in order to carry out their day to day job. As such, the purpose of these systems is to help the organisation discover, organise and integrate new and existing knowledge into the business, and to help control the flow of work more effectively. KWS are more generally visible and known as being collaboration tools, which allow the integration and accessibility of information and knowledge across the organisation.

This is typically via repositories of information and team-based information management systems, such as message boards, calendar / scheduling applications, intranet portals, group "blackboards", email and online videoconferencing applications. Within manufacturing IS environments, KWS are realised in the form of scientific or engineering design workstations, which allow teams of workers to collaborate together on product or component design projects. For example, distributed computer aided engineering (CAE) applications, such as those employed within the defence and automobile sector, have gained widespread support over the years due to the manner by which design-specific information can be shared and used between engineers (George, 1991).

Knowledge Scenarios within Manufacturing IS Environments

Given that knowledge is in itself an important aspect of information, and also when discussing the benefits that knowledge can provide to an organisation, attention is now focused on the particular case of how and what knowledge is maintained within a specific organisational context – namely manufacturing IS. In particular, two aspects of manufacturing where decision making tasks rely upon knowledge are in the product design (computer aided engineering) and also investment evaluation business processes. The author has chosen these two facets of the manufacturing cycle as they are particularly dependent upon expert insight, and include aspects of explicit and tacit knowledge respectively. This will be presented in further detail in later chapters of this thesis. For the purposes of this dissertation, such contexts will be defined as being part of an IS environment.

That is, a business or organisational setting within the manufacturing industry where IT/IS is utilised for predominantly decision making tasks, which have a direct input into a specific part of the manufacturing lifecycle. Such an example lifecycle is shown in Figure 0.1.

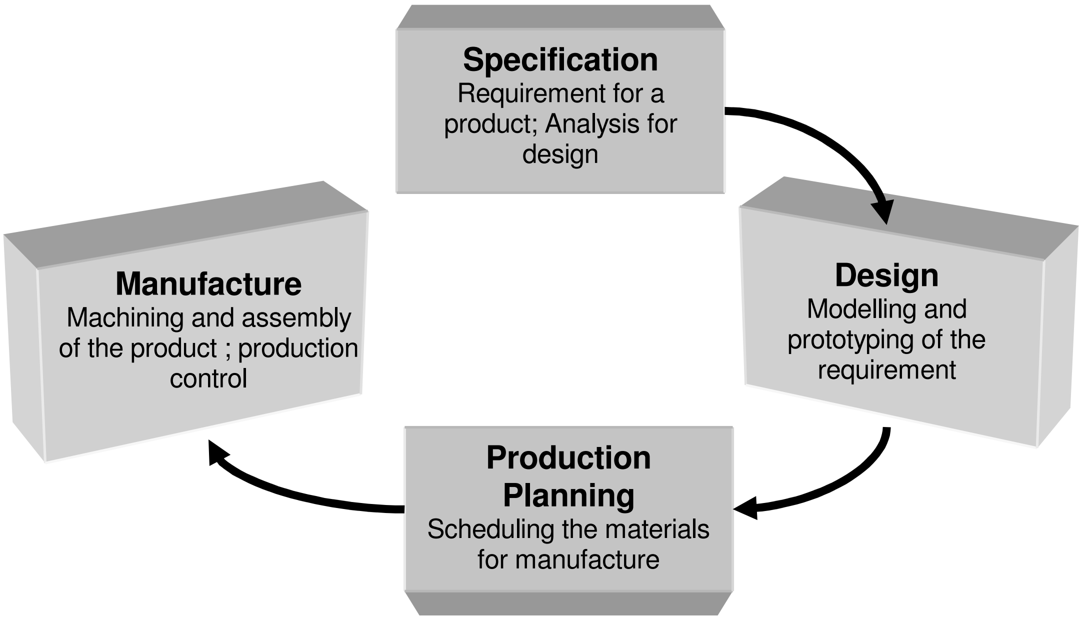


Figure 0.1 The Manufacturing lifecycle (from Ranky, 1990)

Tasks within this lifecycle, traditionally involve the use of explicit or expert knowledge, and from a socio-cultural viewpoint within manufacturing organisations, have attracted much interest (such as by Nonaka and Takeuchi, 1995). As such, the following sections provide a survey of the key literature within each of design and production planning areas, to give a grounding for the development of the focal theory in the chapter that follows.

Product Design within Manufacturing

As can be seen from Figure 0.1, one of the first phases of any manufacturing cycle, involves the selection and specification of requirements, in order to manufacture a product. Computer Aided Engineering (CAE) systems are used for further detailing the design, analysis and manufacture of engineered components and products across a wide range of industries (such automotive, aerospace, electronic, nuclear and chemical engineering). The development and growth of these computerised packages has meant the design, test and analysis phases, can now be carried out on a desktop computer.

In this way, CAE systems, as a class of information system, provide a wide and varied context for problem solving and decision making, as shown in Figure 0.2. Many CAE systems employ design and analysis routines, which can simulate and predict the effect of heat, stress and displacement on a designed component (for example, stress and strain on an aircraft wing). The visualisation of such results is often performed by computing the solution to a mathematical representation of the product being designed, by using a 'mesh' or 'grid' of connecting finite elements, which are then adapted to limit any error in the solution. Amidst the growth of aerospace-related industries during the early to mid 1950's, greater emphasis began to be placed upon automated means of analysing specialised components within the design cycle of a product's development.

Traditionally, aircraft and automotive manufacturing were based upon highly skilled methods of production where little or no specific methods were used to ensure design integrity, safety and operability. The advent of the world's first computer, ENIAC, during the latter end of the Second World War, was to provide the wide scale introduction and use of more analytical methods of design and analysis which would help to support the overall design synthesis of modern engineered components. As such, during this time, the focus of much academic engineering research was on how such computable methods could allow physical phenomena to be modelled and be both simple to use and flexible enough to adapt to new problem perspectives such as computing stresses and forces within beams and trusses in aircraft and related structures (Turner *et al.* 1956). The actual basis of this approach has been argued over the years to rest more with mathematicians rather than engineers, as in the studies of Courant (Owen and Hinton, 1980).

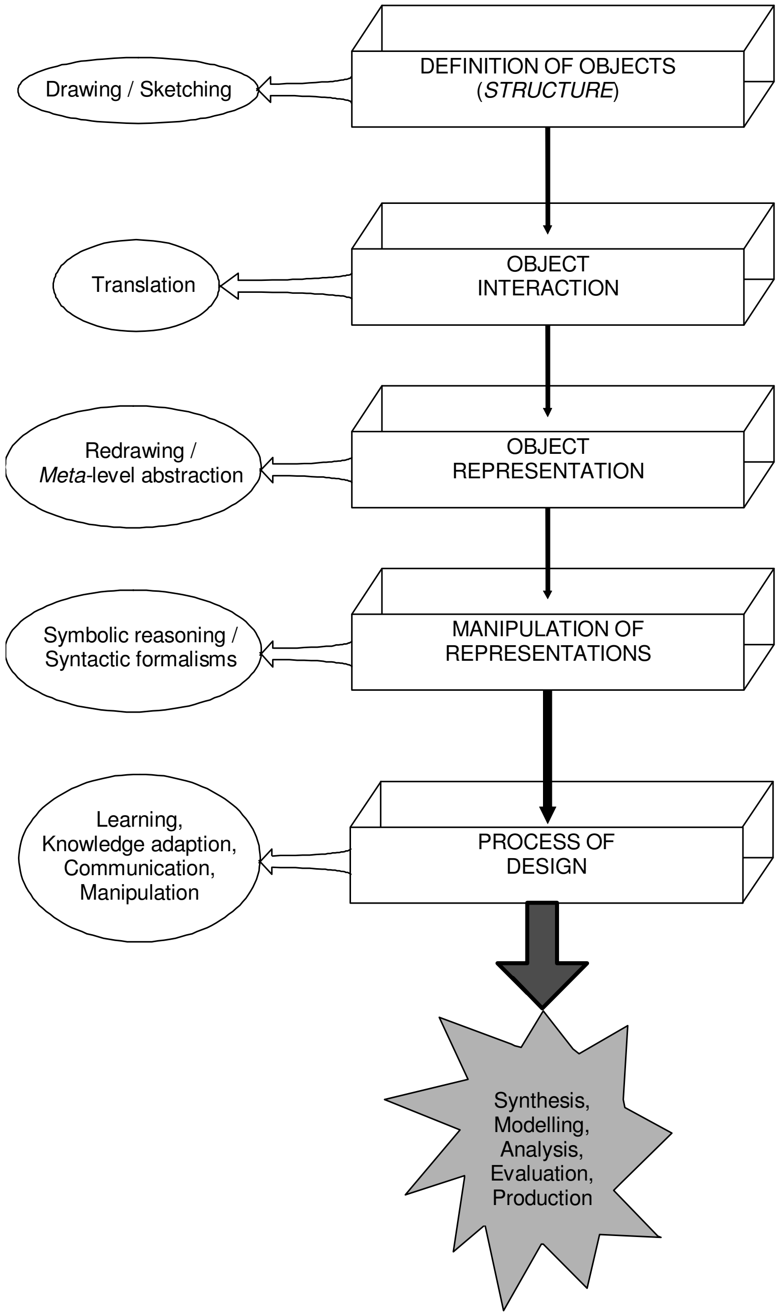


Figure 0.2 CAE System components

However, the origin of the name, *Finite Element Method* (or FEM), occurred much later when also a firmer numerical basis was given provided by Argyris and other European researchers interested in the same problem (Argyris 1960 ; Zienkiwicz and Taylor 1971).

Since the early papers and books written by authors such as Argyris (1960), Babuska and Rheinboldt (1977), Owen and Hinton (1980), Zienkiwicz and Cheung (1965) and many others (such as Kardestuncer and Norrie, 1984), it has become a well known and respected computer aided modelling tool used by many engineers and scientists. Primarily a mathematical technique, the FEM helps in solving ordinary and partial differential equations (PDEs) which describe many systems of engineering and physical phenomena in 2 or 3 dimensions in fields such as aerospace, mechanical, electrical and civil engineering (Kardestuncer, 1984). By using variational calculus, a series of algebraic equations, which are represented in matrix form, are solved in order to yield numerical solutions to the given PDEs. These solutions describe magnitudes and locations of stress, displacement, heat, fluid flow or electromagnetic potential within a specified physical domain.

It should be noted that when the suffix 'method' is used (as in FEM), it explicitly refers to the mathematical formulation of the differential equations being studied. When the suffix 'analysis' is used (as in FEA), it applies to the application of the afore-mentioned formulation to a given problem and its resulting analysis within a computer system. So, it can be analogised that the FEM is the 4-stroke engine, wheels and steering, to the FEA 'car'. The continued and varied application of this analysis method also means that the future design integrity of many engineered components is set to become more rigorously scientific, as well as both intuitive and productive (Argyris *et al.* 1994). The FEA which is implemented in many CAE systems, consists mainly of 4 basic steps:

1. *Pre-processing* : the definition of material, geometrical and error tolerance (i.e. level of accuracy of the solution of the PDEs) properties of the problem via boundary conditions, initialise a mesh on which the underlying equations have to be solved;
2. *Equation solving / Computation* : solve the equations which describe the problem (the PDEs), taking the boundary conditions and error tolerance into account;
3. *Post-processing* : report on the numerical results via graphical visualisation in terms of magnitudes of physical quantities found, solution errors,etc;
4. *Refinement and adaptivity:* if solutions to PDEs produce high errors, refine the mesh and recompute.

This process is shown graphically in Figure 0.3**.** Electromagnetic field analysis was one the first topics to which the FEM was applied and experience of its application in commercial and academic circles over the years, also reiterates that expert knowledge and automation of the refinement of meshes is still a time consuming skill (Babuska 1996; Babuska and Rheinboldt 1977; Emson *et al.* 1994; Krishnamoorthy and Krishnakumar 1988; Naganarayana and Prathap 1992).

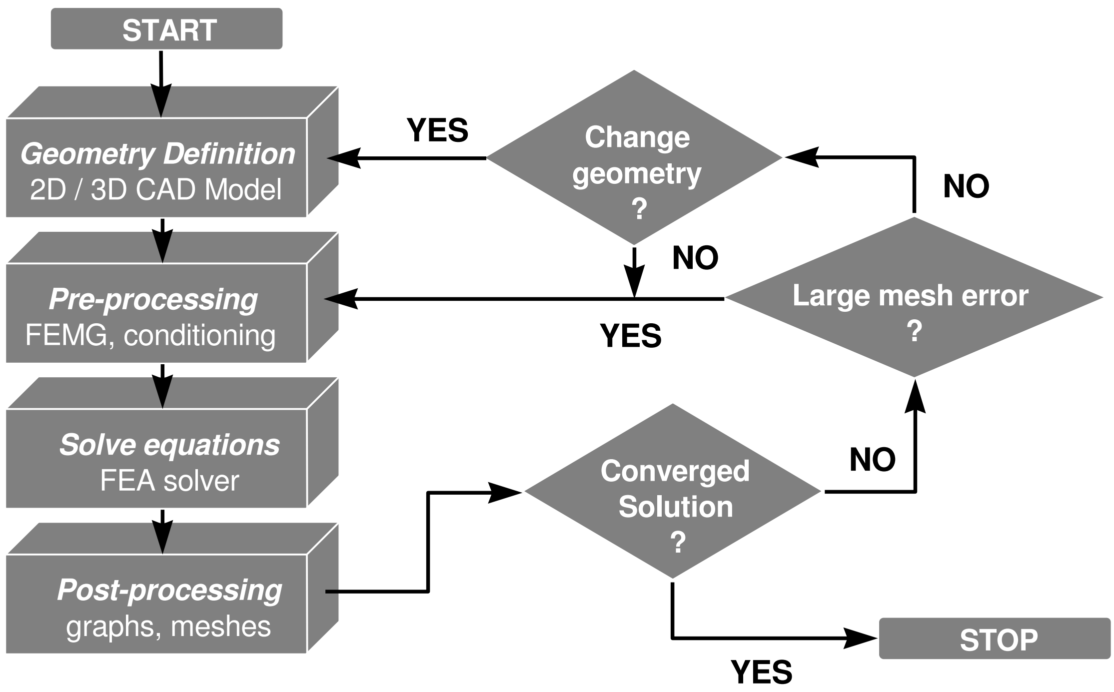


Figure 0.3 The FEA procedure

Hence, the generation of computational models within a CAE system which will provide accurate and robust engineering solutions, requires an approach whereby the correct application of both the explicit knowledge of the problem domain is integrated with the inherent tacit or expert knowledge required to make engineering decisions. In attempting to investigate the information and knowledge requirements involved in the design and analysis tasks within engineering design, the author now presents a particular form of CAE tasks which has been noted as requiring in-depth knowledge and experience, namely that of the design of photonic waveguides, which are used in a variety of electromagnetic devices.

Designing optical waveguide devices

The author has shown that CAE systems integrate both specific knowledge related to the design of a component, as well specific expert knowledge which is required in order to rationalise the modeled entities. In this section, the author expands upon these statements by presenting a case study of a particular application of a CAE system, for the design of photonic waveguides.

Waveguiding, or photonic devices, are widely used in many electromagnetic devices to switch or polarise beams of light to a particular frequency such that electromagnetic effects can be realised. A waveguide is a small passive electronic device which is used in laser and other optical equipment to channel light to a particular source frequency or amplitude. Waveguides are very useful in controlling the optical properties of the dissipated light mechanism (either continuous/pulsed laser or visible light) and hence the associated electromagnetic fields also (Hunsperger 1991; Kogelnik 1981).

Such phenomena is found to be useful for many electro-optic and magneto-optic applications, such as in telecommunications equipment. Since the speed of light far exceeds that of electrical impulses, by channeling a combination of electrical, magnetic and lightwaves, such devices are now being considered as the harbinger of the next stage of computing technology, in the guise of optical chips which will use light instead of electricity to operate. This will allow computation to increase ten or maybe even one hundred fold, in magnitude. Hence, the efficient and accurate modelling and analysis of these components is required, not only to achieve such results, but also to assist in the eventual manufacture of these devices.

In the so-called modal analysis of waveguides, electromagnetic fields and their associated frequencies are computed with respect to the longitudinal propagation of a light wave passing through the dielectric part of the device (Fernandez and Lu, 1996). This can be seen in Figure 0.4 wherein a beam of light is being passed into the upper part of the waveguide, i.e. the dielectric (shown in the left hand diagram).

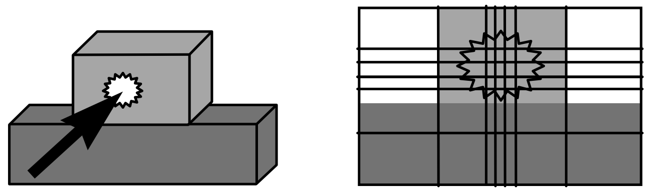


Figure 0.4 Light Propagating through a waveguide and an associated finite element model

In using a CAE system to simulate this effect, the purpose is to use an appropriate modelling technique to capture the results of the interaction between the propagating light beam and the material, such that information about the power and frequency of the electromagnetic fields can be computed (such as the dispersal of light and electromagnetic waves, in the right hand diagram). Historically the analysis of manufactured waveguides has been notoriously time-consuming and complex relying upon heavy experimental validation and theory. Since the design of these devices requires intensive calculus, even using CAE packages which employ the finite element method (Rahman and Davies 1984; Fernandez and Ettinger 1991; Davies 1993), the visual solution to how the light and electromagnetic fields are dissipated through the device is not always accurate. Making an experimental mock-up can be prohibitively expensive due to the dimensions involved which are usually micrometers in size. The advent of CAE systems which employ computational routines such as the finite element method, has meant that waveguides can now be more easily modeled (Fernandez and Lu 1996; Hunsperger 1991; Silvester and Ferrari 1995). Normally, the effect of the materials (known as the dielectrics), affect the results of the propagated field through the waveguide (Hunsperger 1991). This is because different materials allow varying amounts of optical and electromagnetic fields to pass through them, due to their material characteristics (density, reflectivity, refractivity, passivity, absorption quantity, etc – see Chartier, 1981). This is the section of the waveguide through which light passes as denoted by the large black arrow in Figure 0.4. Each material can be either passive, active or non-linear in nature. Active materials serve to change the optical properties of the guided wave, while Passive materials do not. Non-linear materials on the other hand, produce a frequency conversion, which is therefore an electromagnetic switching effect (Ettinger *et al.*, 1991b). Devices of this type are hence termed non-linear waveguides. Realistic modelling of the non-linear effects of the dielectric and the dissipation of the electromagnetics waves into the surrounding environment can cause large errors in the numerical solution of the electromagnetic frequencies to occur. Thus, specific expert knowledge of both the explicit physics of the waveguide as well as the tacit and instinctive reasoning and understanding of the computation results is paramount.

Manufacturing Technology and Strategic IT/IS

Another aspect of the manufacturing lifecycle is that which relates to the planning and scheduling of the component to be built. This is also an important knowledge-intensive process. Modern manufacturing plants and factories have a wide array of machinery: from simple hand tools through to lathes, milling machines, right up to fully automated computer numerically controlled (CNC) flexible manufacturing systems (FMS). As such, the efficient allocation of time, materials and technology are vital ingredients to any successful production organisation (Goldman *et al.*, 1995; Ranky, 1990). However, as Carrier (1999), and Brown and Eisenhardt (1998) point out, there are a myriad of other factors which also need to be taken into account, which relate to both internal and external factors: innovation, management of disruptive technology (technology which replaces business processes), management of creative technology (which enhances business processes), maintenance of competitive advantage within the organisation's sector, customer satisfaction and organisational learning. The appropriate and correct choice of manufacturing technology which takes into account these factors, is an important and necessary decision which can determine the success or failure of a company. The knowledge that is required within this decision making task, is therefore crucial to the outcome also.

In addition, it has rapidly become clear that IT/IS is also a significant component of any modern manufacturing organisation. The evaluation of technology and IT/IS within such organisations, is therefore an important task, which must inherently be based upon knowledge of the organisation and strategic, tactical and operational needs. The stance of strategic information systems, as Avison and Fitzgerald (1998) and Remenyi (1994) point out, encapsulates notions of addressing both the internal as well as external factors which impinge upon the organisation, through technology or competitor-led models, in order to maintain competitive advantage. Of the latter, the strategic role of IT/IS must enable the organisation to deal with purely external influences, through facilitating communication and the exchange of knowledge internally (Earl, 1989). Such strategically focused technologies, are based upon the objectives, current processes and future opportunities observed by the business. The latter, technology-driven model, instead focuses on the assumption that investment in IT/IS will automatically result in business success and the achievement of competitive advantage. Due to the capital costs of technology generally within the manufacturing sector, any approach which can achieve success at the "right price" will be welcomed. As such, the field of Investment Appraisal of IT/IS is concerned with methods and techniques which address how best to evaluate both direct (capital) and indirect (human) costs of an investment in technology (Farbey *et al.*, 1993). Thus, information systems evaluation (ISE), aims to provide an understanding of such decision making tasks through a mapping of critical success factors to the investment justification process (Irani *et al.*, 1998). This process is also heavily reliant upon knowledge, in the form of financial appraisal techniques, strategic decision making, and some understanding of the IS used within the manufacturing cycle. Some pertinent aspects of this task, are now detailed in the next section.

Decision making within ISE

The efficient management and operation of business processes are considered closely aligned with the development of a comprehensive IT/IS infrastructure. Industry's innovative development of IT/IS in manufacturing is evident in its evolution, from a limited data processing perspective, to an expanded organisational-wide scope of manufacturing computer-based activities, where information is recognised as a corporate resource, with much potential to improve strategic and operational processes. Therefore, it would appear that during the evaluation process, there is much need for suitable mechanisms that can acknowledge the 'full' implications of an IT/IS deployment. The consideration of such issues as constructs for success, support investment decision making.

This is crucial, as the absence of such a criterion may be affecting the success of many IT/IS deployments. Also, organisations are appreciating the significance of human and organisational factors, and seeking to address these, as their contribution is acknowledged as supporting the successful deployment of IT/IS (Meredith, 1987). In addressing the need for structured evaluation tools, many researchers have approached investment decision making from a variety of perspectives. Much of this effort has been focused on developing a 'single' generic appraisal technique, which can deal with all types of projects, in all circumstances. This has resulted in the development and use of the widely known 'traditional' appraisal techniques (Farbey *et al.*, 1993; Irani *et al.*, 1999b). As a result, it would appear that more attention has been focused in recent years on prescribing how to carry out investment appraisal, rather than taking a holistic view of the evaluation process, which identifies those factors that support the rigorous evaluation of IT/IS. Some of the key steps in a typical evaluation process are shown in Figure 0.5, as based upon the work of Farbey *et al.* (1993), Remenyi and Smith (1999), Remenyi *et al.* (2000).

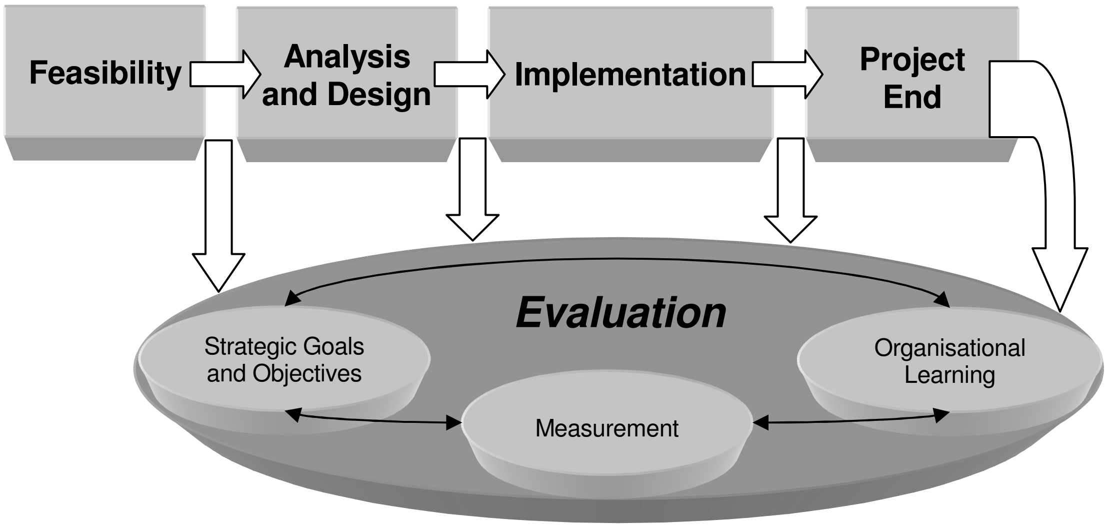


Figure 0.5 Typical decision making steps in Information Systems Evaluation
(adapted from Farbey *et al*., 1993)

The aim of any justification processes is to identify a relationship between the expected value of an investment and a quantitative analysis of the project value, benefits, costs, and risks. This is even more important as typically, a large number of IT/IS projects fail to deliver their perceived benefits, relative to the costs that are incurred (Hochstrasser and Griffiths, 1991; Strassmann, 1990). Whilst the value and benefit of IT/IS investments are traditionally complex to justify due to their subjective nature (Willcocks, 1994), the evaluation of costs and risks can be modeled in more of a straightforward manner. Hochstrasser (1992) notes that indirect costs maybe up to four times as high as direct project costs.

This can lead to a direct impact upon the success or failure of such systems, and has led many researchers to conclude that there are as many failed information systems implementations, as there are successful ones (Remenyi, 1991). Hence Willcocks and Margetts (1994) suggest that in order to mitigate some of the inherent risks associated with ISE, project planning estimates and management of this decision making task in ISE, should improve with greater information. This is in terms of knowledge gained from successful (or otherwise) IT/IS implementation experience, as well as knowledge derived from coherent and consistent decision-making policies. Furthermore, failed systems can be costly, both in human cost as well as technological terms (Irani and Love, 2000).

Another aspect of the decision making task within ISE, is that which is attributed solely to financial appraisal of the investment. Many traditional investment decisions are made on the limited basis of financial appraisal. The reason for this is because organisational capital budgeting processes often rely exclusively on conventional appraisal techniques. However, the major limitations in using traditional appraisal techniques are that these methods are unable to accommodate the intangible benefits and indirect costs associated with an IT deployment. Kaplan (1985, 1986) explains that many companies who use such predictive forecasting methods may be on the road to insolvency, if they consistently invest in projects whose financial returns are below their capital costs.

The Knowledge Conundrum

From the reviewed literature so far, it has been seen that the concept and understanding of knowledge, is as perplexing as the number of definitions that exist for it. It has also been seen, that for both individuals and organisations alike, the relevance of human knowledge is important. This is irrespective of how, where, why and when such knowledge is created, collected, represented or used. These points have also been echoed lately by Onions and Orange (2002), who note the multiplicity of knowledge definitions and the need to understand and appreciate suitable methods for manipulating knowledge. From the myriad of definitions about the fundamentals of knowledge, it is understood that knowledge is such a quantity as to describe aspects of learning, understanding (all that has been perceived or grasped by the mind), heuristics (rules which convey the essence of practical experience), skill, cognisance, recognition, organised information – indeed any quotient related to describing a clear and certain perception of some "thing".

Once again, in the context of the research presented in this dissertation, the concept of representation differs from the formal AI concept of knowledge representation (i.e. Structural Knowledge), and also the information science topic of information retrieval (i.e. Interpretive Knowledge). These representations, be they in the form of deduced reasoning, inference and / or intuition, or decision making capabilities, are based largely upon human belief and experience.

This commitment to experience, ultimately allows the refinement and optimisation of knowledge, which at its peak represents mastery or expertise within a domain. Thus, as highlighted within the background theory within Chapter 2, Structural and Interpretive modes of knowledge are typically rooted within theoretical or at least academic, arguments. These are in the form of computational IS which tend to suggest that logical assertions and relationships exist within bounded, explicit knowledge (such as with semantic or frame-based systems), or when dealing with the inference of information search results (such as with library and document retrieval systems). Such types of knowledge are rarely implemented within organisations due to the inflexibility of the respective approaches, when attempting to represent uncertainty, human inter-relationships, technological dependencies and human behaviours relating to unbounded, tacit knowledge. Also, such approaches typically are far too abstract for operational usage. Evaluative knowledge, on the other hand, is most readily translatable into the organisational context, as can be seen through the proliferation of research and practice in the guise of knowledge management. Since this form of knowledge is essentially multidisciplinary in nature, amalgamating concepts from across management science, economics and philosophy, it is more amenable to the multiple socio-technological needs which exist in an organisational setting. This addresses issues of infrastructural, sociological, and psychological significance to individuals within companies, which this research is specifically interested in.

Hence, the existence of all these forms, although testament to the scope and significance of our understanding of knowledge, do not necessarily lead us any closer to understanding those factors which play a part in determining how knowledge is, and should be, used. As an additional example, within the theoretical confines of structural representations, even more detailed definitions of knowledge can be expounded: procedural knowledge ("Knowing How"); declarative knowledge ("Knowing what"); semantic knowledge ("Knowing why"); episodic knowledge ("Knowing when and where"); meta-knowledge ("Knowing Knowledge about Knowledge").

Therein lies what the author can best describe as the knowledge conundrum: so many different definitions of knowledge and its usage exist, which are all manifestly applicable to problem-solving or decision making situations that it is difficult to discern between them. Furthermore, when assessing which type of knowledge is inherent within a business process or decision making task, it is almost impossible to provide an answer which reflects the overall *context* of the task undertaken. That is to say, it is difficult to define what type of knowledge is being used for a particular process, even though practitioners would have us believe it is just as simple to define a process which defers a particular knowledge form (Davenport and Prusack, 1998; Probst *et al.*, 2001; Sveiby, 1997). Indeed, it may well be the case also that having a choice between using different knowledge types and representations is unnecessary or meaningless, without understanding first of all *how* and *where* knowledge is to be utilised.

Therefore, the remaining sections of this chapter now seek to expand upon these ideas, in order to show the synthesis of these issues within this area, and to focus attention towards knowledge-intensive tasks within manufacturing IS.

Constraints upon knowledge

Although key research and practice in the field of evaluative knowledge (in the guise of knowledge management), has highlighted the usefulness of knowledge within organisations (Davenport and Prusack, 1998; Kluge *et al.*, 2001; Probst *et al.*, 2001; Ruggles, 1997), it is still unclear as to whether or not the collation, codification and distribution of knowledge, really allows the organisation to understand where and how knowledge exists, any better. The focus of most work in the area, has been largely in addressing the mechanistic, *systematic* or purely IT-focussed aspect of knowledge use and transfer (in the sense of processes and tools to assist knowledge). Hence, it can be seen that in each form of knowledge involved, Structural, Interpretive, Evaluative, there is almost a certain level of proprietary application, or exclusivity, about each respective definition. Rather, it could even be said that in practice, knowledge management or other techniques are more akin to "schemes" than actual explicit structures which detail knowledge within an organisation itself. For example, the structural representation of knowledge which relates to, say, the diagnosis of throat-based bacterial infections (such as with the infamous diagnosis tool, MYCIN – see Genesereth and Nielsen, 1987), is not directly relateable to an *interpretive* view of that same knowledge, i.e. making sense of the decision ultimately is up to the domain expert, or as Saracevic puts it, the enquirer after knowledge (Saracevic, 1996). This is due to the fact that the fundamental driver and basis for each form of knowledge, has been based upon differing assumptions about how knowledge is going to be used, and where and when it should be formulated. In the same light as this, Evaluative knowledge would not be able to reconcile the *reason* for diagnosing a streptococcal bacterial infection, inferred from a range of patient symptoms, as the prime concern for this approach to knowledge representation in providing the *process* for the realisation of this knowledge.

Thus, it is contended that the codification and structuralisation of knowledge alone is insufficient, as these approaches only seek to operationalise a process for knowledge creation and transfer, instead of addressing the underlying *behaviours* that give rise to knowledge use. It is the author's contention, that it is important to question the particular knowledge requirements and the associated behaviours which are needed to be addressed within knowledge intensive situations and environments. Authors such as Binney, have in their own ways, sought to expand this idea through offering an overview of knowledge-intensive tasks within organisations, as part of a wider context of evaluative knowledge management activities (Binney, 2001). This "knowledge spectrum" outlines 6 key stages of knowledge utilisation and their respective technologies: transactional (via expert systems), analytical (via database / data mining systems), asset management (information retrieval / document management systems), process (workflow systems), developmental (on-line training systems), and innovation creation (collaboration technologies). Even though such a model attempts to provide a unified "theory of everything" with regards to knowledge use, there is sadly lacking any attempt to identify inter-relationships between each stage of this approach. Also, there is little to distinguish between the importance of IS, as opposed to IT, dependent characteristics which drive knowledge itself.

Thus, there is no multivalent or inclusive model of knowledge representation and use. Structural, Interpretive or Evaluative modes of knowledge representation are mutually exclusive and in some sense are restrictive in their use, purely in themselves. Only the scope and transparency of knowledge transfer, via a deeper understanding of explicit and tacit knowledge, could provide us with an approach to modelling the psycho-sociological dimension of knowledge use and exchange.

By understanding an approach to utilise this type of knowledge, it may then be possible to go beyond the presumption of facts which define structural knowledge, and to go beyond the purely systemic aspects of interpretive knowledge and the codification lifecycle of evaluative knowledge. As it has been argued previously, most if not all, knowledge concepts within organisations, are based upon three key notions: (i) knowledge is the basis for any knowledge work; (ii) the correct and relevant information is required to carry out knowledge or intellectually-intensive tasks and operations; and (iii) individuals must be empowered to utilise and seek knowledge in order to make best use of it. The first and most important notion is that knowledge is the basis for knowledge work. This is a fairly obvious, if not wholly tautological statement. Without having some previous experience and insight say, into computer programming, it could be fairly difficult for someone to program. The problem is exacerbated, if that particular individual's job role and requirement, was to write Java or C++

programs all the time. Hence, the second notion of commitment to using knowledge, becomes readily apparent. A knowledge worker who wishes and needs to use knowledge to carry out their job, is heavily dependent and ultimately committed to making sure they have all the correct information and resources to hand, in order to complete each task. If there is a lack of commitment in terms of these areas, then it follows that there will be a lack of commitment to transforming information into knowledge, for the benefit of the individual or the organisation. This can also be thought of as a requisite part of successful teamwork also, which also requires the implicit inclusion of a third notion: the empowerment of an individual to utilise knowledge.

Given that a knowledge worker has the right tools, information and opportunity to use their own or collective organisational knowledge within their job role, is there sufficient support and capability to allow that individual to achieve their goals? Many organisations, will no doubt align the issue of empowerment, or allowing individuals to control their own "destiny", to that of the strategic aims of the business. When placed in the context of knowledge intensive work, such an alignment is misleading and does not necessarily help the individual to relate the opportunity to carry out a task, to their respective role. Empowerment in the guise of knowledge then, relies upon the existence of a particular level of individual or organisational behaviour, in order to make knowledge "live".

In this light, most approaches to implementing knowledge tasks and processes within organisations, have been largely marketed as being highly successful, provided a certain approach or underlying methodology is taken. For example, the knowledge scanner approach proposed by McKinsey and Co. management consultants, Kluge *et al.* (2001), requires a preliminary survey of individuals involved in knowledge work in order to quantify the scope of their requirements. Whilst methodologies to ground a resulting approach provide rigour, there is a tendency towards bias in the selection and use of techniques to bind the human process factors, to solely IT solutions (i.e. applications or systems). A reason for this, is in the fact that most Evaluative knowledge models and frameworks have so far arisen from within management consulting and associated professional service firms (Mills and Friesen, 1999; Quinn, 1992; Wiig, 1999). Such companies typically promote such process-centric knowledge techniques and schemes, as part of wider generic organisational change programmes. Thus in order to utilise such knowledge forms requires the individual, or organisation, to : (i) Select a suitable model or form for representing knowledge; (ii) Identify relevant business processes which will be able to support adopt the chosen knowledge scheme; and (iii) Support individuals in knowledge work situations where knowledge is incomplete and a knowledge scheme is to be used.

Noting these factors can play a major role in the introduction of knowledge concepts within companies, and that the three preceeding notions of the existence, commitment and empowerment to use knowledge exist, does the existence of explicit and / or tacit knowledge have any bearing on how such schemes are adopted? The following sections now provide a more detailed discourse upon the relevance of explicit and tacit knowledge, in relation to both the CAE and IS evaluation types of manufacturing IS, defined earlier, in this light.

Of the Explicit and of the Tacit

Many organisations which have adopted Evaluative, i.e. purely knowledge management techniques internally, have found that productivity and exchange of knowledge has enabled their company to maintain competitive advantage (Nonaka and Takeuchi, 1995; Porter, 1985; Probst *et al.*, 2001).

This has been highlighted in the literature, through knowledge management success stories at companies such as Hewlett Packard (Sieloff, 1999), SAP (Kluge *et al.*, 2001), Volvo (Rimmel, 2001; Stenmark, 1999), Xerox (Biren, 2000), Cap Gemini Ernst and Young (Hjertzen and Toll, 1999), and Sony Corporation (Numata and Taura, 1996; Numata *et al.*, 1997). Throughout all of these examples, a consistent theme has been to relate *explicit* and *tacit* forms of knowledge together. In this regard, the definition of explicit and tacit knowledge, seems to be a much simpler matter than the definition of knowledge alone. This is quite possibly due to the fact that these concepts, specifically that of tacit knowledge, were most succinctly presented approximately 40 years ago, by the economist and philosopher, Michael Polanyi (Polanyi, 1962; 1966; 1967). Although Polanyi himself recognises that tacit knowledge is the background or canvas upon which all human understanding is based, the adopters of his work, have tended to make a different distinction. Polanyi has described tacit knowledge mostly from a positivist epistemological stance, and one from which the explicit (or known, visible and decipherable) is related to the tacit (or unknown, invisible, undecipherable). As Davenport and Prusack (1998) note, that codifying and transferring tacit knowledge tends to require extensive inter-personal contact and validation to ensure that the knowledge is correctly represented and maintained.

Perhaps the most infamous of interpretations of Polanyi's work, is attributable to the Japanese management researchers, Nonaka and Takeuchi (1995). In their now seminal work based upon notions of explicit and tacit knowledge, Nonaka and Takeuchi analysed three Japanese organisations where both of these aspects of knowledge existed. Whilst Polanyi did not make any categorical distinction in terms of the underlying relationship between explicit and tacit knowledge, the Japanese researchers did. As such, they and others who have followed in their footsteps (such as Karl-Erik Sveiby for example, Sveiby, 1997; Sveiby, 2001), consider explicit and tacit knowledge to be separate, distinguishable and capable of being harnessed. This philosophical disjointedness, has not inhibited the evolution of knowledge concepts within the field of management science however, as has been noted by the copious amounts of published work in the area. In their model, Nonaka and Takeuchi chose to view explicit and tacit knowledge in terms of a dynamic relationship relating to particular forms of knowledge work. As such they identified, four key processes relating to the transformation of one form to the other, in terms of a knowledge transfer process (tacit to explicit, explicit to tacit). This is shown diagrammatically in Figure 0.6 and is now explained briefly.

Socialisation is the process of *sharing* experience (creating tacit knowledge with others and across the organisation); Externalisation is the process of transferring or *understanding* tacit knowledge into explicit concepts; Combination is the process of converting or *capturing* explicit knowledge into systems and processes; and Internalisation, is the process of converting or *classifying* explicit knowledge into tacit knowledge. As shown in the diagram, the process of transferring explicit to tacit knowledge, can be thought of as a collaborative act, in that knowledge is transferred from the individual to the organisation.

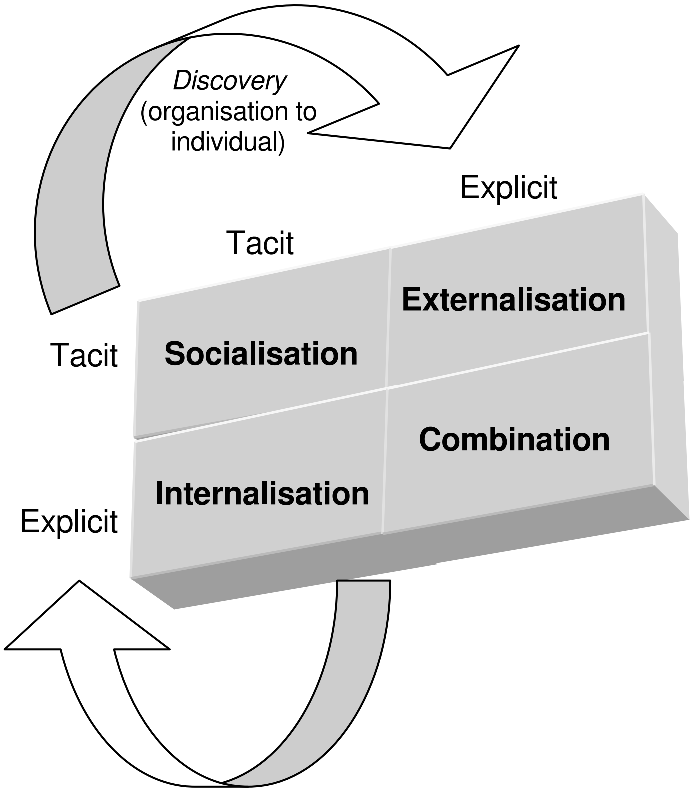


Figure 0.6 The Knowledge Transfer process (Nonaka and Takeuchi, 1995 ; Ovum, 1999)

The opposite can be said of the tacit to explicit transfer, which can be thought of as being based upon the idea that knowledge is somehow discovered by individuals, and then returned back into the organisation. Sveiby (1997) as stated earlier, also builds upon this model, although he suggests that instead of there being an explicit dimension to knowledge, tacit knowledge is the only knowledge there is.

Furthermore, he takes an almost structuralistic view of these two components, in that explicit and tacit knowledge must be governed by rules and actions. The only concession to the impact of the individual, is that knowledge is forever changing and dynamic, and hence requires an intangible dimension to handle the intervention of a human expert who has access to tacit knowledge. However, one key component of this philosophy is the lack of detail given to the implementation of such concepts. As an evaluative, or rather process-oriented, view of knowledge goes, these fundamental ideas are not described in relation to how they should be implanted within IS.

In fact, Nonaka and Takeuchi completely ignore the impact of information technology upon their ideas, which at the time very few noticed. Certainly, practitioners such as those at Sony Corporation in Japan, like Numata *et al.* (1997), were very much in favour of such approaches, although by this time the technological implementation of tools to capture and disseminate tacit knowledge, were beginning to emerge. This was mainly in the guise of distributed and local network applications within the organisational IS infrastructure. Maki *et al.* (2001) highlights the work of Maula, who stressed the fact that IT/IS in delivering knowledge throughout the organisation. However, IT/IS is more suited to the delivery of explicit as opposed to tacit information, which requires a closer, distinct relationship with the embedded information. And as Newman and Conrad (1999) and also Kreiner (2000) note, the existence of knowledge, whether explicit or implicit (tacit), is reliant upon the user or consumer of such knowledge.

Whitley (2000) also states that as a result of the reliance upon the importance given to the *interpretation* of Polanyi's description of the tacit view of knowledge (which actually is a view of tacit "knowing" rather than "knowledge" per se), there is a general inconsistency about what such a term actually means. This precludes the formation of two schools of thought about tacit knowledge – those who legitimise the fact that the unknown is unknowable, and therefore tacit knowledge is also undefineable; and those who contend that all knowledge is tacit and needs to be formalised (Hedestrom and Whitley, 2000).

However, as Suchman (1987) has observed, tacit knowledge enables us to take actions that are situated in particular social and physical circumstances, and that tacit knowledge thus is contextually bound. Stenmark (1999) also notes:

> *'Polanyi claims that tacit knowledge has two distinct properties, which he names its* proximal *and* distal *terms. The proximal term is the part that is closer to us, while the distal part is further away. In Polanyi's example, he describes how the police help a witness who is unable to describe a suspect to create a photo-fit picture by selecting images from a large selection of human features such as eyes, noses and hair. By attending* from *the first, closer image that resides within,* to *the second, more distant picture collection, the witness is able to communicate her awareness of the face. Tacit knowledge is, argues Polanyi, the understanding of the unity that this proximal/distal pair together constitutes. We become aware of the proximal term only in the presence of the distal term but remain unable to communicate the former.'*

(Stenmark 1999, pp.63)

By its very nature, then, tacit knowledge, as compared to explicit knowledge, is highly elusive and difficult to discern. Given that it is also hidden within individual's behaviours and psychological makeup and actions, it is also quite difficult to understand when and where tacit knowledge is actually used. For example, are there in fact situations, where tacit knowledge could "masquerade" as explicit knowledge, and vice versa? As an adjunct to this, Whitley (2000) also ascribes the importance of the concept of the commoditisation or social import of knowledge. Whitley describes an alternative view of the tacit dimension, in terms of both behavioural intention, and polimorphic and mimeomorphic actions. These concepts basically describe tacit knowledge as socialised knowledge, or that which involves and requires some level of behaviour plus intent, in order to describe it. A polimorphic action defines a mutual understanding by society of a piece of knowledge, whilst a mimeomorphic action, requires only that an individual understand the context. This is an interesting view of the explicit-tacit state of affairs, and appears to conclude that there must be a deeper sociological meaning to tacit knowledge.

Whilst this may be the case, there has been a general interest in reviving these concepts, as Augier *et al.* (2001) have shown, through the introduction of the element of contextual relevance, i.e. externalisation; and as how Biren (2000), Herschel, Nemati and Steiger (2001) and Soo *et al.* (2002b) have highlighted through case study research, where the focus has been on knowledge creation, i.e. internalisation within firms ; and the importance of knowledge work in terms of the role that both tacit and explicit knowledge play in the workplace, i.e. socialisation, as highlighted by Smith (2001).

This latter aspect, leads to perhaps the most intriguing aspect of knowledge within the workplace so far, and that is to do with its actual usage. It has been discussed so far, that the combinative and transcriptive act of using tacit and / or explicit knowledge, is reliant upon the existence of some tacit dimension of the knowledge itself. The author contends that the focus needs to turn to the manner by which these concepts are actually adopted and recognised, both behaviourally, psychologically and sociologically, between and within individuals. Perhaps the best approach to this manner of thinking, is via the discussion of intuition by Herbert Simon. In his book *The Sciences of the Artificial*, he discusses the concept of intuition, or as he puts it, the sudden leap of recognition which enables novices and experts alike, to have insight or preternatural knowledge about the correct course of action to take (Simon, 1969). He takes the example of a Grand Master Chess champion, who is able to discern and outplay his opponent in a rapid series of chess moves. Simon contends that this is simply a fast recognition algorithm in action, in that the master chess player has the ability to recognise and compare a multitude of chess moves based upon a large amount of experience, and in part, his memory.

This intuitive action is therefore relegated by Simon into a structured knowledge category (i.e. one that requires systematic or computationally valid assertions to be true). However, this concept is quite useful in the light of the discussion on explicit and tacit knowledge, as it provides a psychological explanation for the tacit dimension. That is to say, that tacit knowledge is attributable to being an individual's knowledge, which cannot be easily articulated, in the sense that this type of knowledge relies upon specific recognition variables, *only* known to the individual. In their work on the subject, Järvenpää and Immonen, also conclude this theory. They state that in some aspects, knowledge intensive work does seem to require significant cognitive information processing capability, in order to guide work in order to manipulate and communicate symbols effectively (Järvenpää and Immonen, 1998). This is perhaps one of only a handful of potential reasons for the reasons behind tacit-explicit knowledge transfer. Zack (1999) expands upon these ideas by suggesting that a consensus needs to be reached by both individuals and the organisation about what knowledge is made explicit and what is left as tacit. Bhatt (2000) qualifies this even further by suggesting that different knowledge development lifecycles should be used to distinguish between knowledge held by organisations as distinct from knowledge held by individuals.

In each of these cases, then, it therefore becomes possible to highlight the distinguishing features of explicit and tacit knowledge. This can be via the four key knowledge aspects of the knowledge transfer process, which the author has recast via the characteristic aspect of philosophical, behavioural, sociological and psychological drivers, as shown in

Table 0-1.

Table 0-1 Critical factors underlying Explicit and Tacit knowledge

Knowledge Aspect	***Fundamental Driver***	***Realisation***	***Representative literature***
Creation and Transfer (Socialisation)	Environmental	Context of Information within an IS : the epistemological and phenomenological cause for the existence of knowledge	Polanyi (1962, 1966, 1967) ; Nonaka and Takeuchi (1995); Sveiby (1997); Davenport and Prusack (1998); Biren (2000); Ovum (1999); Augier *et al.* (2001); Soo *et al*. (2002b)
Realisation (Externalisation)	Psycho-Sociological	Alignment to core Business Processes: making sure that knowledge "fits" and is pertinent to the individual and the organisation	Newman and Conrad (1999); Seufert *et al*. (1999); Augier *et al.* (2001); Rimmel (2001); Maki *et al.* (2002); Kreiner (2002)
Distribution (Combination)	Systematic	Development of knowledge tools and processes within IT: providing a systems and support infrastructure, to allow individuals to share and access knowledge	Numata *et al.* (1997); Stenmark (1999); Hjertzen and Toll (1999); Whitley (2000); Hedestrom and Whitley (2000); Herschel *et al.* (2001); Kluge *et al.* (2001); Smith (2001)
Operationalisation (Internalisation)	Behavioural	Tactical usage of knowledge: learning from and adapting available knowledge (i.e. knowledge re-transformation)	Simon (1969); Numata and Taura (1996); Järvenpää and Immonen, (1998); Bennett (1998); Sieloff (1999); Zack (1999); Bhatt (2001); Sveiby and Simons (2002)

The factors within this table, are those which are critical to the formation and implementation of the three forms of knowledge that have been discussed so far (Structural, Interpretive and Evaluative), but also take into account the conjectures of Polanyi and others. This is a novel view of the explicit-tacit landscape attempts to define a mapping between philosophical, behavioural, systematic, and psycho-sociological drivers, via the previous discourse on the research in this area. Thus, the experience and insight into the creation and transfer of explicit and tacit knowledge, shows that the main focus of mapping knowledge to business process tasks, lie with understanding the psychological and physiological context of information use.

This is a natural progression of the concepts of Structural, Interpretive and Evaluative forms of knowledge previously discussed. Through including not only the "what" (in terms of information content), but also the "why" and "how" (in terms of the psycho-sociological context), Polanyi's and Nonaka and Takeuchi's models of knowledge transfer, are more in tune with those implicit, indirect factors which drive knowledge use.

Hence, it is now becoming apparent, that the reasons that necessitate the usage of knowledge are inherently dependent upon a few key factors: (i) Knowledge must be definable, in some sense (structural, interpretive, evaluative); (ii) it must be available to both the individual and collective; and (iii) it must be either definable (explicit) or unknown (tacit). Underlying these aspects, there must also be some contextual modifier which allows knowledge to be relevant to a situation – there must also be some behavioural, sociological or psychological drivers which determine just how tacit or explicit, knowledge is. As such, the author suggests a social dimension case-specific "thread" can be discerned from the data theory, such that it can be said that *an underlying psychological and sociological relationship between Explicit and Tacit knowledge, must exist.*

In stating this, the conjecture is put forward that there needs to be some identification of critical success factors (CSF), which define how explicit knowledge is transferred into tacit knowledge. Since most of the research and experience into this area so far has concerned itself with the identification and resolution of processes which must exist for such a transfer to occur, there is little to suggest what underlying *drivers* exist to enable such knowledge transformation.

Assumptions and Intuition within CAE tasks

The author now presents the first of two knowledge-intensive tasks within manufacturing IS. As noted previously in Chapter 2, Computer Aided Engineering (CAE) systems, allow engineers and scientists within manufacturing and R&D organisations to simulate and model products and components through (mostly) interactive, visual design tools. To recap, most CAE systems implement design optimisation and / or mathematical modelling routines to realistically capture and represent how a product or component may react in the real world (such as in the simulation of stresses and strains on aircraft wings and the structural response of direct impact on cars). These routines as previously mentioned, are based upon a set of techniques known as the Finite Element Method (FEM), which effectively discretise a physical object into finite objects, for which a particular physical law is applicable. When combined with the interpretation of the computed simulation results, the overall method is then known as Finite Element Analysis (FEA). The flexibility of the FEM as an analysis tool has been one of its main strengths. However its limitations tend to be not so much overlooked, as taken as part of working practice (Clarke and Robinson, 1985). In their research conducted during the height of the integration of the FEM into computer-aided design software during the mid 1980's, they found that:

- Specialists are required to operate and fully understand the nature of pre-and post-processed FE data, i.e. is the model a viable approach?
- Mesh refinement and optimisation is still an art - no single approach appears to be best;
- Economics of choosing finite elements for accurate modelling, hinders accurate solutions: which elements are best suited for a particular problem?
- Irregular boundaries are difficult to mesh : maximisation of elements in regions of high solution requirement such as re-entrant corners and points of singularity, require potentially judicious and subjective meshing;
- Commercial pre- and post-processors for FEA are biased in their field of application and require a high level of human expertise to operate;
- Data input *seems* easy, but rarely is so simple.

Clarke and Robinson (1985) report that these limitations were in effect hampering the process of modelling, simply due to the success of the method and its rapid and somewhat haphazard implementation in computer packages. These findings were also bourne out in many defence and aerospace-related research circles at the time, wherein vigourous development of various mesh and grid generation techniques attempted to find a happy medium between mesh optimisation and FE solution techniques (Carcaillet *et al.,* 1986). Gloudeman also suggested that future finite element software systems should enable the transformation and representation of FE information in the easiest way possible. Since most users of specialist and non-specialist analysis programs have developed expertise in applying those programs, the proper utilisation of that knowledge must be achieved first before implementing new methods of modelling problems (Gloudeman 1986).

Babuska and Rheinboldt also make the important point that any numerical solution procedure within a CAE system, is not always the most important part of the analysis phase, but it is the *interpretation* of the physical results which is more important (Macneal-Schwendler Corp., 1996). This could be due to confusion over the perceived accuracy and reliability of computer-aided models: most, if not all, engineers merely wish to *predict* the physical behaviour of their models to some realistic degree and are not concerned with the computational aspects and ultimate accuracy of the results per se. Thus, it is quite possible for 'good engineers to produce poor results' (Babuska, 1996) possibly due to any one of the following factors:

- Poor understanding of the problem area;
- Poor modelling of the problem;
- Application of inconsistent mathematical formulations and error estimators;
- Over-reliance on graphical results.

These points have been picked up in the light of the assessment of computer-aided systems in engineering companies. Liker *et al.* (1992) point out that, in general, a large number of professional users and practitioners of such CAD/FEA tools, rarely take enough time to understand how their software works in order to produce meaningful and satisfactory results. This is a salient point since effective use of the features of an FE program, such as mesh generation and error analysis, can take over a year to master successfully (Cagan and Genberg 1987). Szabo and Actis (1996) who conducted an appraisal of FEA in professional practice where they found that:

- Average time taken for a complete CAD/FEA analysis of a problem is approximately 5 man days for each project (including geometrical, physical and numerical representation of the problem);
- 82% of FEA users do not know or wish to use error analysis techniques in their analyses;
- Too little time is given to effective modelling of the problem : observation and experimentation are favoured over scientific deduction and theory, such that 'numerical empiricism' is largely employed;
- Engineers do not investigate the full benefits of using FEA within the primary and conceptual design phases. For example, in some mechanical

engineering component design scenarios FEA is usually used for failure analysis of components rather than failure prevention;

- Representation and modelling of the problem by the analyst should be assessed for accuracy and realism as far as possible, before the software is blamed for producing 'unsatisfactory' results;
- A general lack of confidence exists in FEA results and modelling techniques due to the verbosity and at the same time, generality, of current commercial FEA and mesh generation software.

Specifically, within the modelling of waveguide devices, it has been noted that the use of expert knowledge and implementation of methods which can properly enable the analyst to model such devices, has generally been lacking (Cvetkovic *et al.*, 1994).

The physics of the problem mean that special care needs to be taken in adapting the mesh of finite elements, to take conditions of the modelling scenario into account. For example, excessive reflection of lightwaves passing through the waveguide may not give a correct representation of the modal frequencies, within an FEA model. These so-called 'spurious modes' (Svedin, 1989), are usually caused by the dissipation and scattering of light via a 'lossy' dielectric medium (Lu and Fernandez, 1993). In technical parlance, this means that the magnetic field does not change when the frequency of the propagating light is increased, and the system of equations to be solved becomes underdetermined and unsolvable. From these points, it appears that the "bureaucracy" of modelling a given problem overrides its actual analysis. The automation of such analysis packages has meant that some aspects of FEA become clouded, mostly as a result of the verbosity encountered in preparing data.

The developments of integrated CAE / FEA packages are beginning to consider the benefits of human expert interaction to overcome these modelling issues. Using CAE / FEA software can be argued to require a certain level of intelligence above and beyond so-called expert knowledge of the application area and any tools required to carry out an analysis (Sharif, 1995). Early CAE systems which employed computational routines to analyse computerised models, could only cope with well-formulated problems, such as in the modelling of fluid flows around objects (Andrews, 1988). However, for many design and analysis tasks, over-simplifying the underlying nature of the problem, such as in the Inductive Logic codes, GOLEM and FOIL (Dolsak and Jezernik 1991; Dolsak *et al.* 1994; Lavraz and Dzeroski 1994) may lead to assumptions about how the problem is to be modelled and analysed, by modelling relationships within the system being studied (Genesereth & Nilsson, 1988; Kowalski, 1979).

Computer based design systems have tried to overcome this through the introduction of 'design assistants' (i.e. Knowledge Based Expert Systems), which monitor and control the means by which design solutions, or rather decisions, are taken by the designer to encourage and support the creative 'flow state' (McCallum 1990). The interaction of the designer within the design process to optimise design solutions can greatly help in the understanding in the modelling of the problem through the input of expert knowledge, representations and solution criteria.

An intriguing predicament which arises out of this view is the selection of 'good' design solutions. Adaptation and reasoning, in this regard, are consummate characteristics of intelligent or tacit knowledge and behaviour and, if realised, can provide a further dimension to the modelling of the creative behaviour of the process of design (Grecu and Brown 1996). For a large part of the engineering community, subjective assessment and analysis of design components does not allow an objective evaluation of the performance of a design. Numerical results are always favoured over linguistic interpretations within the evaluation and testing phases of the design cycle (Szabo and Actis 1996).

It is for this reason that AI technologies have been applied to the numerical and scientific analysis fields within computer aided design and a review of these approaches by the author, have shown this appears to aid in this process (Sharif, 1997). This is achieved by largely mimicking and automating the response of engineers and designers when quantitative judgements are to be made and further analyses have to be carried out. Such assistance does not strictly employ intelligent, autonomous behaviour *per se*, but rather augments the complete process by allowing the designer to concentrate on the practical issue of designing (IEE 1997). As has also been noted by Gallopoulos *et al.* (1994), the integration of such systems will be a prime focus of engineering design development in the coming years.

However, almost all of these systems have been of the *assistant* rather than *decision making* type, in that a sufficient amount of *a-priori* knowledge is still required to understand and interact with the CAE system, to achieve a coherent result. Application of paradigms such as fuzzy logic, neural networks and genetic algorithms have been mostly to assist in the determination of data values to be used in the resulting finite element analysis.

Thus, the conclusion reached by these investigations over a period of 10 years, has been that FEA and FEMG (Finite Element Mesh Generation) generally requires a fair amount of understanding of the problem trying to be modelled. Furthermore, the optimisation of FE models and results is, in its simplest form, an arcane task. Software implementations of the method can sometimes be needlessly verbose and technical, so much so that even experts find difficulty in the effective modelling of relatively straightforward problems (Babuska and Rheinboldt 1977; Liker *et al.* 1992; Soerensen and Boehmler 1985). This could be argued to be a result of poor software design and communication between end FEA-users and vendors and the lag between academic and professional research. However, this does not detract from the fact that many users of FEA / CAD programs still require assistance in using their expert knowledge properly.

Hence, this then leads us to the formulation of another case-specific thread within the thesis, which is that *Tacit knowledge, is reliant upon a-priori assumptions and intuition, and is reinforced through on-going individual experience*. This will be formulated conceptually in the preceding pages of this chapter and tested empirically in Chapter 5.

The justification for this statement is that it is widely taken as granted that the CAE / FEA modelling task within a typical manufacturing cycle, should be almost irrefutable and accurate in terms of the simulation results that are produced. This is because of the fact that in essence, FEA codes are reliant upon a codification of particular laws of physics (thermodynamics, electrical conductivity, aerodynamics, fluid dynamics, to name but a few). These laws are intrinsically inviolate, although as has been discussed there are still occasions when the interpretation of these laws becomes highly dependent upon the engineer or analyst viewing the computed model. The reasoning behind this is as follows.

To be able to use FEA software, ultimately requires expert and largely explicit understanding of the domain area (aircraft design, car design, waveguide design for example), and also a working knowledge of the IS itself (the CAE system). This is a fundamental requirement. Secondly, since most FEA codes are essentially simulation and modelling environment, the representation and implementation of engineering and physical science laws, must be correctly defined. In this sense, the context of this type of IS, is *explicit* knowledge: bounded, logical, known, provable, and reproducible. However, it has been discussed and shown that even given these known factors are successfully implemented, poor or incomprehensible computational results can still be achieved.

The research within this field highlighted by the author in the preceding pages, has shown that the focus within FEA and CAE is mostly towards understanding the economics of the modelling task, in the sense of selecting the correct variables, taking the time to interpret the data and so forth. However, the significance of the fact that poor results can be attained needs to be also highlighted, which is not immediately apparent in the literature. Thus, these factors are predominantly based upon the effect of *a-priori* assumptions and the impact of intuition, or rather *tacit* knowledge.

In the first case, previous experience can be used by an engineer to modify a modelling scenario, as he / she sees fit. This can be typically based upon rules-of-thumb, or heuristics. Such modifiers, can greatly affect the outcome of a simulation, but sometimes need to be included as part of the overall algorithmic / logical formulation of the physics of the scenario. It may not always be ideal to justify that a piece of metal that is heated, always has a perfect relationship to the temperature that is applied to it, for example. Additional modifiers of pressure, material composition and other external factors, may be required to accurately represent the environment within which the piece of metal exists. Hence, although heurism takes into account the fact that laws of physics are not always ideal, it can introduce error in the interpretation of computed models. Secondly, through intuitive use of such experiential knowledge, an engineer can be said to want to apply a previously known decision making approach, based upon the recognition of a sequence of events and variables. Ultimately, this recognition of a *pattern* within the problem solving task, can automatically lead an individual to a pre-determined solution (as noted earlier). This can also be risky, as even though a tried and accepted approach to solving a problem may be valid, it may not necessarily be valid for all cases. Table 0-2, shows the mapping of these factors to the knowledge transfer aspects defined in

Table 0-1.

In either way, both of these factors (assumption and intuition), are tacit dimensions of the knowledge required within the CAE task, as the table shows. That is knowledge which is unknown, largely incommunicable, refutable and lacking in grounded theory (due to the effect of heuristics, say). So in some sense, this particular task can be said to exist as *explicit context which requires tacit content, modified via heuristic, or behavioural, assumptions*. In other words, although the CAE task may be well defined within the manufacturing cycle, the complexity of the process requires a domain expert in order to judge and guide the waveguide design and analysis.

Table 0-2 Explicit-Tacit knowledge within the CAE task

Knowledge Aspect	*Fundamental Driver*	*Realisation*	*CAE Task*
Creation and Transfer (Socialisation)	Environmental	Context of Information within an IS : the epistemological and phenomenological cause for the existence of knowledge	Explicit
Realisation (Externalisation)	Psycho-sociological	Alignment to core Business Processes: making sure that knowledge "fits" and is pertinent to the individual and the organisation	Explicit
Distribution (Combination)	Systematic	Development of knowledge tools and processes within IT: providing a systems and support infrastructure, to allow individuals to share and access knowledge	Explicit
Operationalisation (Internalisation)	Behavioural	Tactical usage of knowledge: learning from and adapting available knowledge (i.e. knowledge re-transformation)	Tacit

Justifying decisions within IS evaluation

The second knowledge-intensive task within manufacturing IS, which has been chosen for the purposes of research, is that of IS Evaluation (ISE). This decision-making task was chosen by the author as it was seen to be a task which is rich in both explicit as well as tacit knowledge in terms of the individual, organizational and environmental factors which are involved (see Figure 0.5). Again, to recap from the background theory, the field of ISE is predominantly concerned with methods and techniques to evaluate both direct (capital) and indirect (human) costs of an investment in technology. Through carrying out a mapping of critical success factors to the investment justification process, an understanding of the decision making task within this process is hoped to be achieved.

There are two distinct schools of thought within this field, which relate to the core aspects of the decision making task: generalists, and holists. Generalists, have typically based IS evaluation models upon singular financial appraisal techniques, where the justification of investments in technology have been largely driven by accounting methods. Whilst these approaches are robust and rigourous in nature, they do not always allow for the quantification of indirect, intangible costs, benefits and risks (such as those attributed to human costs, for example). Holists, on the other hand, approach decision making of ISE, based upon, oddly, a more general approach (in the true sense of the word). By this it is meant, that ISE models and frameworks do not rely solely upon financial measures alone, but also attempt to take into account, the unspecified, almost tacit, quantities such as indirect human costs, neglected by generalists.

Ultimately, the method of assigning a generalist or holist approach to ISE and carrying out decisions which affect the capability and competitive advantage of the organisation, is in itself, a complex affair. So far, as the literature surveyed within Chapter 2 has shown, the key researchers in the field, have only considered the effects of approaching the procedural aspect of ISE. This is from the perspective of choosing either a generalist or holist stance. For example, Farbey *et al.* (1993), Remenyi and Sherwood (1999) and Irani and Love (2000, 2002) all concede that the inclusion of the wider human and organisational factors, need to exist as a minimum requirement. However, the issue of the form and type of knowledge required in order to make such decisions, has not generally been focused upon too much. The main reason for this could well be due to the continuing interest within this field, in getting the basic measurement and contextual relevance of ISE right in the first place. This is obviously a fundamental requirement, and the field is still evolving and maturing in this respect. Not surprisingly, most of the literature so far on the subject, tends to also cover the subject of IS success and failure as well. Within this sphere of research, there appears to be more interest in identifying organisational learning and knowledge deficiencies. And specifically within manufacturing industry, there have been many case studies carried out which have tended to identify the strategic and developmental requirements in approaching either a lean / agile organisation (Goldman *et al.*, 1994), total quality management, work-directed teams, and other miscellaneous process-improvement techniques. Interestingly, the concepts of knowledge improvement, or knowledge definition and understanding within key decision making tasks, such as ISE, have not specifically been touched upon.

Since the context of IS evaluation typically revolves around the strategic decision making process, the more pertinent aspects of knowledge usage and transformation, can be assessed within this sphere. Ultimately, when the focus of any decision that is made within an organisation is termed as being of a strategic nature, it usually stems from those who have access to and have to reason with organisational information in order to confer authority or leadership capabilities, i.e. managers. Especially within the manufacturing sector, it has been perceived that the influence of managerial decisions upon the organisation, can tend to have detrimental effects. In Barker's review of 13 manufacturing Small and Medium-sized Enterprises (SMEs) within the UK, the decision-making capability of middle management became brittle and unusable in the light of sustained business pressures (Barker, 1998):

> *'It has been observed that pressure upon a company and its employees greatly increases when the manufacturing organisation cannot cope with the time and cost demands of lower competitive pricing and shorter delivery cycles. In other words, when there is a severe mismatch between the internal value adding capability of production systems and the demands of the customer that cannot always be resolved by (costly) stock buffers. This pressure appears to give rise to a behaviour modification in managers and directors, which is not always in support of the objectives and strategic aims needed to meet the new market demands'.*

(Barker 1998, pp.551)

The reason for this was largely due to some significant, though quite straightforward management behavioural traits. The root of many of these factors, lay in the manner by which managers were able to complicate and make the scenario requiring a decision more difficult than it actually was. Barker also notes this to be a particular trait of UK manufacturing managers in this regard, were there is typically a low uptake of best practice philosophies and strategies. This highlights a more serious failing in terms of a lack of general knowledge and appreciation of "world class" technology adoption and a greater aversion to risk, as opposed to say Japanese or even American counterparts. From the quote above, it can be seen that Barker is suggesting that the typically cited failures of strategic managerial decisions lies with how managers as a collective, instill and communicate their decisions throughout the organisation.

Therefore, in some sense, managers control the mindset and the underlying culture of the organisational in how issues are dealt with. It is understood that managers who are successful at handling and resolving decisions quickly, decisively and making best use of knowledge, reflect the same qualities back into their workforce. Thereby increasing the competitive awareness and success of the organization, at large. The influence of such a behavioural aspect does not necessarily end there. Moving up the organisational hierarchy beyond middle to senior management and boards of directors, a hardening of specific managerial behaviours can be observed, within the collective mindset of a small group of authority-wielding managers. Strategic decisions which are made at board level, are usually and typically based upon a similar oversimplification and de-sensitised view of the issues at hand, i.e. context of the situation where a decision is required is almost completely removed via the often asked "50,000ft view of things" (Ansoff, 1979; Donaldson and Lorsch, 1983; O'Shea and Madigan, 1998). By implication, this latter statement always tend to suggest that senior management are so far removed from the operational and tactical aspects of the organisation, that they can only observe actions and events from a distance. Because of this distance, and the need for managers to exert authority and control over one another via their leadership qualities, a second behavioural influence upon strategic decision making can be discerned – that of networking or sharing of knowledge within particular groups. As Hislop *et al.* (1999) also note from their investigation into senior management at two chemical engineering companies, the implementation of decisions and change was seen to be primarily centered on this networking concept. The importance of a methodology and technique in order to implement change within these organisations, was not amplified through process or via IT/IS, but squarely through influencing and motivating individuals within the organisation, by *leveraging* tacit (i.e. privileged) knowledge against explicit (public domain) knowledge.

In due course, this emphasis on tacit knowledge in preference for explicit knowledge, initially allows individuals to distinguish themselves from their peers in terms of their leadership capability. This preference, almost taken on a whim or as a result of some *intuitive* insight, ultimately relies upon explicit knowledge in some respect. However, as Bennett notes, successful (or otherwise) strategic decisions based upon incomplete or uncertain knowledge, requires such a leap-of-faith approach to be taken. This however, can only be achieved after much experience and interpretation of explicit knowledge has been undertaken. Once the decisions have been taken in this light, the decision maker can then return to the original cause for the decision and suggest a deeper tacit reasoning for their initial explicit decision.

As Bennett (1998) notes, when discussing how tacit knowledge is used by investment bankers, a particular banker was reported to have exclaimed,

> *'When it's a big decision, we can usually answer NO with the data, but to get to YES we must go with our gut!'*

(Bennett 1998, pp.589)

In other words, in this particular instance the decision-making technique employed by the banker was suggesting that some decisions could be made by predominantly using explicit knowledge, although in order to justify their *reasoning* about such decisions, they would prefer to use instinctive or tacit knowledge.

Returning to the issue of decision-making specifically within IS evaluation, and taking these largely behavioural and sociological influences upon the process into account, it becomes increasingly clear to the author, that there must be a link between the transformation between explicit and tacit knowledge. As has been noted, typical approaches to ISE in the generalist or holist sense make use of either one of these knowledge forms, but not both *per se*. In fact, within this field, the emphasis has been largely on measurement than on identification of causes for IS success or failure. As such, there tends to be more of a *de-emphasis* of tacit knowledge, in favour of explicit knowledge, due to the fact that technology and processes which support strategic decisions are more visible and accountable to managers (Johanssen *et al.,* 2001). Hence there exists a potential imbalance within this strategic management process, as far as the representation and use of knowledge is concerned. On the one hand, the leadership and decision making behaviour of those in control of the business can appear to be highly intuitive (therefore, tacit). Yet at the same time, when attempting to assess decisions and justifications which will determine the future success (or failure) of the organisation, IS evaluation suggests rational factors instead.

IS Evaluation, requires an understanding of an organisation's strategic, tactical and operational goals, with respect to the technology that it invests in (i.e. IT/IS). So, there is a need to not only understand basic principles of business, but also a need to understand the specific nuances of *a* particular business (i.e. behaviour and culture which is exemplified via tacit knowledge), and the benefits and limitations of IT/IS across numerous business processes (i.e. systems and processes exemplified via explicit knowledge).

The ISE task in itself, requires a method to be able to map goals and objectives of the organisation to some measurement criteria, noted in the way in which the organisation learns. These can be via direct or indirect measures, for example, such as cost-based approaches.

However, the literature relating to ISE has shown that investments have tended to be done as an act of faith, based upon almost adhoc decision making (Hochstrasser, 1992; Hochstrasser and Griffiths, 1991; Kaplan, 1986). That is, it has been based upon tacit knowledge alone, in some respect. This can be attributable to the following, modifiers: uncertainty of the business environment, unquantifiable risks, costs and benefits; poor managerial control and responsibility; and a poor understanding of how IT/IS works. In all of these aspects, the underlying theme and conclusion that can be drawn, is that the influence of organisational culture and learning, greatly affects the decision making flow of individuals. This impact, has a great significance when those aspects of the knowledge transfer process (Socialisation, Externalisation, Combination and Internalisation), are considered. Given that the remit of any knowledge process is to capture and codify knowledge from individuals back to the organisation (and vice versa), any factor which modifies this knowledge may exert an unknown influence on decision capability. Although this is at present, an unsupportable statement, it can however be stated that without considering these factors, ISE within manufacturing IS, will continue to provide unsuccessful evaluations if this issue is not taken into account.

What can be clearly supported at this stage, is the fact that these adhoc decisions based upon tacit knowledge, have to be justified. However, any validation and justification, is somehow "reverse engineered". That is, explicit facts and knowledge are used to justify adhoc, intuitive decisions *after the fact* (such as quantifying known risks, benefits, costs via techniques such as financial appraisal, scorecard techniques / key performance indicator analysis, production throughput metrics, etc). In a similar vein to earlier, the author now shows the mapping of these explicit-tacit factors once more, as in Table 0-3 relative to the knowledge transfer aspects defined in

Table 0-1. Here, the distinguishing feature of the ISE task, is that the socialisation of knowledge within the organisation, is tacit. Thus in some sense, it is proposed that the ISE task can be said to exist as *explicit context which requires explicit content, modified via organisational culture factors.*

Table 0-3 Explicit-Tacit knowledge within the IS Evaluation task

Knowledge Aspect	***Fundamental Driver***	***Realisation***	***ISE Task***
Creation and Transfer (Socialisation)	Environmental	Context of Information within an IS : the epistemological and phenomenological cause for the existence of knowledge	Explicit
Realisation (Externalisation)	Psycho-sociological	Alignment to core Business Processes: making sure that knowledge "fits" and is pertinent to the individual and the organisation	Explicit
Distribution (Combination)	Systematic	Development of knowledge tools and processes within IT: providing a systems and support infrastructure, to allow individuals to share and access knowledge	Explicit
Operationalisation (Internalisation)	Behavioural	Tactical usage of knowledge: learning from and adapting available knowledge (i.e. knowledge re-transformation)	Tacit

Here, the distinguishing feature of the ISE task, is that the socialisation of knowledge within the organisation, is tacit. Thus in some sense, it is proposed that the ISE task can be said to exist as *explicit context which requires explicit content, modified via organistional culture factors*. In other words, the ISE task must involve the full capture of both indirect as well as direct costs and factors as far as possible, along with clear communication and involvement of the stakeholders of the IS.

This can be attributable to the fact that in the case where an SME has to justify investment in technology, the pressure of time-to-market and the maintenance of competitive advantage (profit margin), means that an instinctive decision has to be made, sometimes regardless of the consequences. This is an unfortunate, but not altogether unrealistic, assumption of the reality of ISE within manufacturing organisations. As such, once such a deliberate course of action is taken to invest, there is little alternative for senior management but to communicate and motivate workers, to utilise the technology, once installed.

This is the reason why the internalisation of the ISE justification knowledge, is also tacit: it becomes part of the culture within individuals also. This loop and interrelationship, therefore seems to pervade such a task, as has been witnessed in the literature.

Thus far, it has been noted by the author that particular explicit and tacit factors, may influence the CAE and ISE knowledge tasks within manufacturing IS. The issues raised subsequently, have concentrated on attempting to state whether or not the tacit dimension is represented, if at all, in either of these cases. In the following section, all of the pertinent aspects of knowledge, its definition, import, influence and outcome, are defined as part of a conceptualised model, which seeks to focus the data theory outlined as part of the literature review in Chapter 2. This model, therefore also relates directly to the previously defined themes presented.

Development of a focal theory of Knowledge within Manufacturing IS environments

The argument in the preceding sections thus far has been, that the representation of knowledge as information content alone, is insufficient. As has been also presented and argued within the previous sections, the importance of the dynamic relationship between explicit and tacit knowledge, implies that *context* is somehow fundamental to the creation, synthesis and exchange of knowledge between the individual and the organisation also. This supposition also tends to agree with Heylighen's core stance also: without relating the knowledge being represented to its environment that it exists in, the representation *itself,* becomes meaningless.

In other words, the goal of any knowledge representation philosophy is to convert content into knowledge, via some contextual modifier. In order to satisfy the research aim of being able to provide a frame-of-reference for navigating through the many forms of knowledge, there should be some conceptual construct, which will allow the research questions raised so far, to be framed within a methodological context, and this is now defined in the following section.

A framework for Knowledge Transformation in IS environments

In order to conceptualise a model for the existence of an inter-relationship between explicit and tacit knowledge within manufacturing IS environments, the author will now formalise the preceeding discussions by highlighting key drivers for knowledge transformation. By this it is meant, providing an integrated model relating tacit and explicit knowledge to Structural, Interpretive and Evaluative knowledge forms, taking socio-psychological and behavioural critical success factors (CSFs) into account. This is in the context of the SECI model of Nonaka and Takeuchi (1995) as outlined in section 0 earlier (within Figure 0.6), and the associated formalization of knowledge constructs as also discussed by Sorensen and Kakihara (2000). The finding that concepts of heuristics and intuition are quite strong within the two decision-making tasks viewed, is also a significant shift in focus from many other views of knowledge within the organisation and the individual.

Experience and research suggests that information systems and information technology alone, does not for the capture of all aspects and connotations of knowledge, in this regard. Indeed, as it has been shown, current approaches to knowledge integration within companies, are more infrastructure-based (i.e. IT) than people-based (i.e. IS). This particular characteristic, further distinguishes the notion of IS being different to IT, and as such, the novel framework shown in Figure 0.7, is derived by the author from the previous issues and concepts presented in

Table 0-1. To recap, each of these concepts relates to the SECI model, whereby the author in the context of this dissertation has realised each of these concepts in terms of Environmental (Socialisation), Psycho-Sociological (Externalisation), Systematic (Combination) and Behavioural (Internalisation) factors.

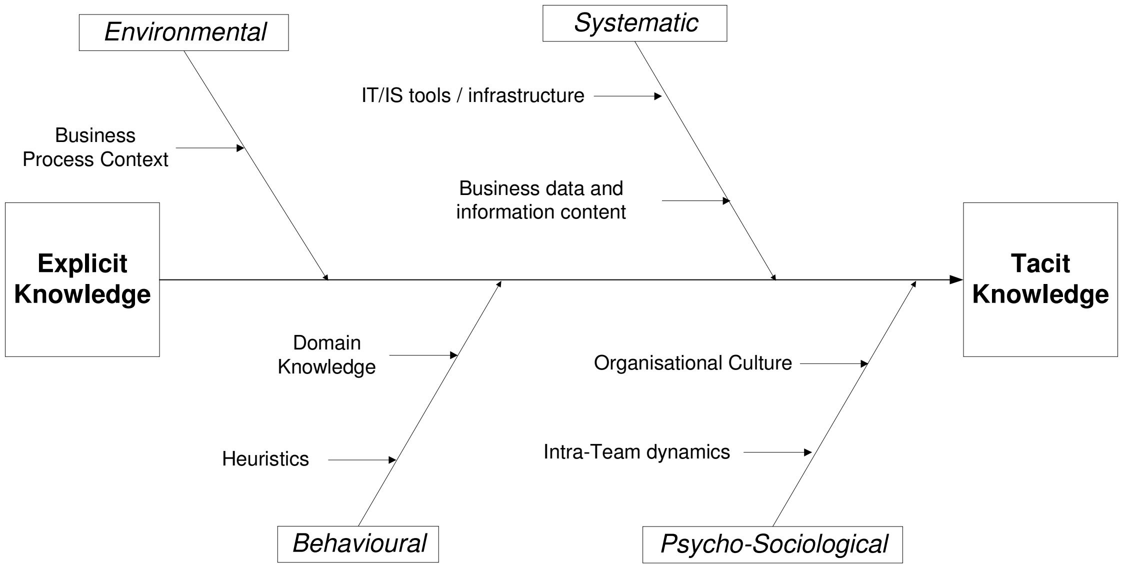


Figure 0.7 A framework for Explicit-Tacit knowledge transformation drivers

By recapitulating and aligning these core SECI factors within the authors' interpretation of them in this light, and within the context of IS decision-making tasks, Figure 0.7 shows that the contributing factors to explicit and tacit knowledge, are essentially drivers for the transformation between these two states. It is not known whether or not these drivers have any special significance in terms of the magnitude and order of importance. This figure also shows that although knowledge can be defined generally in terms of its relation to data and information, there are more subtle factors which pertain to the social as well as psychological importance of knowledge use.

Thus, a concise statement can be made based upon these assertions: knowledge *behaviour* is more important than knowledge *process*. That is to say, the way in which individuals and organisations deal with and relate to knowledge should be more important than the manner by which knowledge is captured and codified, as has also been noted by Onions and Orange

(2002). On this point, Wiig (1999) has pointed out that one of the key areas for development within Evaluative or knowledge management is in the role that mental models play in intellectual work (i.e. understanding knowledge). As he goes on to note, there may in fact be a requirement to define further specific theories of how particular individuals or organisations use knowledge, in order to have an understanding of knowledge (i.e. meta-knowledge).

Because knowledge is boundless, the focus of the argument so far has been to attempt to identify how knowledge is used. Also, the manner by which knowledge is produced, and how it correlates to specific explicit or tacit tasks has been discussed at length. Attempting to contextualise knowledge within an organisation via a systematic approach (i.e. both socialisation and externalisation cannot be carried out alone, if the dependencies upon these two aspects of Nonaka and Takeuchi's model are to be considered). These factors have to be related to each other as this is part of the explicit – tacit approach taken by the aforementioned researchers (the idea to which many practitioners and academics subscribe to, but don't extend their models and theories towards). Therefore a mapping between these aspects (i.e. the top of Figure 0.7) and the underlying factors of operational (internalised behaviour) and realisable (combined psycho-sociological) factors (i.e. the bottom of Figure 0.7), must also be considered. In other words, to use and represent knowledge effectively, an understanding of the human dimension is required (and not just the procedural or environmental causes for it). This is another reason why understanding how and where knowledge is used within organisations is a complicated matter: the inter-dependencies between these four factors outlined within this transformation model, have been very rarely, if at all, discussed within the literature.

Summary

This chapter has sought to develop research questions, or rather case-specific contextual "threads", relating to the reviewed literature on knowledge and in relation to the CAE and ISE knowledge tasks within manufacturing IS. The chapter began by first of all defining the type of IS that are relevant to the manufacturing scenarios which are focused on within this dissertation. These were defined as being either Management IS (MIS) / Decision Support Systems (DSS) or Knowledge Work Systems (KWS). CAE systems fall into the latter category, whilst ISE systems and techniques fall into the former.

The application of knowledge within manufacturing IS, was then presented in the form of two key areas within the manufacturing lifecycle: product design through computer aided engineering (CAE) and the investment evaluation of IT/IS within manufacturing organisations. In both cases, brief overviews of the key knowledge considerations were given based upon published research and experiences in these areas. This was in order to provide a suitable background for the development of the focal theory, which is defined in the chapter that follows.

Following on from this, it was discussed that although there appears to be many definitions, forms and models of knowledge within the research area and scope, the multitude of such approaches, only seeks to make the definition itself, more complex. This was termed as being the "knowledge conundrum", namely that so many different definitions of knowledge and its usage exist, which are all manifestly applicable to problem-solving or decision making situations that it is difficult to discern between them. Through highlighting the prominence of the concepts of explicit and tacit knowledge, as defined by Nonaka and Takeuchi's model of knowledge transfer, it was highlighted that the behavioural and psycho-sociological aspects of this model have not been fully investigated within the literature. This could well be due to the fact that there is an inherent difficulty and complexity in defining these factors, especially when the context of organisational knowledge is defined in terms of an evaluative or procedural approach. Thus, this study attempts to place these two aspects within focus.

It was thus suggested that the manner by which knowledge is utilised (via behaviour), is of more importance than the mere representation and procedural availability of it (as embodied by most evaluative, or knowledge management techniques). It was also highlighted that researchers in the field acknowledge the fact that there has been little research undertaken in order to analyse, systematically, how different variables affect the flow and utilisation of knowledge. This is even though it has been recognised that knowledge within organisations is dependent upon realising what knowledge is, providing access to it and making it relevant to stakeholders within the organisation.

The subsequent sections also suggested that the studied knowledge forms so far, Structural, Interpretive and Evaluative, are mutually exclusive in terms of how they relate to one another. Instead, the underlying notions of explicit and tacit knowledge were introduced, in order to address the non-IT/IS aspects of knowledge. Following this, the author outlined several critical success factors (CSFs) which attempted to define a mapping between philosophical, behavioural, systematic, and psycho-sociological drivers, via a mapping of the core phases within the knowledge transformation process. This novel view of the explicit-tacit landscape, was based upon previous discourse on the research in this area.

It was also noted that in order to harness and utilise properly, knowledge itself must be defineable, in some sense (structural, interpretive, evaluative); it must be available to both the individual and collective; and it must be either defineable (explicit) or unknown (tacit).

As a result, a social dimension case-specific thread, was presented which stated that *an underlying psychological and sociological relationship between Explicit and Tacit knowledge, must exist*, based upon the concepts defined above.

It was concluded that investigations by researchers into knowledge within the CAE modelling task found so far, highlights that the explicit context of the representation of scientific laws, utilises tacit content, modified via heuristic assumptions. This is in terms of domain experts (engineers) having a tendency to re-use previous knowledge in order to carry out simulations. This led to the development of another, assumption-based, case-specific thread, which stated that *Tacit knowledge, is reliant upon a-priori assumptions and intuition, and is reinforced through on-going individual experience.*

For the knowledge within ISE tasks, the opposite to CAE knowledge tasks was proposed: i.e. the tacit context of adhoc decision making, utilises explicit content, modified via organisational culture factors. This is in terms of adhoc managerial decisions within IS evaluation which need to be justified via explicit, factual knowledge.

These factors were presented within a novel conceptual framework which highlighted the importance of non-IT/IS factors as drivers for explicit-tacit knowledge transformation. This model was generated in order to situate the analysis of the case studies in this research, with respect to formulating a frame-of-reference for a knowledge representation in manufacturing IS environments.

CHAPTER 4

RESEARCH METHODOLOGY

Following on from the formation of the context of a focal theory in previous pages, this chapter presents a research methodology which will be used in order to investigate the nature of knowledge representation within manufacturing IS environments. Through the definition of an overall research design structure, the core components of the background theory, focal theory, and selection of an appropriate research strategy and methodology are presented. For the purposes of this research, an empirical, interpretivist methodology of case study, research has been used and implemented via an observational approach, in order to capture the rich and in-depth facets of the decision-making behaviours in each case. An overview of the core component of the research approach is shown in terms of a research schema also, which summarises the methodology used.

Research Methodology

In presenting any piece of research, it is crucial to identify the method by which it is carried out. A scientific approach is required in the sense of developing a set of specific tasks or procedures, otherwise known as a methodology, in order to do this. This chapter therefore, provides a methodological basis for the research in this dissertation, based upon an empirical case study approach. An overview of the research design is given, which details the specific stages involved in formulating appropriate hypotheses from the reviewed literature. This is in terms of the steps required to carry out the research.

Next, a discussion of the importance of selecting an appropriate research methodology is then also given. This section notes the fact that in order to contextualize the arguments (within the "threads" presented in the previous chapter, within Section 3.4.1 and 3.4.2), requires a multidisciplinary approach, in order to collect field data from the case companies. This is because the Evaluative form of knowledge (i.e. explicit and tacit knowledge), is based upon socio-psychological aspects. As such, the use of both an interpretivist stance to gather the data and a positivist stance to frame the data sources in an epistemological sense, is made. Following on from this, a method for analysing the case material is also presented. The chapter concludes with a summary of the overall research context of the dissertation is presented, which highlights the focus of the empirical case study research and the chosen methodology.

Research Process

The key stages required in order to carry out the research within this dissertation are now presented in the form of a flow chart which describes the overall research process and, specifically, the research design. The stages within the research process shown, are similar to those outlined by Phillips and Pugh (1994), in terms of background theory, focal theory and data theory; and the structured linear research process as described by Mumford (1985).

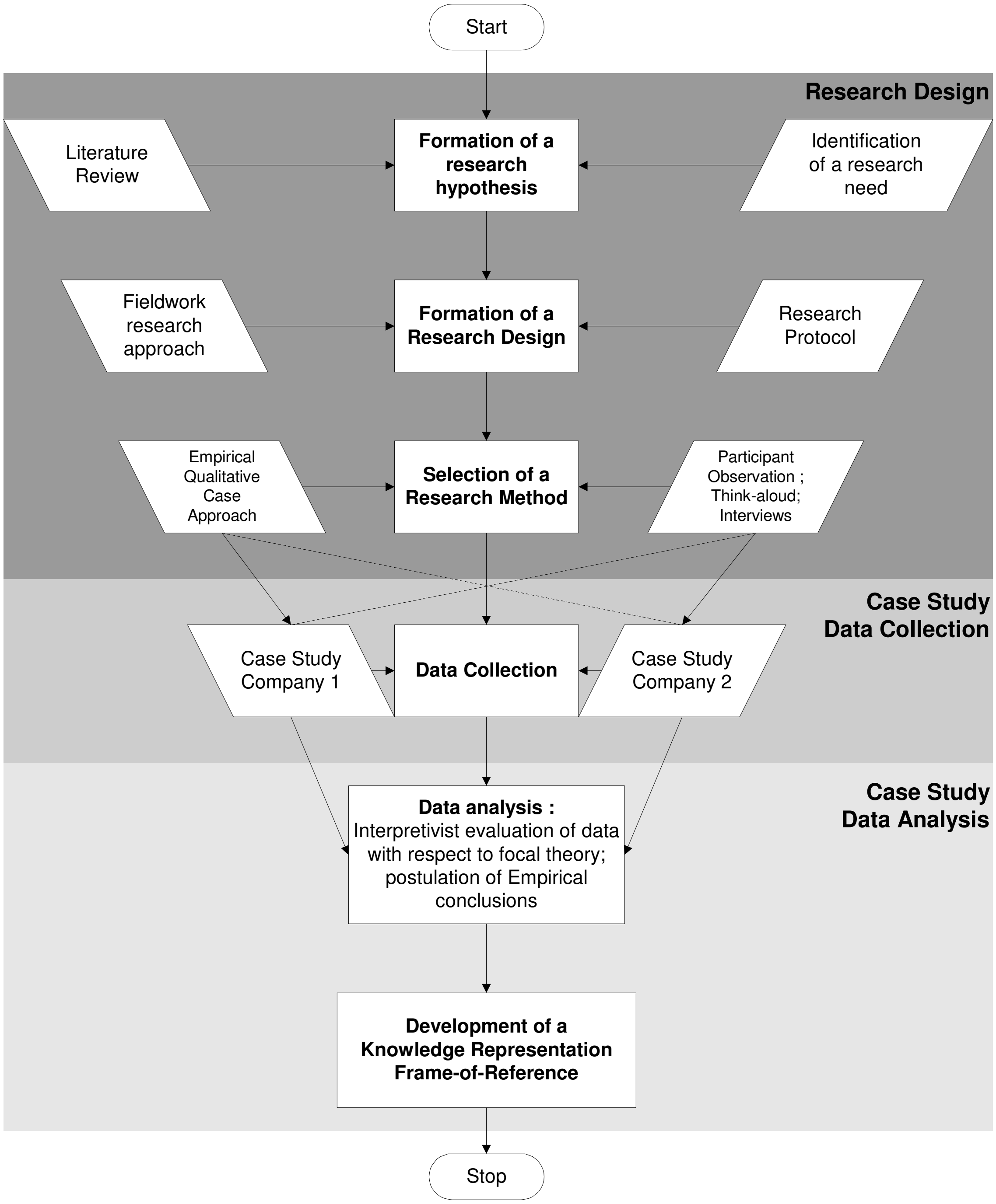


Figure 0.1 Empirical Research Methodology Model for the dissertation

The diagram, shown in Figure 0.1, highlights the complete research process, which includes the research design, data collection and data analysis techniques. In terms of this dissertation, the author has defined the first stage of this process (i.e. a hypothesis or basis for philosophical argument), in the previous chapter.

This chapter will concentrate on the development of a research strategy and methodology. Whilst Chapter 5 and 6 will concentrate on the data collection from the case study companies. The thesis continues with an analysis of the case study material and the formation of a frame-of-reference, for knowledge representation within manufacturing IS environments. The dissertation then concludes by offering an evaluation of the research process and data gathered, and provides avenues for further research. As the diagram shows, the research process is a series of sequential tasks that will allow the research to be carried out. The research design on the other hand, is a more specific logical plan of *how* the research is to be carried out, *why* a research question needs to be answered and *what* conclusions can be drawn from the output (Yin, 1994). Before collating data to be assessed against the arguments raised in Chapter 3 (the research threads of assumptional and behavioural knowledge), an appropriate research methodology needs to be realised. This is now discussed in the following section.

Research Methodology

As has been discussed in the chapters on background and focal theory, Evaluative Knowledge, borrows and develops concepts from many disciplines as varied as management science, economics and philosophy. An approach to collect and analyse data and information about the topic within this dissertation, or research methodology, is then required, in order to provide justification for the understanding of how a particular system operates or behaves, as Jayaratna has noted:

> *'Methodologies exist to help us in our reasoning. They attempt to raise our conscious thinking, to make us question the rationale of our planned action and to guide us in the transforming of situations'.*

(Jayaratna, 1994 : pp. xii)

Hence, the selection of a research methodology should also be multidisciplinary in nature, in order to reflect the many different aspects of people, process and technology within an organisational setting.

Thus, quantitative as well as qualitative epistemological stances are held in carrying out the research. The research philosophy which underpins the work that follows, is now defined in further detail in the following section.

Research Philosophy: an Epistemological basis

In order to carry out any investigative study or body of work which is to be classed as being scientific, the manner by which theory is derived from the facts of experience has to be carried out in a structured manner, based upon a rigourous set of rules (Chalmers, 1982). By adopting a particular philosophical stance, the range of appropriate rules is then constrained, which allows a finite range of hypotheses and tests to be carried out. In order to carry out the research, a particular epistemology or relationship between the observer and the observed phenomenon, needs to be stated. Hence, an epistemological basis, this can, and should, be derived in terms of two specific research philosophies – the Positivist and Interpretivist approaches.

The philosophical theory of Positivism focuses on investigating *how* things work and exist, relative to some universal laws. Through the use of a scientific method, positivism emphasises the importance of facts over meanings and estimations. Primarily this is done as a result of formulating and testing hypotheses, which in some way relate to measurable and observable quantities. Ultimately, the Positivist stance seeks to test hypothetical theory, in order to understand and infer qualities of the observed phenomena.

As such, a refinement of this philosophy, Empiricism, contends that experience and observation, rather than reason can describe the real world better than purely formulaic rules and theories. Within IS, the empirical, positivist philosophy is best represented through the use of case study research (Avison and Fitzgerald, 1998; Walsham, 1993; Yin, 1994).

An alternative philosophical stance is that which is known as being phenomenological (hermeneutic) or Interpretivist in nature. Since positivism only accepts and reflects the outcome of tested hypotheses in relation to objective statements and facts, the interpretivist philosophy is better suited to situations where sociological or human factors are involved. The underlying argument here is that knowledge is limited in time and space, there is no objective truth and it is not always possible, or desirable, to separate facts from values. Furthermore, the interpretivist stance recognises that a scientific study may not be able to yield wholly repeatable results, as the positivist school of thought supposes. That is, as Mumford notes, this is a repeated process of purifying experience through attempting to understand phenomena, through meanings that are assigned to them (Mumford, 1985). Such an approach does not require proof that a hypothesis is testable, rather that the underlying theory and principles which uphold an observed phenomenon can eventually lead to a set of generalised laws.

As Walsham (1993) notes, for IS research, interpretive methods should be used in order to gain an understanding of the context of an IS, and the manner by which both internal and external influences, affect it (for example, business processes and stakeholders; and the associated implicit and inherent depth or "richness" of data within its natural setting). Thus, the purpose of an interpretivistic philosophy is to provide meaning and convincing interpretations to an observed phenomenon; whilst the positivistic philosophy involves the testing and resolution of hypotheses based upon specific rules and laws that govern the existence of the observed phenomenon. In terms of this research, it is suggested that an empirical and interpretive case study approach is taken, based upon semi-structured interviews and direct, non-participant observation, as defined by Yin (1994). However, whilst Yin defines case study research in terms of a positivist agenda, the author notes that knowledge within the two IS environments selected (the CAE and ISE tasks respectively), involve some level of tacit and explicit knowledge transfer. The author therefore contends, that it is difficult to apply a methodology which is primarily and wholly rooted in the analysis of quantitative facts and data. This is as opposed to adopting a methodology which is more amenable to handling meaning, causality, descriptive and narrative commentary, behavioural intent and other "soft" human factors. These issues have been defined previously in Chapter 3, and so the analysis of the case study data will have to be relateable to the two themes of psycho-sociological and behavioural (assumption-based) effects of knowledge, within manufacturing IS.

A quantitative, positivistic stance is therefore only reserved for the ontological view of how knowledge is encoded and utilised within each case company (i.e. the explicit data, which is recognisable and discernable from the intuitive, complex, expert or tacit data which in the course of investigation required further field data to be captured. This was in order to understand the nature and meaning of particular tasks carried out, by the case study participants).

Hence, both case studies were likewise based or framed within the context of a positivist ontological view of each decision-making task. By this it is meant that the underlying nature of the CAE and ISE tasks were based upon quantitative premises and theories (for example, the mathematics behind the physics of waveguides in the CAE case, and cost accounting / ROI models within ISE). Although not directly relevant to the actual gathering and logging of field data in this research, this essentially quantitative component of the case data, is once again only apparent, in order to *frame* the qualitative data in the context of each case. This approach is similar to that mentioned by Probert (2001), where he suggests adopting a blend of both "hard" rigorous justification for a chosen methodological approach, as well as a "soft" or authentic method for collecting and situating data from the case study. This is in terms of increasing the understanding of how the IS works and the causes and effect of the individual and the organisation upon such systems. As such, Farhoomand (1992), Scott and Ives (1992) have found through their respective surveys into research methods within IS, the majority of the approaches used have been based upon empirical, qualitative research methodologies employing the case study approach. The bulk of these studies have tended to support and uphold the notion of increasing or augmenting the understanding of how an IS affects the organisational context within which it is placed and the manner by which both of these components affect and influence each other.

Klein and Myers (199) also note that the nature of interpretive research within MIS means that the investigation and analysis of the context of the IS in relation to its users and processes, requires a judicious research methodology to be adopted, in order for such contextualised relevance to be applicable. In doing so, they present seven principles for conducting and evaluating such research based upon hermeneutic or textually recorded field data : (i) the hermeneutic circle (a specific perceived meaning of an observation, and its relationship to the understanding of the wider context); (ii) contextualisation (reflection of the social background of the research setting); (iii) interaction between researcher and subject (social construction of data between the interaction of the researcher and participants); (iv) abstraction / generalisation (relating and interpreting the hermeneutic and contextual data in general terms of human understanding and social action); (v) dialogical reasoning (sensitivity to contradictions arising from preconceptions); (vi) multiplicity of representations (sensitivity to multiple differences in interpretation and the narrative context); (vii) suspicion (or the sensitivity to bias or distortion in collective recorded narratives). These principles essentially distill the issue of contextuality and relevance of the research being conducted, and the need for accurate and clearly relateable interpretations of the field study data to be made. For the purposes of this research, the author contends that these principles need and should underpin any evaluation of the case data collected. The author now presents the research design which details the specific approach taken in order to gather the field data, based upon this research philosophy.

Research Design

It has been noted that the formation of a philosophical context to the research is imperative in order to frame the resulting understanding of the topic or subjects under investigation. A research design or approach to implementing the methodology is then therefore a necessary and vital step in order to carry out the research itself (as highlighted within Figure 1.1 in Chapter 1). As a first step, the generation of a research hypothesis or series of research questions, is required, based upon a review of the published literature in the area and the formation of a research question. As Yin notes, the purpose of a literature review is to develop insight and propose questions to the key issues that the published literature has brought to light (Yin, 1994). Thus, the purpose of surveying the published literature on the subject area, is to identify a research question which states the context and relevance of the proposed research. By clearly stating this research question, an appropriate (set) of hypotheses or conjectures can be therefore created. This has been developed previously in Chapter 2 and 3 respectively.

Once this hypothesis is created, the next step is to define a suitable strategy, which will enable data to be collected. This strategy should define not only the type of research to be carried out (computational, fieldwork, etc), but also the governing policies and procedures which will enable the researcher to effectively record data (i.e. the protocol). These components are vital to selecting a particular research methodology. The methodology must not only reflect the hypothesis raised, but also be representative of the subject of the research as well (i.e. cogniscent of the *context* also). The data collection phase of this approach, needs to define the manner by which data will be collected. In essence, this is the research itself. An analysis of the collated data is then carried out, with respect to testing the hypothesis raised during the research design phase. Finally, from this analysis, some empirical conclusions can be formed which either support or reject the hypothetical basis of the research. The following sections now define these aspects in further detail.

Application of a Case Study approach

Given these fundamental concepts defined, how has this approach been implemented within the investigation of IS within manufacturing organisations? A good example of such an approach recently used, is in the form of the paper by Frishammar (2003), relating to the investigation of information use in the strategic decision making tasks across four organisations. This research is typical of most which are found within manufacturing IS, namely that an empirical case study approach was used, with data being gathered via observation, documentary and interview-based data sources. The sample size of the data (number of organisations involved and their industry segment, number of interview participants, scope of decision-making tasks), were essentially limited. The data analysis was therefore limited to making generalisations within the sample – if not only because the extent of the data was highly qualitative, and based upon narrative analysis. A similar approach was taken by Bali *et al.* (1999) in attempting to qualify a conceptual model for MIS implementation within a bespoke thermo-electrical engineering company in the UK. Here, the case study organisation involved was used and analysed in terms of its ability to adopt an information system and the openness of its organisational culture in communicating this adoption.

In terms of research methods relating to harnessing and capturing forms of knowledge within organisations (including those who do not necessarily have a specific IS to cater for knowledge), the approaches used are more varied. Gao *et al.* (2002), present perhaps the clearest understanding of research methods used for representing knowledge, as it relates to knowledge management. Their research and survey reports that researchers involved in this field are typically cross-disciplinary in nature, coming from fields as varied as social science, psychology, business studies and computing. As such, there are a multiplicity of approaches and solutions which are offered – which all vary in their epistemological construct. For example, the work of Davenport and Prusak (1998), although highly strategic and business-focussed, has been used interchangeably between both researchers interested in managerial aspects (such as Kluge *et al.*, 2001) and those interested in the IS implementation aspects (such as Probst *et al.*, 2001). This is due to the fact that in an epistemological sense, knowledge tends to be regarded as an object as opposed to an activity or tasks (Al-Hawamdeh, 2002). Thus, Gao *et al*, note that this multiplicity or multivalent thinking which pervades research into organisational knowledge, tends to either focus particularly on methods which seek to quantify the process of encoding and distributing knowledge (via IT/IS tools) at the expense of understanding organisational behavioural and cultural factors. As such, the latter form of research tends to gloss over specific methodological approaches, for example in the case of Marr *et al.* (2003), who present a highly philosophical model of knowledge creation without detailing a specific methodology used to arrive at their thinking. Again, this is indicative of the difficulty involved in understanding knowledge use within organisations. Hence noting the preceding points, the author chose to adopt a traditional approach to IS research, in terms of an Empirical Qualitative case study.

Selection of Case Study organisations

As noted within the review of literature within the background theory, and the formation of arguments within the focal theory, the two key areas of interest and concern to the author in the context of this dissertation, are the product design (i.e. CAE modelling) and investment appraisal of IT/IS (i.e. IS evaluation), within the manufacturing cycle. These two aspects of the manufacturing cycle were chosen, as in the view of the view of the author, these tasks have attracted considerable debate in terms of the effects of knowledge in the decision-making processes. In presenting and carrying out the remainder of the research in line with the outlined research process, design and methodology, the selection of representative case study organisations which exhibit aspects of the stated behaviour, are now described.

The focus of the first case study is specifically centered on how domain / expert knowledge is used in the CAE modeling task. In order to accommodate a sufficient amount and depth of observable expert, and explicit knowledge an R&D electronics manufacturing organisation has been chosen. This is due to the fact that this particular organisation is not only known to the author, but also has in the past notably experienced some of the key issues relating to the dependency upon expert engineers within their product design division. This has been in terms of the effective sharing of information and knowledge across design teams: upstream requirements gathering to downstream prototyping production); the use of a set of standards and common best practices for design and manufacture (i.e. a lack of an organizational R&D "lingua franca"); sight and understanding of the implications of (fundamental) orthodox and (heurism-based) unorthodox design decisions on the production and manufacture process. Also, the proximity and openness of this firm, engenders the potential detailed observation and interpretation of a domain expert (electrical engineer) to be carried out, unhindered. It was felt that this case example would therefore highlight those behavioural and systemic factors identified within the focal theory.

Similarly, the choice of a manufacturing organisation with which to investigate the explicit – tacit knowledge transfer qualities within the IT/IS evaluation process, has been chosen based upon previous research involvement and experience (see List of Publications arising from this research, page x). It was believed that this case company had sufficient depth of issues, which would engender an investigation into knowledge required within the ISE decision-making process. Once again, it was felt that this case study, company would be an excellent choice to highlight those psycho-sociological and environmental factors from within the focal theory conceptual framework, presented earlier in Figure 3.7 in Chapter 3.

It was also decided that the type of case study company chosen would be discrete as opposed to a process-oriented manufacturing enterprise. This is mainly due to the fact that a discrete manufacturing company, matches the manufacturing lifecycle model more closely (as given in Figure 3.1 in Chapter 3). Furthermore, the context of explicit and tacit knowledge, derived from Nonaka and Takeuchi's model also highlighted in Chapter 3, is predominantly based around the concept of innovation. Hence, this also defines another aspect upon which to constrain the selection of case study organisations. It was therefore necessary to look at those decision making processes within manufacturing IS, which related to innovation-led tasks (such as in the case of CAE and ISE). Finally, it was decided that, given the qualitative, interpretivist case study approach taken, those aspects of the manufacturing cycle should be chosen which would be liable to provide deep, feature-rich sources of data amenable to interpretivist analysis. In other words, those decision-making tasks which would display aspects of real-world subjectivity (ontology); an understanding or relationship between observer and observed within a given environment or situation (epistemology); and finally, social and individual behaviours which delimit subjective human experience (methodology). Thus, in each case the research attempted to build upon those aspects of the literature which had alluded to and defined an interplay between both explicit and tacit knowledge within CAE (Babuska, 1996; Liker *et al.*, 1992; Szabo and Actis, 1996) and ISE tasks (Farbey *et al.*, 1993; Irani *et al.,* 1999; Kaplan, 1986).

These aspects of the manufacturing cycle were also chosen in order to highlight the potential diversity (and / or similarity) of explicit and tacit knowledge representation within manufacturing IS. This was as opposed to comparing decision-making tasks on a like-for-like basis, which although may have yielded supporting evidence for the explicit and tacit knowledge usage in this task, may not have shown the full spectrum of factors (i.e. Environmental, Behavioural, Psycho-Sociological and Systemic factors). More importantly, the choice of two dissimilar case studies was taken in order to support and uphold the ontological and epistemological view taken within the thesis (i.e. a constructivist view, which attempts to analyse and interpret the changing features of human practice – Golafshani, 2003, pp.603). In terms of the quantity of case companies chosen and the number and types of participants chosen, the case data was limited to this number as there was sufficiently rich and in-depth case data gathered by this point. Furthermore, the research sample selected for this research study was derived from purposive sampling which allows the author to select suitable respondents who have the knowledge of the IS environment and the means by which IS and related processes are implemented and impact their organisation (Sarantakos, 1998)

Data collection and analysis

As has been shown in the previous sections, IS research tends to involve understanding the social nature of information systems. Research methodologies within this area have therefore tended to use techniques which allow for the interpretation and meaning behind human decision-making tasks (Walsham, 1993). The interpretivist and positivist approach used within this research, and which is also typical of most research within the IS field, then also requires that the data which is collected for analysis, not only be an interpretation of other people's interpretation of their manner of being and working, but also a direct representation of their context. Hence, methods for collecting and analysing data are congruent with each other in the sense that one drives the other: when data is collected, it requires analysis which then can then further lead to subsequent collation of data again, and so on, in an iterative cycle. As such, the author highlights the fact that the method of analysis used within this research is that of Explanation-building (or narrative discourse), which is an iterative process which is used in order to derive and progress a theoretical statement in terms of a refinement of this initial proposition, based upon a discourse of the data so presented (Tellis, 1997; Yin, 1994). It is understood, and quite acceptable then, for researchers engaged in interpretivist research to be directly and fully participant with the subjects of their research over a period of time, in order to gather this data and make sense of it. The author also wishes to note that in order for such case analysis to be useful and pertinent to the research objectives, a pragmatic view of the case data needs to be taken, in terms of understanding the context of the participant. Therefore, in order to capture the data, an appropriate research procedure or protocol, must therefore be used, which is now explained in further detail.

Application of a research protocol

For the purposes of this research, the data collection and analysis techniques employed, primarily fall into the category of observational approaches, and in some sense, mirror the approach taken by Al-Hawamdeh (2002), Bali *et al.* (1999) and Frishammar (2003). Thus, the research focusses on eliciting field responses based upon a limited sample size (two manufacturing organisations have been chosen, research data being collated from a maximum of 6 individuals across each company), and constrained to a specific organisational context (both cases relating to observing specific individuals within specialised, bespoke manufacturing enterprises). As such, the data which was collected was indirect in terms of influencing the research participants, yet direct in terms of harnessing and recording the information. The techniques employed were Participant Observation, the Think Aloud protocol and Semi-structured interviews, the practical details of which are given in Appendix A and which are now described in further below.

Participant observation was used in the guise of the researcher being a subjective participant in interacting with the research subject (i.e. the interviewees at the case study companies), as well as being an objective observer (i.e. simply recording and detailing the subjects tasks, opinions and behaviours). It is widely accepted that such a technique can infer a large degree of bias towards the recorded data through simply being directly visible to the study participant, as well as lacking a rigorous theoretical basis (the validity of which is discussed in the following sections). However, the strength of this method lies in the fact that participant observation immerses the researcher in the full context of the case environment and allows nuances of social interaction with the IS to be observed and noted more clearly. More specifically, the level of detail of the observation can be classified along Quinn-Patton's 5 dimensions of participant observation (Quinn-Patton, 1986):

(i) the role of the observer was as full participant within each case study firm;

(ii) the portrayal of the role to others was via overt observation (i.e. the engineers, managers and directors within both case companies knew that observations were being made for research purposes);

(iii) the portrayal of the study purpose was fully explained to the subjects (i.e. the research motivation, objectives and protocol were outlined beforehand);

(iv) the duration of the observation was limited to several observations (i.e. interviews conducted with the research subjects lasted from between 20 minutes to 2 hours); and finally,

(v) the focus of the observations was expanded and predetermined (i.e. the data collected pertained to the specific search for evidence relating to explicit and tacit forms of knowledge).

In addition to this approach, the Think-Aloud protocol (otherwise known as the concurrent verbal or thought-listing protocol), was used as a method to get the research subjects to verbalise and "self report" on their mental thought and process models (Ericsson and Simon, 1993). This approach allows the researcher to find out how a person approaches a problem or task, and allows them to gather rich, qualitative information which would be difficult to infer or deduce from purely observation or interviews alone. The research subject is encouraged to talk through their actions and decisions until they complete the task(s) that were being observed.

This trace of information is then recorded as part of the verbal research protocol. The inherent limitation of this technique means that a subject can only report what they are aware of and not the underlying subconscious processes which lead them to carry out tasks and decisions. Since this approach is inherently qualitative in nature, it is necessary to corroborate and support the data collected via observation as well as via any documentary evidence or via cognitive interviews. In terms of the research within this dissertation, both the engineer in Company A (the CAE knowledge case), and the project managers and directors within Company B (the ISE knowledge case), were encouraged to describe their thoughts and decisions as a result of the observed tasks recorded. This method is therefore prone to bias also, on the behalf of the observer.

Hence, the third data collection method used was that of semi-structured interviews. The purpose of any research interview is to use open-ended questions in order to encourage research participants to provide detailed responses. These responses should be defined within the terms of the research objectives, the researcher taking care to explain the purpose of the interview (if this is the sole approach being taken), all the while seeking to maintain the correct context of the interview relative to the topic and field of study (Gubrium and Holstein, 2002; Kvale, 1996). There are many styles which an interview can be given in order to elucidate this information, such as structured, semi-structured or informal (conversational). This research used a combination of a semi-structured and conversational approach, as it allowed the researcher to define an overall outline of the type and form of questions to ask, which could then be tailored in relation to the responses given, within an informal setting. All interview questions and responses were recorded onto tape and transcribed later. Within Company A (the case study described in Chapter 5) responses were elicited primarily from the senior electrical engineer who was the main user of the CAE system. As such, the case responses from this participant, were in terms of a one to one interview format. This was because User X generally guided the work of others and was noted as being the key stakeholder / driver of modelling and analysis decisions. Additional auxilliary input was also recorded from members of his team members also, as appropriate, where they contributed to or supported the participants' reasoning and this was also recorded, and refined as part of the case data.

Within Company B (the case study described in Chapter 6), responses were elicited from the production planning and control manager (Manager N), and managing director (Manager M). The difference in the amount of interviewees questioned between the case studies (namely 1 in the case of Company A and 6 in the case of Company B), was purely due to the nature of the knowledge task that was involved within each case study organisation. The first task involving a specific task using specific domain knowledge from a subject matter expert; the second task involving a more general, organisation-wide knowledge from individuals with responsibility for carrying out business decision-making tasks. The interviewees were chosen by the author to be the direct case research subjects who can be said to be owners and utilisers of knowledge, within their own respective roles within their companies. Since the overall aspect of the research was explanatory in nature, seeking to find specific interrelationships between explicit and tacit knowledge within each IS environment, the interview approach used was particularly suited to gathering narrative responses, which provide more information for detailed analysis later on. The three approaches to data collection outlined within the previous section, essentially outline a method to corroborate or rather triangulate the data collected.

Thus, the topic of triangulation, is in itself, an important issue within research design, since the output of any research must and should be referenced with respect to not only the reality within which it exists but also with reference to the manner by which the data was collected (and the extent to which it should be trusted). The following section, now provides further details on the triangulation approach used for assessing the case data in terms of the concepts of constructivism, reliability and validity.

Validity, Reliability and Triangulation in Qualitative IS research

An important and constituent part of any research methodology and research design, is to be able to provide some fundamental basis upon which research data (and hence analysis and therefore conclusions), can be based. As such, a central tenet of scientific inquiry and the auspices of the classical scientific method (sic), has been to be able to not only construct valid research questions, aims and lines of inquiry, but also to provide a robust and rigorous approach for ensuring that the research data collected is representative of, and reflects, reality (Chalmers, 1982). The history of scientific thought is rooted within a deductive and positivist view of the world, where the formation and testing of hypotheses are core parts of the scientific process.

However, even though qualitative, interpretivistic approaches to research present different challenges to the researcher in terms of attempting to "quantify the unquantifiable", issues of validity and reliability of data still remain. Indeed, in Qualititative research it is even more important for researchers to define boundaries and limitations to research data, so that effective and relevant interpretation can be done. In so doing, the notion of Triangulation or corroboration of data by multiple means, is an equally important step in order to improve the validity and reliability of the research and its findings, which is now discussed in further detail in this section. Firstly, and as Cohen and Marrion (1994) describe, any social sciences experimental design should impose control over conditions that affect independent and dependent variables. Therefore in order to control to understand the implications of engaging in the research process, it is important to ask whether or not treatments to experimental or field data make a difference to the research carried out (internal validity), or whether or not the effects observed and recorded by the researcher, can be generalised and harmonised into some universal "truth" at all (external validity).

The concept of Validity is defined as how time and the relationship between the observer and observed affect one another. Numerous authors have dealt with the concept of Validity in various ways, as applied to Qualitative research. For example Golafshani (2003) notes, that the qualitative research field largely agrees that there must be some measure by which research findings can be addressed: in short a method to determine if the approach truly measures what it was intended to measure (or more specifically, a measure of social reality). Bijlsma-Frankema and Van De Bunt (1994), also concur that in order to validate and realise research data, requires a combination of external as well as internal validities. Thus, it is not only important to discuss and extract the mental models of individuals in participative research, but also to contrast such social realism with reference to other data sources (documentary evidence, additional points of view from other participants, etc). Likewise, Yin advocates the use of multiple sources in order to maintain construct validity, and the use of theoretical relationships (i.e. deduced or universally derived assertions and laws), in order to achieve external validity, alongside a chain of evidence (Yin, 1994).

However, in the case of fully interpretivist, explanatory research, where a discussion via a descriptive narrative is sought, the usage of theoretical grounding to assess validities may be difficult due to the lack of generalized or known "truths" beforehand, as these assumptions may introduce dependent bias. This is also congruent with the nature of qualitative research which is to provide a Constructivist, human-practice view of the data context, as in the case of the research within this dissertation. As Kvale (1996), Tellis (1997) and Yin (1994) outline in their respective papers, the problem with case study research is in establishing *meaning* rather than making positivist assertions against theoretically-grounded laws. Thus in order to maintain and uphold notions of quality regarding the elicited case data, it is also important to make sure that any such understanding generated is based in terms of making sure that not only the refined data has been treated accordingly with respect to a given research, but is part of an overall research process (Lincoln and Guba, 1985)..

Golafshani (2003) also describes that many qualitative researchers note that the concept of reliability is meaningless in an interpretivistic sense, as the general notion of reliability is based upon some level of measurement to a norm (which for purely descriptive, explanation-building research is simply not achievable). Hence, it has also been discussed such as by Patton (2001), that Reliability or trustworthiness of the research, is a direct consequence of the concept of Validity. This essentially entails maintaining consistency, precision, and repeatability of the process of data capture from the field. Continuing this line of reasoning, how can the concepts of both Validity and Reliability be tested in themselves? Again, Patton (2001) elucidates this most clearly by stating that only through the method of Triangulation can a study be strengthened, via combining methods in order to control and / or reduce the bias of interpretation and effects of observer-induced variables.

Triangulation is rooted within the discipline of surveying (Blaikie, 1991) and in terms of social science approaches, Quantitative methods, whereby the purpose is to view a phenomenon from multiple perspectives using multiple and if possible, combinative processes (Denzin, 1984; Jick, 1983; Knafl and Breitmayer, 1989; Kvale, 1996; Massey, 1999; Morse, 1991) This technique allows the researcher to investigate the research construct in closer proximity, allowing greater clarity via these different viewpoints. Triangulation can be carried out in several ways, in order to achieve confirmation of convergence validity (Massey, 1999). Furthermore, Denzin (1984) and Miles and Huberman (1994) define some principle forms of triangulation in terms of: Data triangulation (assessing the consistency of data with respect to changing contexts); Methodological triangulation (the application of different research methods and processes in order to increase confidence in the elicited result data); and Theoretical triangulation (the application of different theoretical or philosophical perspectives in interpreting the data, i.e. a particular stance).

The antithesis of any triangulation method used, is to provide control over the research process in terms of the validity and reliability of the data gathered. A weakness in one method or point of view, can therefore be supplanted by a stronger method or view, that overcomes or rectifies the deficiencies of the first, in a holistic manner (Jick, 1983). In the case of the research design within this dissertation, a methodological as opposed to theoretical triangulation approach has been used. This is typical of interpretivist, qualitative approaches, wherein human methods of interaction in order to acquire data, are supported by additional social or observational techniques (e.g. use observation and verbalization in order to validate and confirm the results arising out of semi-structured interviews, or purely as a direct result of known or understood variables).

Given these preceding definitions, it was left to the author to choose and use the most appropriate protocol for the research method to be used in this light. It was stressed to each participant beforehand the nature of the research, the reason for selecting them as a participant and the need to record their responses for evaluation and analysis later. In capturing the case data via the given protocols, it should be borne in mind that each approach was mutually exclusive, yet supportive of the other as shown and this is shown in Figure 0.2, which shows the overlap or method of triangulation used within this research.

In order to elucidate a reason for why User X then proceeded to modify the model he had just defined, the author then asked the engineer to go through the steps again, and highlight those specific aspects of this modelling task which he could identify as part of his thought and problem-solving approach (i.e. providing feedback and verbalising the participant response). So, as noted in the previous section, the case data was captured using a variety of approaches and techniques, being transcribed in the form of notes taken when in the company of each of the case participants (principally being User X of Company A and Manager M and Manager N of Company B respectively). Following each case visit, these responses were then examined independently, as part of an iterative data refinement cycle.

This is shown as the lower half of Figure 0.2. Each set of responses were then checked and evaluated against the set of semi-structured interview questions defined, as well as the aims and objectives of the research. This equates to the “Read” and “Relate” stages of the data refinement cycle. Based upon the responses recorded in notes, transcriptions would then be either rejected outright (the "Reject" step); flagged to be discussed and resolved with the participant (the "Resolve" step); or selected to be included as part of the complete dataset (the "Representative" step). In the case of resolving data, inadequate or inconsistent responses or noted behaviour (such as 'did not make sense' or 'elusive answer – follow up') were primarily resolved by revisiting the participant, in order to clarify their responses. This occurred on several occasions, both within Company A and Company B, the latter case involving the clarification of the aspect of responsibility for the ISE decision making task. Subsequently, if the response data was still of low quality in terms of the fact that is was not justifiable and verifiable against the focal theory, it was then not taken into consideration as part of the overall case data. This process continued until sufficient case data was collected in order to begin an evaluation and synthesis against the focal and background theories.

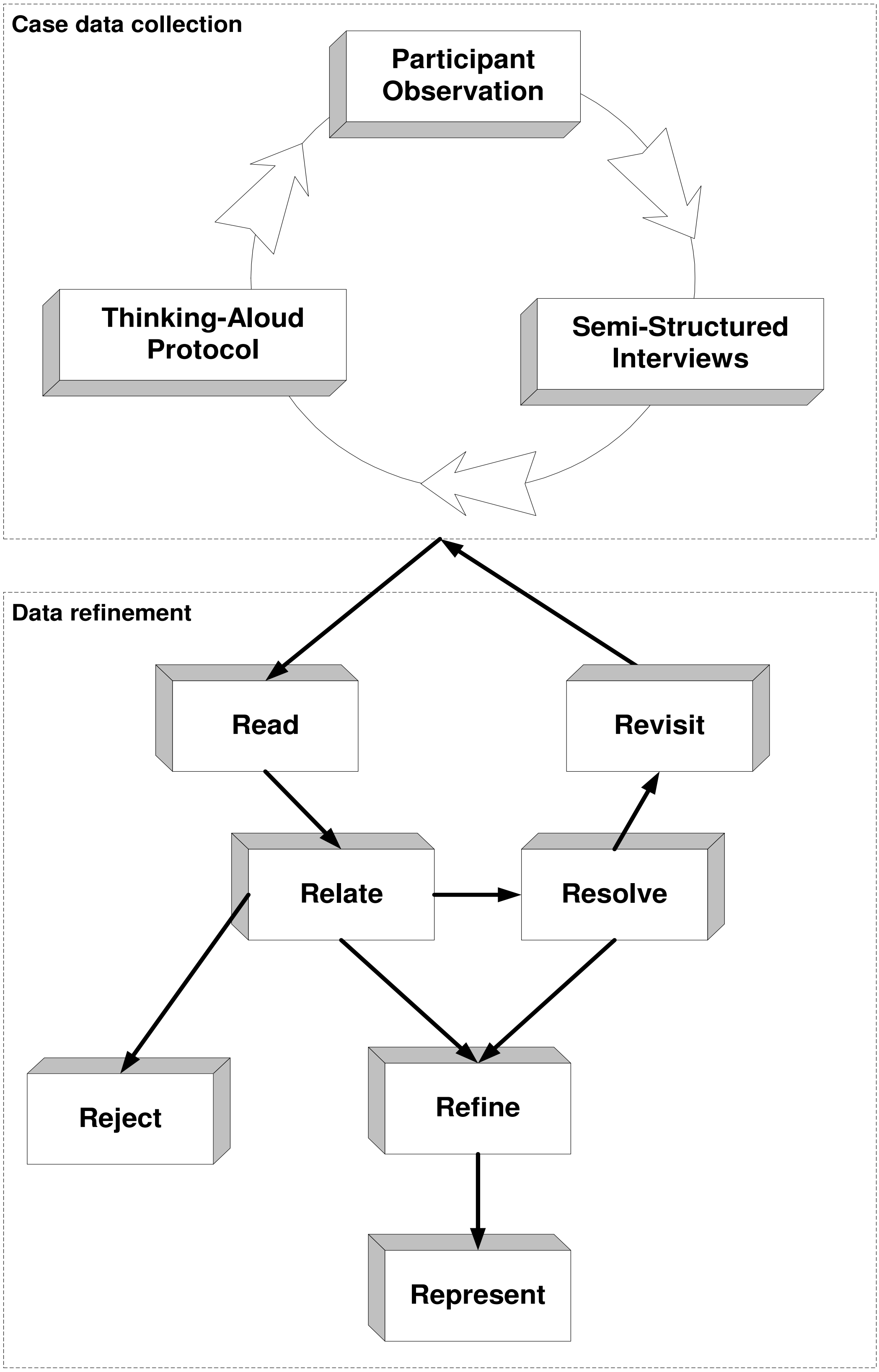


Figure 0.2 Case data collection (research protocol overlap) and Case data refinement cycle (triangulation)

Research design model

Hence, in the context of the research presented within this dissertation, and in the light of the reviewed literature, hypotheses raised, and the selection of a research methodology, Figure 0.3 shows the complete context of the research in detail, in terms of the research design. This is in terms of Yin's view of the research design: "how" the research will be carried out; "why" the research question is important; and "what" conclusions can be drawn from the data analysis phase of the research.

The purpose of the research study, is primarily to explore, and identify specific drivers for explicit to tacit knowledge transfer, within the two manufacturing IS case studies already outlined. Hence to provide a frame of reference for knowledge representation within manufacturing IS environments. Within this research, two research themes have been identified, based upon the extant literature surveyed within the background theory (via Chapter 2), and the generation of a conceptual framework (in Chapter 3). The purpose of the data collection and data analysis chapters is therefore to test these conjectures in practice, against the framework given in Figure 3.7 and Table 3-1 (in Chapter 3) avoiding encountering and duplicating the work of other researchers in the field, by asking pertinent, context-based questions.

As shown in Figure 0.3, for the purposes of the research presented, an empirical, interpretivist case study approach will be undertaken, with the resulting *analysis* of the case study data being carried out in an interpretivistic sense. Using qualitative sources of evidence from case study participants within Case Study 1 and Case Study 2, the research seeks to develop a frame of reference based upon an evaluation of the case data in the context of the knowledge transformation framework given in Table 3-1 and Figure 3.7 in the focal theory in Chapter 3.

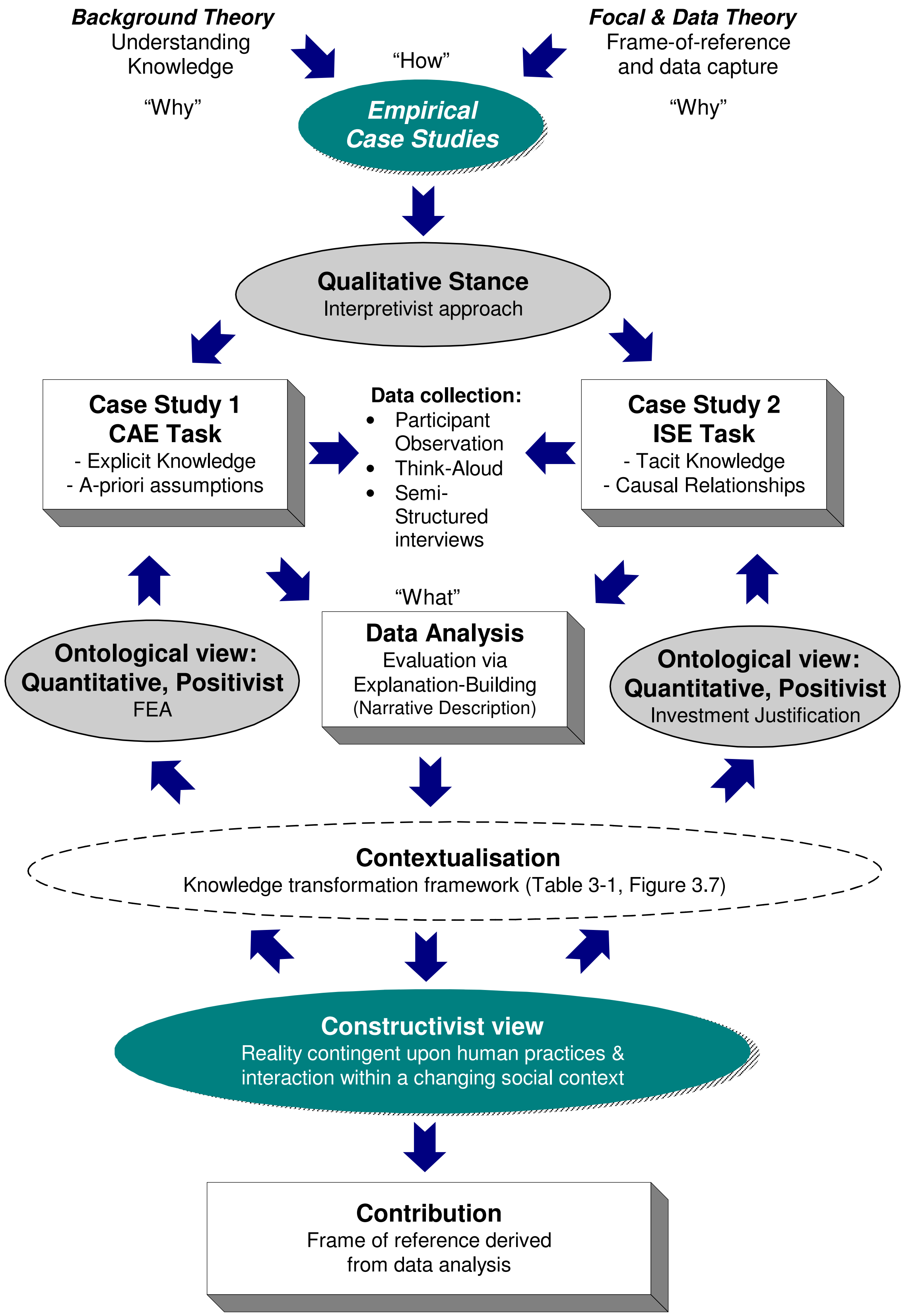


Figure 0.3 Research Design detail for dissertation

The research also develops a multitude of epistemological models of knowledge within organizational and manufacturing contexts, previously derived by the author, in the course of the research in this dissertation. The primary available source of information were through semi-structured interviews, participant observation and interpreted personal experience of domain experts within the fields of product design and IT/IS evaluation, in terms of a descriptive discourse. Thus, in Quinn-Patton's terms approach used was primarily explanatory in nature. The resulting data analysis approach taken, was in narrative form, against the elicited data (Miles and Huber, 1994) where the case data was evaluated and classified in terms of factors for knowledge transformation outlined in the focal theory earlier (Table 3-1 and Figure 3.7 in Chapter 3): Socialisation (Philosophical driver); Externalisation (Behavioural driver); Combination (Systematic driver); and Internalisation (Psychological driver). In summary, in order to define the research process and research design discussed earlier, the author uses the categorical research design "building blocks" model, as used by Hjertzen and Toll (1994) in Table 0-1.

Table 0-1 Summary of research components – a research schema

Research Component	***Detail***
Scope and period of study	• Organisational context - Case study participants : adhoc "snapshot" in time over 2 months
Philosophy	• Interpretivist (Qualitative) (with a Constructivist Ontological stance taken for framing the data sources, i.e. nature of tasks based upon Quantitative, explicit knowledge)
Methodology	• Empirical Qualitative Case study to test the theoretical framework (given in Figure 3.7, Chapter 3)
Data Collection	• Background theory / literature survey; • Purposive sampling (selection of case participants who have relevance to the context of the research); • Documents (case company description; participant details); • Direct Participant Observation (full participant, overt observation, fully explained, several observations, time bound and predetermined); • Think Aloud protocol (walk-through of CAE and ISE tasks); • Semi-structured Interviews (conversational style; filter questions used)
Data Analysis	• Explanation-building (i.e. narrative description): iterative refinement of the focal theory – knowledge transformation framework; • Methodological Triangulation technique adopted to validate and verify the data gathered

This tabulation or schema, allows the researcher to specify the focus of the research design along dimensions of methodology, information source, purpose, scope, time and type of data.

The definition of such a schema therefore also makes the eventual comparison and analysis against the research hypotheses easier.

Summary

This chapter has defined how the research within this dissertation is to be carried out. The overall research process, followed that of Mumford (1985), wherein the components of research design, methodology, data collection and data analysis were defined. These were in relation to the generation of two research themes, based upon a review of the literature in the field, and the selection of an empirical case study research methodology, as defined by Yin (1994) and Walsham (1993). The data gathered was via interpretivist instruments of direct participant observation, semi-structured interviews and verbalisation techniques (the Thinking aloud protocol). Further to this, the analysis of the data was carried out in a qualitative manner, using iterative refinement to collate and evaluate the case data against the research questions and the focal theory defined earlier. This was carried out using the narrative, explanatory form of data analysis against the focal theory conceptual framework (Figure 3.7 in Chapter 3). Furthermore, the importance of validity, reliability and triangulation approach was discussed and specified for the case studies within this dissertation, as being a combination of the three protocols described earlier. Finally, a table summarising the key components of the research approach in terms of a research schema (Hjertzen and Toll, 1994) was also presented.

Chapter 5

KNOWLEDGE WITHIN THE CAE TASK

In attempting to provide an insight into how knowledge is used and represented in a manufacturing information environment, this chapter describes a case study relating to the use of a Computer Aided Engineering (CAE) information system. This highlights the information flow and dependencies on key CAE tasks, by describing the steps involved in a typical design and analysis process for the modelling and design of photonic waveguide devices.

Knowledge within the CAE task

This chapter describes in detail, the impact of information and knowledge in computer aided engineering (CAE)-related tasks. As such, the purpose and nature of this chapter is to provide an insight into knowledge requirements for explicit decision-making tasks, which are reliant or dependent on tacit, or inherent knowledge. This is achieved by presenting collected case data where the focus of the observation, is to describe and then to highlight the analysis and modelling tasks associated with the design of photonic waveguiding devices via the specified research methodology protocol for data capture as outlined in Chapter 4. The reader is referred to Chapter 3 for a more detailed discussion of knowledge issues within CAE and the main texts on CAE within photonic waveguide design (such as those by Fernandez and Lu, 1996 ; Hunsperger, 1991 ; and Silvester and Ferrari, 1996). Through the observation and description of the typical tasks encountered and carried out by a domain expert, the remainder of the chapter then outlines, specific knowledge components which are inherent in the modelling and design task. Finally, the chapter concludes by comparing the case study findings with the focal theory defined in Chapter 3.

Background to the case

The case study presented, is used to describe and define the range of knowledge-based processes that are involved in carrying out the task of designing optical waveguides, via an empirical approach. The research protocol used for this is as has been explained in Chapter 4 and outlined in detail in Appendix A. This is in terms of the approaches of Participant Observation, Think-Aloud protocol and Semi-Structured Interview techniques, as defined by Ericsson and Simon (1993), Mumford (1985), Quinn-Patton (1986), Walsham (1993) and Yin (1994). In doing so, the basis for the case study centres around observing the approach to modelling and design used by an electrical engineer within a research and development department of a high-technology electronics organisation, which will be referred to in the text as Team A, User X and Company A, respectively. Company A is an electrical and electronic engineering organisation, which has a workforce of 1400 and an annual turnover in excess of £5 million. Company A specialises in producing microelectronic fabricated devices for a variety of applications, from healthcare through to defence. One of the specific product lines which the company is involved in, is in the design and manufacture of laser-based switching devices (photonic waveguides). Within the research and development (R&D) division of the company, there are approximately 30 or so professional electrical and design engineers who work together to produce these high technology devices, as have been described in Chapter 2 and 3 of this dissertation. The knowledge and skill set required by the personnel in this department is typically based upon 10 or more years of practical experience as well as theoretical, academic knowledge also (typically to Master of Science level). Team members have to have undergraduate qualifications in electrical and / or electronic engineering, with team leaders and managers expecting to have postgraduate qualifications as well (including up to doctorate level) and / or relevant experience in the field. For those managers and technical experts wishing to, the Company A also encourages and supports its employees to achieve Chartered Engineer status as well.

In attempting to investigate the specific knowledge requirements which are needed within the design and production facets of a manufacturing organisation, Company A was chosen not only as a result of the availability of a high technology manufacturing organisation to expose its operational workings, but also for its dedication and consistency to adopting an integrated design-to-production approach. By this it is meant that the company fully supports and empowers all those involved in the design of its products, to utilise knowledge and information across the organisation as appropriate.

The knowledge tasks that have been recorded as part of this case study were via an experienced and professionally accredited (Chartered) Senior Electrical Engineer, who shall be called User X for the remainder of this dissertation. User X is a team leader for the waveguiding devices division of Company A (Team A), and has 15 years experience within the field of electromagnetic device analysis and design, including a number of years service as an academic researcher too. He manages and works with a small team of 4 R&D engineers, and also works alongside the production manager for the department also. Team A, which User X heads, essentially is a R&D modelling and design team. As such, the Team A also interacts closely with both the upstream electromechanical components programme team (to be known as Team B) and the downstream product prototyping and test team (to be known as Team C). User X has also been involved in investigating tools and techniques which can assist and aid him and members of his team to carry out their design and analysis work in a more productive manner. It is for this reason that this particular engineer was also chosen to be observed. However, it should be bourne in mind that in this case, User X is atypical of most types of CAE user which have been identified in the literature, such as in Szabo and Actis (1996), and the reader should be aware that this constitutes an introduction of an additional data variable in terms of the capture of case data (in terms of the effect of User X on the CAE system, due to his proximity and overall expertise with this form of IS).

Bearing this in mind, the stages involved in the design and modelling task which User X and his team are routinely involved with, loosely correspond to the CAE and FEA lifecycles, as highlighted in Chapter 3 previously. The preferred method of capturing the design and modelling tasks were to primarily record actions and design decisions taken by the engineer, at various stages of the modelling process. After each set of tasks were carried out using the CAE system, these recorded actions were then recounted back to the engineer, whereby further detailed insights into the respective knowledge and information required via a semi-structured interview approach.

Since the outcome of the case study was not specifically to validate or falsify pre-conceived notions of knowledge use and application, the approach taken was to observe and feedback the actions and decisions of User X, without influencing the decision making choices of the latter. Thenceforth, attempting to contextualise the observed and noted phenomena. Hence the approach to use participant observation. Furthermore, since the target of the case study had very specialist domain knowledge, it was deemed that the use of the verbalisation technique known as the Think-Aloud protocol (Ericsson and Simon, 1993) would be suitable in order to capture and reflect on the design decisions taken. In this respect, the observations which were fed back to User X, were carried out in order to contextualise each task in terms of the process by which he was using his expert knowledge.

In observing User X, it was apparent that there was a specific set and subset of tasks that were typically carried out in order to progress with the modelling operation(s). After recording a number of modelling tasks for waveguide designs which were specified to a number of different requirements, a generalised series of knowledge tasks were then formulated. Due to the fact that the design task is based heavily around a traditional, theoretically-grounded engineering design approach used to model waveguiding devices, it was even more important to capture the information and knowledge flows through each task, as clearly as possible.

These can be loosely categorised along the lines of explicit and tacit knowledge (as per Nonaka and Takeuchi, 1995), although there is a significant amount of overlap between these. As such, the following sections describe specific instances of each of the steps taken by User X, in terms of explicit and tacit knowledge tasks.

Overview of the CAE system: ANISO3

Company A employs a varied IT/IS infrastructure across its organisation, which includes financial, accounting, Enterprise Resource Planning (ERP), and Computer Aided Engineering (CAE) systems. Specifically within the Waveguiding Devices R&D department, engineers have access to a combination of Unix-based workstations as well as desktop personal computers. In the former case the machines are used for the primary waveguide design, modelling and analysis simulations whilst in the latter case, desktop personal computers (PCs) are used for secondary design analysis and report writing (spreadsheet and word processing software). These machines are also used in order for the team production manager to have access to the ERP production management module, as well. A high-level schematic of the organisation's IT/IS infrastructure is shown in Figure 0.1.

Specifically, the CAE system (ANISO3) is available to the design team via the networked UNIX workstations and has been derived out of various application software and bespoke code that was written in-house, and subsequently developed by User X as part of the generic development of photonic device CAE software.

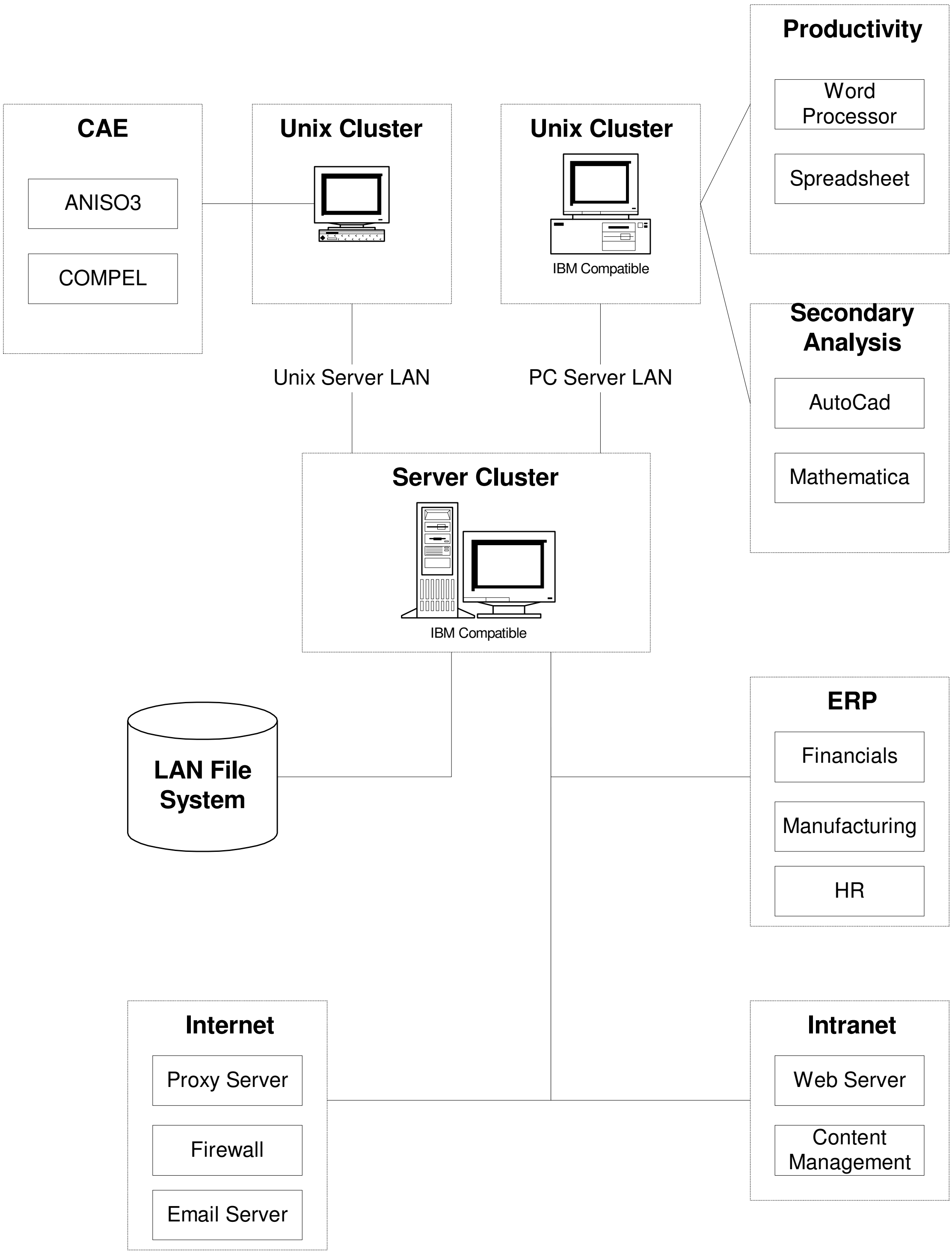


Figure 0.1 IT/IS infrastructure within Company A

The package consists of a generic point-and-click, graphical user interface which allows the engineer to draw the waveguide geometry on screen, much like in many commercial automated design applications. Once the basic geometry of the waveguide model has been defined, the user can then prescribe boundary and constraint conditions, such as material characteristics of the chosen device, radiation dispersal modes, etc. The final stage of the modelling process is to define the method of result output – this can be either in the form of the superposition of the electromagnetic field dispersal directly on the geometry so defined, or output as numerical data for graphing purposes. Following the definition of the model in such a manner, the application then also provides the user with the ability to execute a simulation of the behaviour of the waveguide device. The algorithm for this was also written by User X. As such, it should be noted that this implies the introduction of an additional variable into the case data, since User X was responsible for developing the software (and thus being influenced by his explicit knowledge of how it works). Once the simulation has been run, the results are then displayed in accordance with the user preferences defined earlier.

Interview responses

The following sections outline and describe the collected data resulting from the field study research through the empirical approach as described in Chapter 4 and in Appendix A. As such, the author attempts to segment the data along the lines of both explicit and tacit knowledge forms. The protocol used within this approach, was primarily participant observation-driven, which was supported via verbalisation techniques, as well as using some of the filter and specific interview questions detailed in Appendix A1.3.2.

General observations regarding waveguide design

The predominant responses from User X, suggested that most of the work which was carried out in order to design and modify waveguiding devices, relied upon individual / self knowledge, as well as information which was gleaned from other members of the team, published data, internal specifications and the internet. In terms of the level of knowledge that was required in order to use the IT/IS within Company A by the engineer and his team members, it was noted that the average level of work that was being carried out required a fairly high level of competence with regards to not only using the CAE software (appreciation and working knowledge of CAE / FEA codes, intermediate and / or advanced grasp of the

Unix operating system), but also interpreting the results from its output (knowledge and appreciation of the effect and impact of FEA error tolerances, comparison with theoretical / textbook-derived results). However, User X commented that whilst having such general knowledge was very useful to the demands of the role within the team, the main contributory level of knowledge was that of having a deep working knowledge of electrical engineering principles:

> *"I would say that we are, first and foremost, physicists first, engineers second and computer scientists third. Not only do we need to know what we are doing in terms of designing or modifying an electromechanical component, but we need to know why too. So I try to encourage others to look beyond the problem – to look at the why and the how of the problem, and see where we have gaps in what we know; that is the trick".*

User X also stated that since the team was highly specialised and focussed towards their particular area, it was typical for them *not* to share information and knowledge across teams, unless it directly affected the work of others (such as the testing team, Team C). This was largely due to the fact that in some part, Company A still adopted an "over the wall" design-to-manufacture approach, where specifications and the resulting delivery of a design would be passed between teams with little collaboration. This rigidity of the corporate culture in terms of the R&D component of the enterprise, meant that it be interesting to see how knowledge required in such a typically collaborative process, was being used in almost an isolated sense. Following on from these questions, further responses were elicited regarding the use of knowledge within the CAE task itself, as given in the following sections.

Explicit knowledge factors driving the CAE task

In terms of carrying out the design and / or development of a waveguiding device, User X first of all commented on the need to carry out preliminary scoping and understanding of the design specifications and change orders (if any), prior to being involved with the modelling task. These loosely correspond to the FEA procedure shown in Chapter 3. In terms of this chapter, User X was observed defining requirements for 4 waveguide geometries (as shown in Appendix B, Figure B1). These designs were being investigated to be used as part of an optoelectronic switching component, for a laser-based measuring device for use in diagnostic healthcare.

Prior to modelling the design using ANISO3, User X had to scope and decide upon the specific characteristics of each candidate device design with his team. The overall specifications for each waveguiding device are largely dependent upon the general technical requirements for the electrical component within which the device will operate (in this case a laser measurement tool). The selection of the appropriate modelling features of the entire electrical component needed to be carried out also.

The process followed in this regard is shown in Figure 0.2. First of all, for the range of candidate geometries that User X was designing, the material and surrounding environment characteristics (i.e. the dielectric), had to be chosen. Each type of dielectric has particular qualities which are used for different forms of electromagnetic field application (e.g. waveguide situated in an air or air-gas mixture environment).

Since the effect of using particular material dielectric effects the overall electromagnetic field dispersion characteristics and the performance and capability of the waveguide, the selection of the right material is largely trivial and is based upon the required electromagnetic field response required. Thus based upon the overall design specification for the measuring device for which the waveguide was to be a component part, User X chose dielectric materials based upon previous experience and sometimes was observed consulting academic published literature results for geometries and devices with similar characteristics.

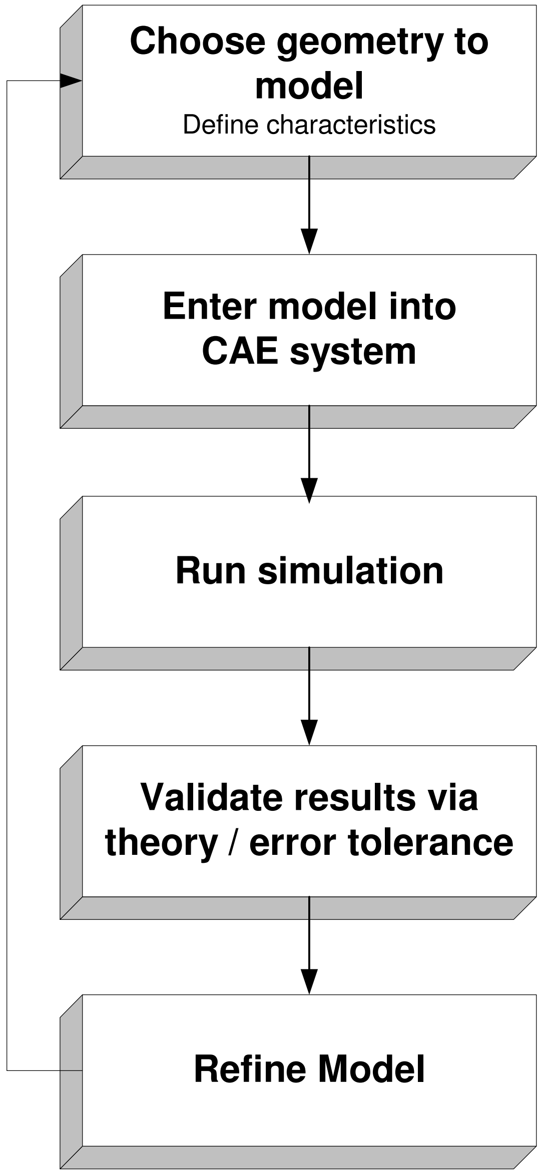


Figure 0.2 CAE design tasks within Company A

Also as part of the pre-modelling phase, User X had to liase with programme Team B (Electromagnetical Components team) in order to take into account additional requirements for the integration of the waveguide with other micro-electronic components which were being prototyped for the measuring device. This again, required User X to include additional specifications into modelling requirements for the waveguide at an early stage. By gathering this information (and in the case of agreeing and deciding upon a material dielectric, gathering data), User X and his team were able to define an overall specification for the waveguide to be modeled. Following this brief definition phase, User X then proceeded to use the CAE system to input these characteristics. In the first instance, User X used the schematic tool in the ANISO3 package to draw the waveguide geometry. As each region of the waveguide is defined, the package prompts the user to define material characteristics and any other additional design constraints for the guide. After this was achieved, User X then defined how the results of the simulation tests should be displayed, by selecting the option within the package to display the computed electromagnetic field dispersion directly within the drawn and defined waveguide geometry. The last step was to define the required error tolerance for the computed results, which would be based upon the finite element method (as described briefly in Chapter 2). This tolerance describes the accuracy to which the simulation results should reflect the actual characteristics of the interaction between the waveguide and the surrounding environment within which it would be placed. The higher the tolerance (i.e. a smaller number), the more accurate the results would be computed to, but at the expense of increased computation time (as the accuracy the finite element method would be using, would be much higher).

Following this, User X was then able to run the simulation and based upon the results obtained, adjust the input model accordingly. When prompted about the manner by which these steps were undertaken and whether or not this was always a consistent approach to take, User X commented:

> *"Yes it is quicker to do it this way, especially if I know the characteristics that the Magnetics team [Team B], want, and the overall design of the device (you know - things like the housing for it, input power, heat dissipation, that sort of thing). So I always start with looking at the big picture: what is it that we need to build here? Have we not produced this sometime before? If so, let's use the same approach, the same design, for speed."*

Coupled with this, was the fact that User X had primarily been involved in the design and development of the ANISO3 package himself, he highlighted that continued successful modelling of guiding devices was only possible largely due to this in-house developed code. The software had been specifically written to be flexible and capable of being customised and tuned to the changing needs of the design situation. Hence, an explicit understanding of the workings of ANISO3 was crucial to User X and his team's working practice and ethic.

Tacit knowledge factors driving the CAE task

It was observed that although the explicit knowledge tasks were part and parcel of the typical CAE design and analysis lifecycle, there were aspects of the approach used by User X, which did not seem to utilise explicit knowledge *per se*. As such, it was seen that whilst the engineer defined the waveguide features and ran simulation tests, using very clear facts and requirements, the remaining tasks of analysing and optimising the waveguide model used knowledge which was difficult to elucidate in an immediate fashion.

For example, when faced with a non-standard geometry such as the dispersion guide shown in Appendix B, Figure B1, User X was observed to immediately begin to comment on the approach that would be needed to model the guide. This would involve considering each portion of the guide in isolation and then through gathering each constituent part of this broken-down or simplified geometry, applying the design steps as before. When asked to justify this approach, User X commented that it was "only natural" to decompose the problem in the simplest and quickest way possible. In another example where the constraints on the model's specification were defined very specifically (in this case having to limit the dispersal of the electromagnetic frequencies to a very localised area), User X was observed to begin to define additional modelling parameters via the ANISO3 package that were not immediately evident in the specification given to him. The reason for this lay in the fact that the ANISO3 package was limited in how accurately it could model these parameters (i.e. the boundary conditions). Hence, some level of heurism and empirical knowledge was seen to be used in order to overcome the limitations of the CAE package.

Following the execution of the simulation tests of each waveguide geometry in order to display the electromagnetic dispersal characteristics, User X had to assess the visual results of the tests. Based upon the error tolerance defined earlier in the modelling phase, the results would have to be interpreted relative to this criterion as well as to the ensemble effects of the characteristics of the waveguide. After observing the 4 waveguide geometries modeled by User X, it was seen that after the display of the initial computed results on screen, User X immediately began to carry out a modification to the waveguide model. Notably, for one of the guides designed, the single ridge / channel guide of a layer of lithium niobate and gallium arsenide substrates within an air medium, User X commented:

"This looks good – although I don't believe this is 100% correct. I would expect the dispersion to be homogenous across the section of the guide. There appears to be some fringing near the interface between the substrates. Looks like I have not drawn the boundaries between the two regions correctly - or the mesh the code is using is too coarse. Let me run that again."

After checking the defined regions for errors in definition, there appeared to be nothing wrong with the simulation model. Following this check, User X ran the test again and this time seemed to be satisfied with the result,

"…Ok, that's the result now. But it's not right – the dispersion should be more adhoc, not so smooth across the substrate interface".

On this occasion, there appeared to be nothing wrong with the definition of the model, although User X began to insist that something in either the model or the specification (or both) was wrong. After running tests on the remaining block, channel and dispersion guides, User X still noted that the resulting output was not what he immediately expected. As such, for the channel and dispersion models he changed the geometry in a subtle manner by elongating the upper and lower sections of the guide (i.e. reducing the overall wall thickness). This achieved a "better" result for him, although this led to each of these designs straying from the original specification. As a result of this change in geometry, the underlying material and dielectric characteristics also had to be reviewed and communicated to the upstream programme design team, Team B (in order for design changes to be recorded and ratified).

Likewise it was observed that whilst User X was involved in both entering model characteristics and modifying them in order to optimise the results to meet the specification, there appeared to be a change in the manner by which User X interacted with the package. In the preliminary stages of analysis of the simulation test runs, the engineer was observed to first of all examine whether or not ANISO3 was running correctly on the workstation. This was done in order to rule out any spurious workstation CPU and memory load which may have inadvertently affected the simulation. User X saved his work and closed the application and re-started the software package after checking network and the UNIX workstation performance. In addition, he loaded a pre-defined waveguide test model and ran a sample simulation test which was successful. Following this check, User X was satisfied there was nothing wrong with the application code itself and instead checked the display (output) parameters for the simulation he had entered. After verifying this was correct, he then began to scrutinise the model parameters and characteristics defined (material dielectric, error tolerances), several times double checking the geometrical layout,

> *"…just in case anything has changed, between me setting up the model and running the test".*

The design specification was also checked with another member of his team. This involved examining the requirements documentation and also verifying the specification with Team B (the programme team). On another occasion, User X was himself unsure as to whether or not the method by which he was modelling the waveguide was correct or not. This became apparent through the fact that all other checks had been completed and the engineer was still not satisfied with the result he was seeing on the screen, and was seemingly at a loss as to how to proceed further. Later, when asked about this apparent lack of certainty of decision, he commented:

> *"These devices, although they look simple enough to design, are not easy to evaluate, when it comes to assessing the test results. There are so many factors to consider – dielectric, substrate composition, resonant properties of the guiding wave through the medium – all of them closely related to each other. So when I see results I don't trust, and everything else looks right, I wonder whether I am thinking about the problem in the right way …".*

Almost in answer to this statement, User X then further highlighted the importance of having access to previous design solutions in order to validate simulation runs. This was noted as being a combination of a design repertoire of earlier designs the team had worked upon via previous logbook entries, as well as published test results of other forms of waveguiding device available in electrical engineering journals.

Summary

This chapter has described case study observations and data relating to how explicit and tacit knowledge is used within an IS manufacturing environment within a hi-technology electronics organisation, Company A. This company manufactures a wide variety of products, such as photonic waveguiding devices which typically require expert knowledge to be designed and manufactured. As such, the case analysed the design and analysis tasks undertaken by an experience chartered electrical / electronics engineer, User X. This was in relation to the knowledge required to use the in-house CAE system, ANISO3, which was used by User X's team to carry out the design and analysis of the said waveguiding devices.

In capturing the case data, the research protocol employed involved using a combination of semi-structured interviews to elicit responses from User X, as well as general participatory observation techniques. As a result, the "think-aloud" protocol was also employed to verbalise specific responses.

It was found that, in general, the level of knowledge required to utilise and model photonic devices, was based primarily upon expert domain knowledge and experience. This is to say that not only was there a need to have a working knowledge of the CAE system, but also an in-depth appreciation of the electrical theory and the overall design-to-manufacture process. Specifically it was found that explicit knowledge could be characterised as being that knowledge which could be derived from an understanding of the engineering and manufacturing requirements, *vis a vis* the overall CAE modelling process (as shown in Figure 5.2). This knowledge also encompassed an understanding of the interplay and dynamic between both User X's team and the other work teams in the same division.

On the other hand, it was found that tacit knowledge manifested itself predominantly in the optimisation and analysis phase of the CAE modelling task. Here it was found that tacit knowledge in the form of specific domain knowledge (knowing how a set of results from a simulation run should look), was supplanted by heuristic information in terms of how to use and manipulate the CAE package.

Thus, of the two types of knowledge encountered and observed, it was noted that the usage of the former type of knowledge, was almost trivial in nature (i.e. specification of requirements for defining a waveguide to be modeled). However, the tacit knowledge used to optimise and modify the modeled waveguide was much more difficult to describe, even after feedback of the observed behaviour of User X.

CHAPTER 6

KNOWLEDGE WITHIN THE ISE TASK

In order to investigate how knowledge is used and represented within a manufacturing IS environment, this chapter now provides a case study description of the IT/IS investment appraisal, hence IS Evaluation (ISE) task, within a manufacturing organisation. The case study attempts to highlight explicit and tacit knowledge components of this process, in relation to specific managerial decisions which were taken in implementing an MRP II production planning module.

Knowledge within the ISE task

This chapter describes knowledge dependencies associated with the investment appraisal of an information system, within a manufacturing organisation. In doing so, the case study attempts to describe both the explicit (direct) as well as tacit (indirect) knowledge components of the information systems evaluation (ISE) process. As such, the chapter outlines three conceptual models which elucidate the investment appraisal process. The first model, provides a scope for those implicit (i.e. tacit knowledge) ISE factors which were originally observed, but not made use of by the case study company participating. Following on from this, a functional representation of these appraisal parameters is presented in order to provide an overall view of the knowledge used within the evaluation process. These parameters are then used to produce a conceptual causal mapping model, based upon the concepts of fuzzy logic. Hence, this relates the direct resource costs and implications (explicit knowledge) with the indirect resource costs and implications (tacit knowledge), via a graphical representation. Finally, the chapter concludes with a brief comparison with the focal theory of the dissertation and a summary of the key findings from the case.

Background to the Case Study

The case study organisation (which shall be referred to as Company B), manufactures a wide variety of made-to-order parts, products, and assemblies, across diverse industries. Specifically, Company B is a privately owned, precision subcontract "job shop", with approximately 150 employees and a turnover of under £5 million. Because of its radical ideas on employee empowerment, and the implementation of continuous improvement processes within its manufacturing and production processes, the company has been the recipient of many accolades from academia as well as local government bodies (Donnelly, 1995; DTI, 1993). Company B has a make-to-order inventory policy, with most component parts having a very low level of standardisation and thus few common components. To produce these differing and often complex parts, a highly flexible production capability is required. This implies versatile manufacturing equipment, flexible employees, and a genuine need to maximise the utilisation of technology, to continuously improve and innovate, and to remain competitive in manufacture.

Therefore, clear communication and the integrity of information between Company B and its customers are necessary for responsive change. Company B's management team is lean, with few functional divisions and encompass the roles of: a sales and marketing director, a finance director, an administrative/general director (to whom the purchasing, human resource, and IT/IS functions report), and a manufacturing director (Irani *et al.*, 1997a; Irani and Sharp 1997).

The company's guiding philosophy forms an integral part of their culture, and drives the organisation forward. Culture in any company is the underlying belief that pervades the organisation about how business should be conducted, and about how employees should behave and be treated (Love *et al.*, 1998). The company culture reflects the vision of the organisation rather than the vision of a single leader, and has evolved over time, although core elements have been maintained. The company's core values and beliefs represent the organisation's basic principles, about what is important in business, its conduct, its social responsibility and its response to changes in today's competitive environment. Hence, the success of Company B's corporate culture can be attributed to a number of key enablers, which have formed the basis for organisational excellence Company B's core and non-core business activities. The success of the organisation has been based on its proactive application of Total Quality Management (TQM) principles and the development of an open culture that is able to adapt to changes imposed on its internal and external environment. It is upon this background, that Company B became involved in attempting to evaluate and appraise the investment of a new production planning and control (PPC) system. In carrying out research within this thesis, key managers in the IT/IS investment appraisal process, were interviewed. These were specifically, the Managing Director (Manager M), and the Production Director (Manager N). The following sections now detail the observation of the sequence of events which were observed, before, during and after the evaluation process was carried out.

Interview responses

As in Chapter 5, the following sections outline and describe the collected data resulting from the field study research through the empirical approach as described in Chapter 4 and in Appendix A. Once again, an attempt to segment the data along the lines of both explicit and tacit knowledge forms, is made. The protocol used within this approach, was primarily driven by semi-structured interview questions (via the use of filter and specific interview questions detailed in Appendix A1.3.3), and was further supported via participant observation.

General observations relating to the IS Evaluation task

In carrying out the field study for Company B, the main area of interest to note was that of the organisation's interest and dedication to maintaining its business, via continuous investment and organic growth. In particular, the investment in information as opposed to solely manufacturing technology itself, was seen as a new *de rigeur* behaviour within the eyes of management, and certainly Manager M fully endorsed and supported this.

He mentioned that in order for the company to remain ahead of its competitors and secure further contracts, the introduction and maintenance of IT/IS was becoming an increasingly important aspect of the organisation. As such, the adoption of manufacturing resource planning (MRP II) was seen to be a core component of the development and evolution of the firm towards that of being an agile, world-class manufacturing organisation (Goldman *et al.*, 1995). Furthermore, since this goal was effectively part of the mission statement of the company, the stakeholders of IT/IS ranged from the shop floor right up to senior board level. This was due to the fact that the impact of IT/IS within manufacturing, especially within such an organisation as this, had a direct and continues to have, a direct impact on production.

As far as the evaluation of the vendor PCS solution was involved, Manager M was asked about the evaluation process they carried out, and the resulting information that they used to support their decisions along the way. In the former case, the approach was based loosely around the tender process : (i) identifying the need for an integrated MRP / PPC system that would complement the existing working practices and setup of Company B; (ii) a request for information (RFI) document was created and sent out to software vendors to gather software-specific information; (iii) an initial shortlist of vendors was drawn up based upon the RFI responses; (iv) a request for proposals (RFP) document was then sent out to the short listed vendors, in order to gain a more detailed and specific response to the needs of Company B; (v) responses from the RFP were gathered and another shortlist of vendors was made; (vi) the vendor was chosen from the shortlist after further discussions with them, and a contract for implementation of the system was signed.

Thus, the resulting PPC system was sourced from a software vendor, Vendor Z, after an appraisal of these MRPII system vendors. The core software function bought from Vendor Z, was the Production Control and Scheduling (PCS) module, together with other supporting modules. Additional functions were also considered by the system selection and implementation team but later rejected due to the software having a poor user interface, high cost, repetitive data entry process and a perceived poor effectiveness in the planning and controlling of jobbing shop production.

The system selection and implementation team also identified a need for a tool management module, which was later purchased from a secondary software vendor. When questioned further about the factors which may have potentially guided this evaluation approach, Manager M was of the opinion that the essential set of factors were centered around how such software could enable Company B to maintain its competitive advantage. In support of this, there was a desire to evaluate products such that production costs could be made more transparent. Thus, the overall production process could be made more efficient and in some sense, it was hoped, leaner and thus agile too. Manager M noted that due to previous successes at evaluating capital goods and products for the company, the same approach should have achieved a successful result also. Through involving the rest of the management team, it was also hoped that specific management responsibilities and requirements could be applied to the evaluation of the MRP system also. Thus, in attempting to understand the nuances of the ISE of the MRPII, the author now highlights responses from both Manager M and Manager N which can be said to be either explicit or tacit in nature.

Explicit knowledge factors driving Investment Appraisal

Company B has in the past boasted of its dynamic approach to the discrete manufacturing business, in terms of its overall agility and information management capability. As such, manufacturing lead times are typically short, ensuring that throughput production flow is maximised. When there are changes in the requirements of customers or the marketplace, Company B is able to respond in an effective manner by re-tooling or re-equipping their production facility.

This capability to redefine the essentials of the manufacturing process on almost an ad-hoc basis also relies upon the effective and judicious choice of manufacturing technology systems. As stated previously, through previous successful experiences with IT/IS investment, the directors of the company were motivated to evaluate and introduce a computerised PPC (production planning and control) system. However, unlike other 'smaller' investments, the driving force behind this project was from Manager M, who ultimately sanctioned all investment decisions. The success of these previous investments in tooling and machine technology on the shop floor, had allowed management to realise that there were tangible benefits to be had in terms of investing in the most current technology available. When asked to evaluate the perceived impact of the proposed PPC system, he replied:

> *"The scope of benefits from investing in IT appeared enormous, and has only been restricted by my imagination. I was the main visionary leader and could see the long-term strategic implications of my decision to invest. I was sure the benefits would far outweigh the costs."*

However, there appeared to be other factors involved in this investment:

> *"We were under significant pressure by our customers to offer year on year cost reductions. So, there were risks associated with not utilising new technology to provide a competitive advantage."*

The range of benefits identified as part of Company B's CBA was categorised by management into three classifications: strategic, tactical, and operational benefits. However, only the direct financial costs, were used within the appraisal of the system (Irani *et al.,* 1997d), as amongst members of the firm's management, it was generally agreed that controlling these costs would allow the company to maintain its competitive advantage in the most effective way possible.

Tacit knowledge factors driving Investment Appraisal

Whilst involved in the appraisal of the MRPII software for Company B, it was observed that Manager M adopted an almost "laissez-faire" approach to carrying out the appraisal. It was later found through further discussion with this individual that the reason for this was that such an appraisal of an investment would not constitute a major issue for the firm, as it was an integral part of running the organisation. When pressed about what specific information he found useful within the ISE task, he was of the opinion that his own individual knowledge and feeling about the type and form of system required contributed heavily to the overall decision. This was even though the rest of the management team was involved and was consulted about the appraisal process. Although he did note that the contribution of individual knowledge from other team members such as that relating to production planning and control would be sought.

Another factor which was not bourne in mind during the evaluation process was that of knowing what the overall impact would be in terms of the additional stakeholders in the company. As noted previously, Manager M and indeed the rest of the management team were eager to create a widespread culture of openness and communication within the firm.

However, as the evaluation of the MRPII system, was largely taken as an intuitive, "gut feeling" by Manager M, the additional *known* but *inarticulated* factors appear to have been left out of the overall evaluation. This is most clearly seen as the failure to understand and the underestimation of the indirect or human costs of the investment. Manager M commented:

> *"I don't see this as being that much different from other capital investments we have made in the past. (Company B) has been successful at maintaining and ensuring that we get the best value from our technology and from our people."*

Hence, the non-direct costs such as those implied by training individual workers and manufacturing process (re)design in order to fit with and make best use of the new planning and scheduling IS system, was inherently assumed to be part of the day-to-day operational cost of the system. Company B's lack of a formal justification approach was because they had not previously invested in projects that could not be appraised using traditional techniques. In particular, major strategic benefits such as perceived market leadership, leader in new technology, promotion of an open culture, etc, although extremely important for the growth and survival of a firm, were not readily convertible into cash values. Previous investments in Numerically Controlled/Computer Numerically Controlled (NC / CNC) equipment had been financed through loan agreements, where cash flow projections and sensitivity analysis had been used to assess the impact and risk of the investment. However, Company B soon discovered that such accountancy frameworks were not suitable for investments with intangible and non-financial benefits, and indirect costs, therefore proving inappropriate for the evaluation of the perceived impact of MRPII (Manufacturing Resource Planning).

These issues together with a new and inexperienced management team that was unaware of the emerging appraisal techniques that could acknowledge, albeit subjectively, qualitative costs and benefits resulted in a simplistic Cost/Benefit Analysis (CBA) being used. Management's use of CBA allowed the listing of perceived project benefits and costs, however, no assignments of financial values were made to the implications identified.

This was due to the complexity, subjectivity and time-consuming nature of identifying and assigning arbitrary values, to intangible and non-financial benefits associated with the investment. Although the appraisal method used was subjective and judgmental, Company B employed much time and effort into identifying the range of benefits associated with the proposed investment in MRPII.

Company B was unable to calculate accurately the financial returns achievable, an 'act of faith' decision to invest was made. A technique which although in some quarters is noted as being inherently risky as it may precipitate and hasten insolvency (Kaplan, 1985), may well be required if no other methodology is available (CIMA/IProdE, 1987).

Implementation issues

During the implementation of the core PCS module, it became evident that the Vendor-supplied software system, required the user to fulfill the 'needs' of the module, hindering the effective representation of Company B's data. As such, issues involved with the redesigning of business processes (such as these), were sought to be avoided in order to limit further expense, time and disruptions to production performance.

Furthermore, these implications appeared as significant cost factors that had not been acknowledged within their CBA. However, the redesign of processes presented themselves as unavoidable, to achieve the necessary functionality for the effective use of the PCS module. For numerous other reasons, the introduction of the computerised PPC system proved more difficult than anticipated. For the first time, Company B had discipline, controls and procedures, with their PPC system producing route cards and operational planning. All of which were 'fully' traceable and dependent on accurate data. Employee resistance also proved to be a contributing factor towards the complexity of implementation. People openly blamed the IS when things went wrong. The production director was regularly confronted with "Work To" lists that had enormous amounts of seemingly meaningless data, and was ready to dismiss the system, and go back to the old manual way of PPC.

However, the production director was eventually convinced by the software selection and implementation team, who described how, computerised PPC was the only way forward. The team explained that the difficulties being experienced could be attributable to the lack of a suitable reporting structure and data format. Furthermore, they explained that the system needed time to 'settle down', and was the only way forward if the company's expansion plans for growth based on efficiency and effectiveness were to be achieved.

Company B's biggest problem was with PCS module from Vendor Z, which only worked well if kept supplied with a continuous flow of 'clean' data. However, if there was any 'hitch' in data recording, or accuracy, then the system became highly unstable. Therefore, the need to alleviate this problem led to the selection and implementation of a team to investigate the purchase of a Vendor Shop Floor Documentation (SFD) module. Further benefits resulting from the adoption of this system, would be improved accuracy with which PPC resource decisions could be made. Furthermore, the purchase of the SFD module seemed a natural progression towards achieving 'full' MRPII integration, and received the endorsement from Manager M.

However, none of the operational workforce had been educated on the importance of PPC. However, in hindsight, the software selection and implementation team regretted not educating the workforce. Furthermore, management attributed this lack of education and training towards the system not receiving the operational support necessary for its successful operation. Therefore, resulting in unreliable data that was reflected in the form of 'noise' in the Master Production Schedule (MPS).

The consequence of 'noise' in the MPS led to additional cost, falls in productivity, and loss of customer base because of inaccurate delivery lead-times being quoted. All these factors had a significant impact on the perceived success of the SFD module, and were not acknowledged as implementation issues during the adhoc justification of the system.

Responsibility of the ISE decision

It was at this point that Manager M, who was considered to be the project champion, turned his attention to a new project, appearing to have either lost interest, due to the lack of success, or being 'driven' by other organisational improvement initiatives. Responsibility of the implementation process was delegated to others, and it was envisaged that the well-established production director would take up the challenge. Interestingly, the production director was not a key member of the software selection and implementation team but operated as an honoree, which on occasions simply advised on technical issues, only when consulted. The Manager N, was therefore expected to take the lead, in his role as head of the production department. This new responsibility for ensuring project success of a 'half' implemented system, of which little consultation with the production director had been sought, was not readily welcomed. Although the production director acknowledged the contribution the PPC system was making/could further make towards the streamlining of the production function. He said:

> *"It was never my project. No one wanted to involve me...So I didn't want to get involved in it [the production planning and control system], even more so, when it was proving not to deliver the benefits sought".*

It is clear that the focus of the software selection and implementation team suddenly changed, from one of great expectation, to a process of blame apportioning – a behaviour well noted within the adoption of information systems, when change occurs (Paul, 1994; Paul, 2002). Many of the problems that 'real-time' shop floor data collection was intended to alleviate appeared to further complicate this technology. Manager N, in his defense, claimed that the failure of the SFD module was because:

> *"We had not sat down in the first place and formalised our systems...People were not informed of the impact the system would make on their job function(s)... nobody on the shop floor bought into ensuring the success of the system. They needed educating."*

Furthermore, it appeared that at this point, the software selection and implementation team reached a "stale mate". No clear direction could be decided, as there was no focused leadership within the team. Furthermore, the PPC software appeared to be dictating the need for a number of dedicated experts, to analyse, manipulate and control the production function.

This was not welcomed by the majority of the management team, who were trying to develop a corporate culture based on openness, through promoting the concepts of flexible, empowered teamwork. Hence, the adoption of such a system clearly did not have the operational support necessary for its successful operation. As a result, management, who were supported by the software selection and implementation team, advocated the development of a bespoke system, more suited to the idiosyncrasies of Company B's processes, and their perceived unique needs as a subcontract jobbing shop.

Summary

This chapter has presented the second case study within this dissertation, which was related to capturing data from case study Company B, in relation to the IS evaluation task it was involved in. Company B was described as being a manufacturing small and medium sized enterprise (SME), which manufactured a range of bespoke parts for a variety of industries and customers. Due to the diverse nature of their business, Company B therefore required and implemented a flexible and adaptive approach to investing in manufacturing technology (both on the shop floor and throughout the organisation). A key aspect of this flexibility was in the importance and relevance given to investing in IT/IS. As such, the chapter preceded to identify key IS selection criteria which the organisation was interested in, in order to highlight the scope of the decision task relating to the investment appraisal of an MRPII resource planning (and production control) system. As in the previous case study within this dissertation, the research protocol also used a combination of semi-structured interviews, verbalisation and observation techniques to gather the field data. Since the principle participants concerned were senior management of the company, greater emphasis was given to the use of the general as well as filter interview questions (as shown in Appendix A).

Following this, a historical account of the managerial decision flow in order to justify investment within a resource planning system, and the associated production planning components, was also shown. This highlighted a multitude of managerial factors, which largely centered on the knowledge and experience of Manager M. This knowledge, in the initial stages of the evaluation task was explicit, in terms of the known and well-communicated aspect of the firm's organisation goals and aspirations.

Specifically, explicit knowledge in this regard was seen as being that relating to purely financial investment appraisal techniques, based loosely around an RFI / RFP tender process from MRPII software vendors. Furthermore, the appraisal and decision to use the PCS module from Vendor Z was primarily driven by the visible features and benefits of the product, and the relation to the success of previous investment appraisal projects which Manager M had been involved in. In addition, Manager M noted the desire to keep production costs as transparent as possible. This was stated explicitly as a goal of the introduction of any MRPII and production planning system within the organisation.

In contrast, tacit knowledge was characterised and manifested itself mainly by the way in which Manager M carried out the remainder of the appraisal process. This was largely, once again, based upon his personal experience and knowledge of evaluating investments on behalf of the company. However, the behaviour arising from the usage of this knowledge, ultimately led to the negation of feedback from the management team around him. Because of this and the tacit assumption that the hitherto "known" explicit financially-based IA process was somehow infallible, Manager M overlooked the importance of indirect costs (namely human, training and other costs attributable to the impact of adopting new technology). These factors were found to be lacking within the IS evaluation approach taken, due mainly to a lack of a formalised justification regime. This was even though a specific financially-motivated (cost accounting and ROI) approach was taken. Also due to the inexperience of the management team at hand, an "act of faith" investment decision had to be taken, based upon a combination of both the explicit aim of finding a cost effective MRPII solution, as well as upon the tacit assumption that the IS evaluation approach would yield a successful result.

Subsequently it was noted, that as the selection and implementation of the system began to fail in terms of the project itself, the responsibility of the ISE decision and implementation was handed to Manager N. It was only then realised that the evaluation task had been ultimately driven by the idiosyncrasies of Company B and the associated influence of the investment appraisal experience of Manager M and the software selection team.

Chapter 7

Data analysis and Synthesis

This chapter discusses the implications of the case studies presented in previous chapters and through an analysis of the observed case data from Chapters 5 and 6. As such, the case-specific research threads raised within Chapter 3 are highlighted once more and evaluated against the collected data, via a narrative discourse of the study findings. The chapter concludes with the formulation of a frame-of-reference which elucidates the interaction between both explicit and tacit knowledge types within the IS manufacturing environments outlined. Finally, recommendations for further work are summarily proposed at the end of the chapter also.

Data Analysis and Synthesis

The preceeding chapters of this dissertation have attempted to show and outline the various facets of knowledge and how they are used and represented within two case study examples, within the manufacturing sector. In the light of the preceeding data collection for both the CAE and ISE knowledge tasks chosen to be reported upon, the purpose of the chapter is ultimately to analyse the case data, via a narrative approach, against the focal theory derived earlier. In doing so, the chapter starts by providing a review of the research methodology that was used in order to capture the case data presented in the previous chapters. The chapter also attempts to outline and define factors and issues which allow the author to present a frame-of-reference, for the knowledge representation within these manufacturing IS environments. The chapter subsequently concludes by presenting avenues for further work and research within the area.

Overview of the research methodology applied

For the purposes of the research within this dissertation, two case studies were conducted within manufacturing organisations within the context of the utilisation and application of IS. The case study approach was chosen, since it was thought to be an ideal method to investigate the rich and in-depth issues connected with the definition, usage and representation of knowledge within IS environments within manufacturing organisations. Such an approach has been supported by Yin (1994) and others such as Eisenhardt (1989), Rouse and Dick (1994) and Tellis (1997), who have stated that many information systems practices are difficult to investigate using only positivist approaches. Furthermore, the inherent difficulty in attempting to understand the implicit detail of knowledge between IS-mediated processes and stakeholders, is a limitation of purely Quantitative methods, which cannot address a holistic, real-world point of view (Rouse and Dick, 1994).

The research methodology involved the application of an empirical, qualitative case study approach, which consisted of a multiple protocol technique in order to elicit and capture data. This involved the use of participant observation, semi-structured interviews, the "think-aloud" or verbalisation protocol, as well as access to company documentation and additional conversations with personnel within each organisation to site the research. In total, 6 semi-structured interviews were conducted with knowledge or domain experts in the respective fields of Computer Aided Engineering (CAE) within Company A, and Information Systems

Evaluation (ISE) within Company B. As such, the research sample selected for this research study was derived from purposive sampling which allows the author to select suitable respondents who have the knowledge of the IS environment and the means by which IS and related processes are implemented and impact their organisation (Sarantakos, 1998). All interviews were taped and later transcribed by the author, amendments and refinements to the case data being carried out in terms of a methodological triangulation against the research protocol instruments (for example, evidence from semi-structured interviews were placed against verbalisation and observation notes taken). In cases where there were differences or discrepancies in the elicited information, either follow-up interviews were conducted or the participant was asked to re-iterate or explain their actions. This was also validated against their observed behaviour by the author as well.

The analysis of the resulting data, will now be shown in terms of an explanatory, descriptive narrative in the sense of a constructivist or human-practice / mental model assessment of the participant observation and interview data (Miles and Huberman, 1994). As such, the results of the foregoing analysis is thenceforth compared and discussed against the focal theory derived within Chapter 3 earlier.

Analysis of case study findings : comparison with Focal theory

As outlined in the previous section, the purpose of this chapter is to carry out the analysis of the data gathered during the field study research. Since the approach used to gather the data was based upon an empirical qualitative stance, the primary vehicle for this evaluation will therefore be via a narrative description. The vehicle for assessing and analysing the case data, will be to compare it against the focal theory developed earlier within Chapter 3 of this dissertation. As such, the data analysis within this chapter takes the approach of Yin, whereby the data is treated fairly, and analysis is carried out of the case data in order to derive conclusions from the data, and to rule out alternative interpretations (Yin, 1994, pp. 108 – 126). Hence the mode of analysis used is that of explanation-building (i.e. narrative description, Tellis, 1997), in order to refine and derive the focal theory model presented within Figure 3.7 and Table 3-1 in Chapter 3 earlier. This approach to analysis is now presented in the following sections.

Utilisation of Knowledge in CAE tasks

Through analysing and assessing the responses and the observations relating to User X within the first case study example presented in Chapter 5, the author shows an overview of the analysed data in Table 0-1, with respect to the earlier presented focal theory. The entries for the right hand side of this table are now discussed in further detail below. It was found that for this particular case, knowledge was represented within the modelling task in terms when there is supporting information and inter-related knowledge and tacitly when intuition is used.

Table 0-1 Comparison of Company A data with Focal theory

Knowledge Driver	*Expected finding*	*Case data*	*Actual Finding*
Environmental (Socialisation)	Explicit	Electrical Engineering theory; Design rationale	Explicit
Psycho-sociological (Externalisation)	Explicit	Inter-team dependencies (such as on Team B and C)	Tacit
Systematic (Combination)	Explicit	CAE package knowledge (ANISO3)	Explicit
Behavioural (Internalisation)	Tacit	Experience of domain expert, User X	Tacit

Although the underlying expert CAE knowledge was codified in terms of knowledge relating to electrical engineering and photonic waveguide theory, tacit knowledge was also seen to exist, inherently in terms of the *application* of this knowledge to the overall design / modelling and analysis process. Hence it can be said that in some sense, an overlap occurs between explicit and tacit knowledge within the overall task. Explicit, or as those in the expert systems community may mention, "surface" knowledge, was ostensibly used to guide decision flow; whilst "deep" or tacit knowledge was used to make adhoc, or intuitive decisions where there was little supporting information to make an explicit judgement (i.e. where team interdependencies played a role such as when needing to optimise the specification as defined by the upstream Team B).

An example of the former was in the modelling of the block guide, which User X commented to be a standard type of guide which is used in many electromagnetic switching applications. In this case, there was little or no modelling required, as the design for such a model has standard, documented characteristics. In the latter case, when modelling the dispersion guide, it was observed and noted that User X began to model the device, by assessing whether or not any models already existed for this geometry; subsequently, he made the decision to simplify his approach by decomposing the geometry into constituent parts, and making some initial assumptions about how each of these component parts would integrate and work together as a whole. Team members of User X were also observed to adopt the same approach although for the most part, the other R&D engineers would tend not to carry out a decomposition of the problem (rather they would go straight into modelling the whiles guide). In contrast, analysing the response of User X it can be seen that he also appreciates a holistic approach to utilising both his own personal knowledge, and that of his and other teams, when he states it is useful to "look beyond the problem…see the big picture".

This interplay of *a-priori* knowledge driving the decision making task, has also been bourne out by earlier published research by the author, in the area of artificial intelligence techniques within CAE (Sharif, 1997; Sharif, 1999a).

In general, such intelligent systems can provide assistance to problem-solving, decision support and process simulation (Gallopoulos *et al.*, 1994). The greatest advantage in applying artificial intelligence comes from taking advantage of the best aspects of each type of technology. This can be either via central control mechanism (an intercommunicating intelligent system) or via a common processing architecture (a polymorphic intelligent system) (see Goonatilake and Khebbal, 1994; Jacobsen, 1998). A key feature of intelligent systems is that they require a mapping between the problem space (i.e. real-world variables) and the solution space (i.e. computed values in the intelligent system). Such mappings are then encoded into the intelligent system through traditional software engineering and programming concepts, which historically, has yielded a significantly large number of excellent problem-solving packages.

Thus, by assisting the user in the definition and the abstraction of a "real-world" problem into a computerised representation, the FEA process could be broken down into a series of sequential steps. Based upon the strengths (and in some sense, inherent limitations) of each of these techniques, it was theorised that given enough information and knowledge about the problem-solving process (including the initial problem definition and potential solution point), the entire FEA task could be automated and supplanted via AI techniques, such as Knowledge-Based Expert Systems (KBES), Fuzzy Logic (FL), Neural Networks (NN) and Genetic Algorithms (GA), as shown in Figure 0.1.

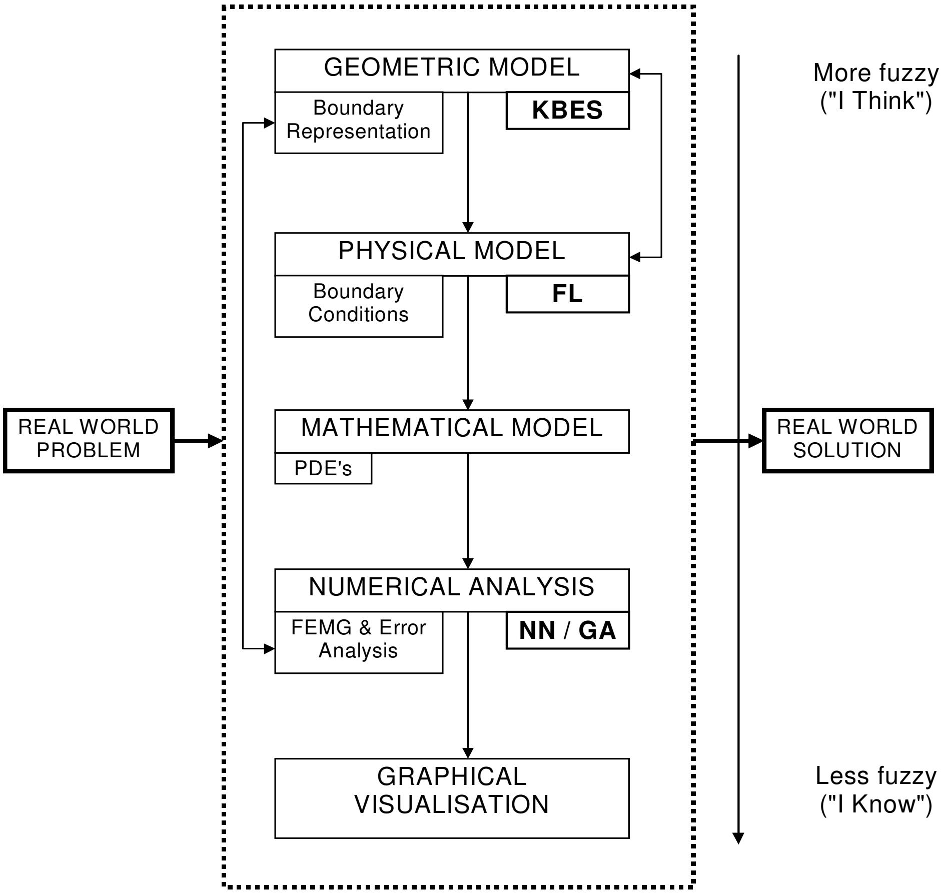


Figure 0.1 AI-driven FEA process (Sharif, 1997)

In this particular research, it was found that the modelling and analysis task within finite element analysis (FEA), effectively involved the correct representation of the problem to be solved, and a representation of the possible solution to be chosen (given that a solution approach was known up-front).

The concept of an Agile intelligent system, is based upon notions of a series of contributions made by both the information system and human user, in order to transfer, represent and management of knowledge processes (Sharif, 1999b). In the case of the Agile Intelligent System (AgIS) model, the user would be able to interact with a number of different knowledge agents in order to gain access to further sources of knowledge via a bespoke user interface. This in turn would utilise a computational engine (such as a neural network or other intelligent system) in order to manage the relevant information flows between the knowledge source components (design repertoires, organisational documents), and somehow formalise the interaction with categorised knowledge. Such an approach overcomes the wholly interventionist or integrationist approaches, which are commonly associated within the AI community (Cohen, 1995; Steinberg, 1994).

The 'interventionist' approach, argues that a human expert will always have to be at hand in order to reconstruct and direct augmented and elicited knowledge for problem-solving and decision support situations. A sufficient granularity of knowledge cannot be embedded into a knowledge base because this would entail describing a multitudinous number of potential cases, which cannot easily be stored, and accessed (Genesereth and Nilsson, 1987). Because AI has been, and will continue to be, a technological panacea the interventionist approach is becoming increasingly brittle due to a reliance upon structured knowledge, rather than an evaluative, explicit-tacit knowledge relationship. In contrast, the 'integrationist' philosophy supported on the basis of the Agile Manufacturing concept (Goldman *et al.,* 1995), is that human domain-focussed knowledge should always play an imperative part within the life cycle of a project. Intelligent assistance is therefore a transparent attribute of any such system, such as an AgIS. The philosophy behind the operational use of an AgIS relies upon a 'push' and 'pull' of information and knowledge between each of these agents, as shown in Figure 0.2.

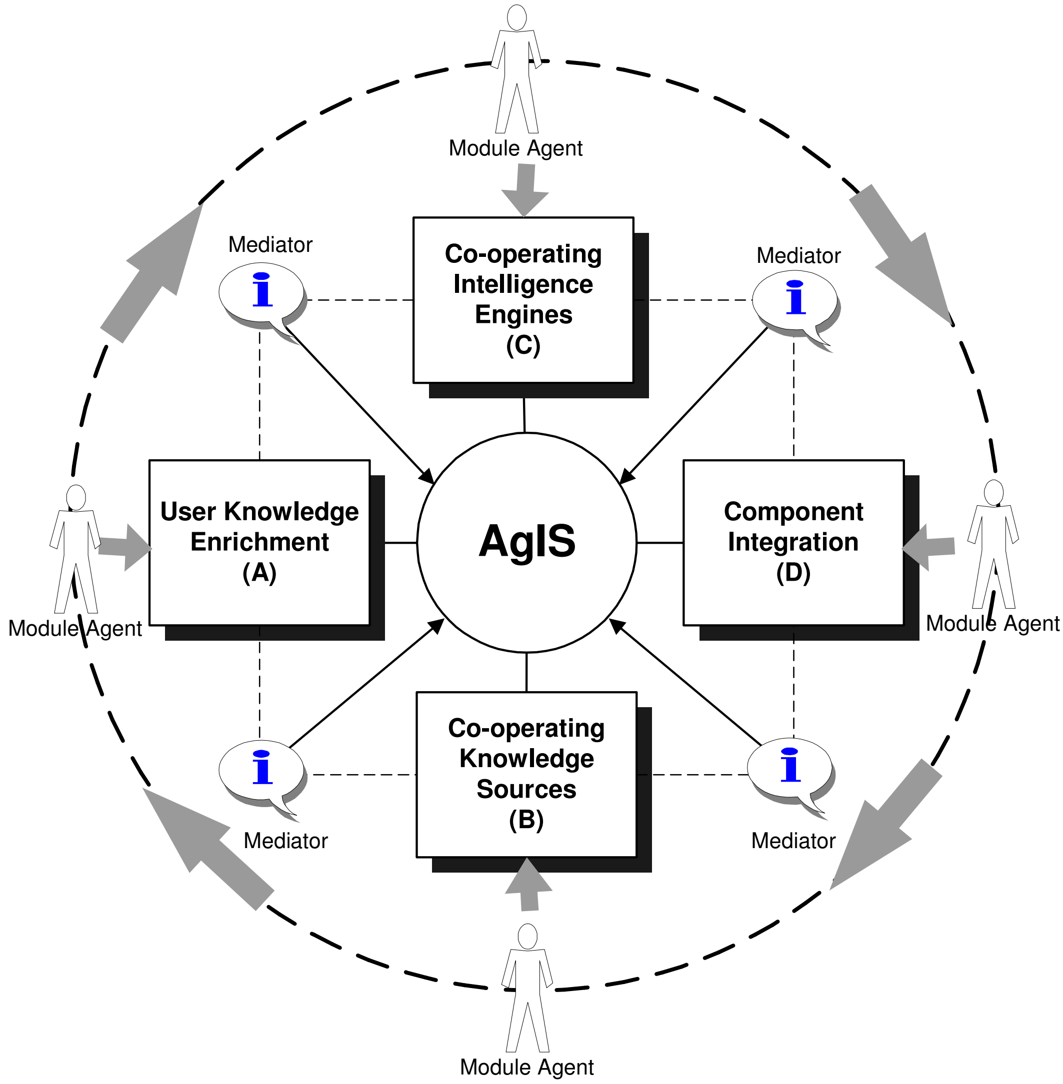


Figure 0.2 Conceptual model of an Agile Intelligent System (Sharif, 1999b)

The user can interact with any of the agents who relate to either imparting further knowledge through a user interface (A); accessing and utilising a computational engine such as a neural network (C); managing the information flows between the system components (D); and activating relevant knowledge bases which are useful to the user (B). Hence similarly in the CAE task, explicit knowledge tends to be used in cases where information is available which supports or helps to reject a decision path in the modelling of the waveguide, i.e. where assumptions match the results of the simulation. This can be seen as centering around primarily those tasks which are typically process intensive. In other words, which would require User X to carry out (repetitive) or fundamental decisions, which would aid him in carrying out the modelling later on.

Tacit knowledge on the other hand, tended to be used where there was subsequently little supporting information. In which case, intuitive decisions in the form of recognising previous design approaches are used and supplanted with team knowledge or input (i.e. get others to do the legwork first).

Hence this facet of the CAE task, involves more of an interpretive mode of thinking for User X. This is in terms of evaluating and putting the results of the computational analysis in context to the problem that was being solved in the first place. Knowledge that was used and represented within this task, was largely based upon the individual behaviour of User X, and influenced by the rate at which he was able to recognise and relate information to previous knowledge (i.e. previous designs). The question arises then, how does this compare to the view in the published literature regarding how CAE and in particular FEA software is used?

To recap, within Chapter 3 it was also discussed that both practitioners and academics had noticed that engineers had mixed feedback and feelings about FEA software in general. The key components of the surveys carried out by the likes of Clarke and Robinson, Babuska and Szabo and Actis can therefore be compared with the output of the research in this thesis also, as shown in Table 0-2.

For each statement, the words "TRUE" or "FALSE" are given in bold typeface, to denote whether or not the case data agrees or disagrees with the statement by the given researcher. So overall, it can be seen that in the majority of the cases, the CAE task observed and analysed thus far, appears to agree with the issues raised previously. The correlation is the strongest with those statements which state the importance of domain specific expertise relating to the FEA analysis itself; and also the impact and reliance upon the results of the FEA analysis as well. Although it has been noted that CAE users need to be domain experts in the field of application of the CAE software, such users have not and do not usually have any input into the development and maintenance of CAE codes, as has been noted by Babuska (1996), Clarke and Robinson (1985), and Szabo and Actis (1996) in Table 0-2. Noting this point, the author has highlighted the fact that User X had largely written and programmed the ANISO3 package himself, and as such, User X was highly a-typical of CAE users in this light. Even so, he did appear at times distrustful of the results presented.

Table 0-2 Re-synthesis of FEA usage issues within the literature as compared to case data (via Chapter 3, Section 3.4.2)

Clarke and Robinson (1988)	***Szabo and Actis (1996)***	***Babuska (1996)***

• Specialists are required to operate and fully understand the nature of pre-and post-processed FE data : **TRUE** • Mesh refinement and optimisation is still an art - no single approach appears to be best : **TRUE** • Economics of choosing finite elements for accurate modelling, hinders accurate solutions : which elements are best suited for a particular problem : **NOT FOUND** • Irregular boundaries are difficult to mesh : maximisation of elements in regions of high solution requirement such as re-entrant corners and points of singularity, require potentially judicious and subjective meshing : **NOT FOUND** • Commercial pre- and post-processors for FEA are biased in their field of application and require a high level of human expertise to operate: **TRUE** • Data input *seems* easy, but rarely is so simple : **TRUE**	• Average time taken for a complete CAD/FEA analysis of a problem is approximately 5 man days for each project (including geometrical, physical and numerical representation of the problem) : **TRUE** • 82% of FEA users do not know or wish to use error analysis techniques in their analyses : **FALSE** • Too little time is given to effective modelling of the problem : observation and experimentation are favoured over scientific deduction and theory, such that 'numerical empiricism' is largely employed : **TRUE** • Engineers do not investigate the full benefits of using FEA within the primary and conceptual design phases. : **TRUE** • Representation and modelling of the problem by the analyst should be assessed for accuracy and realism as far as possible, before the software is blamed for producing 'unsatisfactory' results : **TRUE** • A general lack of confidence exists in FEA results and modelling techniques due to the verbosity and at the same time, generality, of current commercial FEA and mesh generation software : **TRUE**	• Poor understanding of the problem area : **FALSE** • Poor modelling of the problem : **FALSE** • Application of inconsistent mathematical formulations and error estimators : **FALSE** • Over-reliance on graphical results : **TRUE**

In terms of the statements that were not correlated, were those which relate to the "economics" of the modelling approach used. By this it is meant, the choice of discretisation elements to be used in the FEA model, and the realisation of the importance of using error correcting and tracking techniques within the CAE package.

The author also wishes to comment on the fact that the case data agrees with all but the last point made by Babuska (1996). This is unsurprising in a way, as Babuska tends to be fairly strict about making sure the engineer or modeller has full knowledge of the modelling technique being used (e.g. FEA), the area where it is being applied (e.g. mechanical engineering, electrical engineering), and the tool that is being used to compute the results (e.g. bespoke or commercial FEA package).

Decision flow within IT/IS investment evaluation

In a similar vein to that of the previous case study, a comparison of the findings from the second ISE task case study company observed, is now made against the focal theory outlined in Chapter 3 earlier. The main findings based upon the data collected are shown in Table 0-3, and again, discussed further within this section. Again, as in the CAE task discussed earlier, the focal theory assumed that there would be mostly an explicit approach used in utilising knowledge for evaluating IS, based upon the typical ISE process shown in Chapter 3 (Figure 3.5). However, as was found via the observed case participants, the explicit knowledge requirements can be seen to be centering around primarily those tasks which are typically process intensive.

Table 0-3 Comparison of Company B data with focal theory

Knowledge Driver	*Expected finding*	*Case data*	*Actual Finding*
Environmental (Socialisation)	Explicit	Investment appraisal techniques based upon financial considerations	Explicit
Psycho-sociological (Externalisation)	Explicit	Lack of involvement of stakeholders and other decision makers	Tacit
Systematic (Combination)	Explicit	No formal processes or systems found	Explicit
Behavioural (Internalisation)	Tacit	Experience and intuitive judgement of Manager M	Tacit

In other words, which would require Manager M and the associated IS evaluation team to carry out fundamental ISE decisions, based purely upon financial justification criteria. Putting the case data in context, in terms of whether or not there were systems and processes in place to support the ISE process, it was found that no formal and documented process or infrastructure existed at all.

The tacit aspects to the ISE task found, also were different from expected within the focal theory model. It was expected that Company B would adopt at least some of the typical ISE evaluation approach advocated by researchers and practitioners in the field. Instead, it was found that the failure of the implemented MRPII system was due to individual and clearly non-team focussed decisions, based upon the tacit and intuitive "gut-feel" knowledge of Manager M. Again though, what was interesting to note was the change in Manager M's behaviour once the evaluation and decision to implement MRPII had been taken. In a sense, the overwhelmingly tacit decision was driven by an explicit set of financial appraisal factors (direct costs), upheld by the evaluation team and Manager M earlier in the process.

Thus, tacit knowledge was inadvertently used to justify the investment in technology, underpinned and represented by explicit knowledge (the metrics of return on investment and cost-benefit analysis being merely a means to an end). In the absence of any other visible factors that could have had an impact on the seemingly ad-hoc appraisal approach adopted by the management of Company B, the author felt the remaining underlying factors driving the ISE task, may be based upon the inter-relationship or *causality* of decisions made using this approach. As such, in their work, Barr *et al.* (1992) note that the mental models that senior managers within organisations typically use, tend to both assist, and yet at the same time limit, the importance given to information which will have a direct impact on the workings of their organisation. In fact, such mental models which are strongly held by management may even cause them to overlook tacit information, affecting the organisation in an adverse way. Braglia and Petroni (1999) also comment lucidly:

> *"…the managerial perception of which available systems are suitable for the company and of their potential is, in turn, influenced by factors such as the experience and competencies accumulated. The availability of competencies and a positive cultural attitude towards innovation is, in our view, the factor most affecting implementation. In fact, firms, which do not have such strong skills and cultural openness, tend to adopt techniques in a more confused manner, drawn by external pressure rather than pushed by internal commitment."*

(Braglia and Petroni, 1999, pp. 437).

Hence, several technology management factors were identified as having an impact on the failure/success of Company B's adoption of the chosen technology.

Table 0-4 provides those technology management factors that were not immediately considered by Company B, within their appraisal approach, but were found to be bounding the appraisal decision flow of management, following feedback of the observed behaviour. As such, these are specific tacit components of the IT/IS evaluation which were identified in Company B, as having an impact on the investment appraisal decision-making task. This is based upon the published work by the author previously (Irani, Sharif and Love, 2001).

Table 0-4 Business Transformation factors mapped to the 5M model (from Irani *et al*., 2001)

Factor	*Material*	*Man*	*Machine*	*Money*	*Method*
Re-Engineering	✓	✓	✓	✓	✓
Education and training	✓	✓		✓	✓
Information Management		✓			✓
Package Selection	✓			✓	✓
Change Management		✓			✓
Stakeholders		✓			✓

Manager N noted that in carrying out the initial evaluation of Vendor Z's software modules, there was certainly an act-of-faith in assuming the software could deliver all aspects of the required functionality. Those additional factors relating to 'embedding' the software into the organisation, were therefore in essence, also taken for granted.

Those additional factors relating to 'embedding' the software into the organisation, were therefore in essence, also taken for granted. Noting the organisational philosophy of Company B, and the enthusiasm by the directors of the company to implement new technology in order to maintain competitive advantage, such inter-related factors can indeed be seen to have been taken to be tacit knowledge components. This is in the sense that these aspects of the justification approach were implicitly included within the resulting decision to implement the vendor software module. These factors, shown in the figure as the '5M' model in Figure 0.3, detail those primary issues that were later understood to scope and define the implementation of the organisational, strategic and operational aspects of the chosen PPS system.

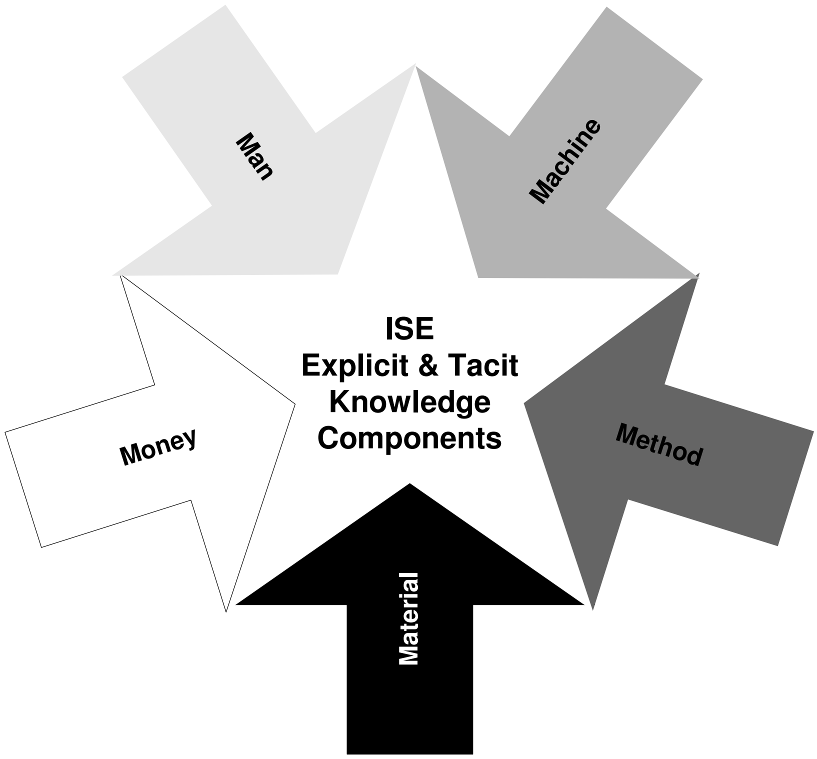


Figure 0.3 Key technology factors in Company B - the '5M' model for MRPII integration (from Irani *et al.*, 2001)

The "Material" facet essentially describes the flow of information packets within the organisation, and the management of mission-critical information (in terms of data, process and knowledge). This can be achieved through the adoption of an open IS, and supported by a consistent reporting scheme and documentation format i.e. the generation of a Master Production Schedule (MPS) that details appropriate information, such as customer delivery dates, material availability, capacity fit etc.

In terms of the "Man" component of the model, to realise the full benefits of combining each of these separate issues together, human and organisational resources should be carefully planned and matched against technological implications. Thus, enabling tactical and operational goals to be achieved. This includes targeting the right people to be trained, and that the required level of training resources is available to them. The culture and management mix of the organisation should also endeavor to encourage goal-focussed aptitude to be an inherent characteristic of each project. This is based upon the notion that within Company B, there is an organisational belief that 20% of the workforce should be capable of 'high' precision manufacture, with the remaining 80% capable of 'general' sub-contract jobbing shop work. The implications for this are far reaching in terms of human and organisational benefits and costs.

The "Machine" component of the model, encompasses the introduction and adoption of new non-human resources, such as IT/IS. This is a necessary requirement in order to maintain competitive advantage, and achieve medium and long-term strategic goals. Investment in appropriate hardware and software is important and issues of obsolescence and up-gradeability should be taken into account when evaluating such technologies.

"Money" (i.e. capital expenditure), is the next most important factor when considering investing in new technology. The reason for this is that no matter how necessary the technology, if finances do not support its adoption, its justification becomes futile. The implementation of technologies should focus on a long-term commitment from which tactical and strategic benefits can be gained for the organisation. Therefore, judicious and accurate modelling of cash flows is required, wherein indirect costs which need to be considered during the capital budgeting process are included.

Finally, an appropriate method to harness and realise the factors to achieve successful integration within an MRPII framework have to be achieved, i.e. some sort of structured evaluation needs to be followed (denoted as "Method" in the model). The development of the decision making process beyond traditionally myopic financial accounting procedures, is a significant step in this direction. In doing so, considering amongst others, those appraisal techniques identified by Irani *et al.* (1997d, 1998). By considering qualitative project implications during the justification process, the wider implications of information, knowledge, human and non-human resources can be put into context. From the study and other research sources (Patel and Irani, 1999), it has been generally agreed that in the holistic evaluation of IT/IS projects, there is a need to view this process in terms of a sociological (team-based) activity, exploiting the maximum functionality of the system and ensure tailorability.

It can be seen that although there were originally a set of explicit knowledge factors which were used to originally drive the appraisal process such as those based upon direct costs and Return on Investment (ROI), and there were a number of tacit, hidden technology management factors which came to light after reflecting upon the outcome of the implemented system such as indirect human (training) costs, there were little or no approaches to relate and / or combine, these forms of knowledge together. Furthermore, in order to test the case study findings against the methodological knowledge matrix model proposed in Chapter 3, a relationship or dialogue between tacit and explicit knowledge forms was required (as mentioned in published research – see for example, Johannessen *et al.*, 2001).

As such, many of these variables were reliant upon tacit knowledge, made visible through explicit knowledge requirements. For example, attempting to quantify costs which include implicitly defined indirect costs, such as those related to training and staff development. Additionally, the nature of IT/IS projects, meant that the entire justification process could be said to approximate an adaptive system subject to external, as well internal, influences (Kosko, 1990; Rose, 2002).

Many approaches exist which attempt to address this problem, such as those provided by expert systems. The justification process in this case, would entail asking the investment decision-makers a series of 'Yes' or 'No' answer type questions (Jackson, 1990) from which a possible scenario solution can then be elicited (Dilts and Turowski, 1989). In this case, expert systems can be used to provide a means to a structured answer and hence to reinforce existing knowledge. However, Coats (1991) notes expert systems cannot capture and deal with incomplete, vague, multi-valued or "fuzzy" knowledge, due to their reliance upon abstracted domain rules. These domain rules rely upon "crisp", yet brittle, logical premises. In other words, such rule-based systems require a finite number of bounded and hence known rules and outcomes. In the case of investment decision-making, the range of possible outcomes may not necessarily be known, due to the range of organisational and behavioural factors involved. Thus, the AI technique of Fuzzy Logic was used (Irani *et al*, 2002), in order to overcome the issue of brittleness, that is, providing a structure that is able to cope with increases in the knowledge domain without relying heavily on excessive *a-priori* knowledge. This AI approach is a method which is generally applied when vague (hence multi-valued or "fuzzy") problems are to be abstracted (Zadeh, 1965). This concept has been used successfully in many areas of technology and science such as in economics, steady-state electronics and politics to name but a few (Kosko, 1992), in order to understand interrelationships between different sources of information and knowledge better. Thereby helping to increase the "intelligence" of the decision making process. Fuzzy logic dictates that everything is a matter of degree. Instead of variables/answers in a system being either 'Yes'

OR 'No' to some user-specified question, variables can be 'Yes' AND 'No' to some degree. The principles that form the genesis of fuzzy logic are built on the notion of variable(s) existing/belonging to a set of numerical values to some degree or not. Membership of variables to a certain set can be both associative and distributive: the whole can also be a part (Kosko, 1990). A Fuzzy Cognitive Map (FCM), is essentially a causal map or directed graph which seeks to mimic how the human brain associates and deals with different inputs and events:

> *"An FCM draws a causal picture. It ties facts and things and processes to values and policies and objectives... it lets you predict how complex events interact and play out"*
>
> (Kosko, 1990, p. 222)

Cognitive and causal rules model the system and thus allow some of the inherent qualitative objectives to be related in a non-hierarchical manner. An FCM is a non-hierarchic flow graph from which the effect of subsequent changes in local parameter values can be seen to effect global parameters. Each parameter is a statement or concept that can be linked to another such statement or concept to produce the nodes of the FCM. This can be achieved via some direct but usually indirect and vague association that the analyst of the system understands but cannot readily quantify in numerical terms. Changes to each statement, hence the fuzzy concept, can be governed by a series of causal increases or decreases.

These incremental variances are generally in the form of a normalised weighting measure (in the ordinal range of 0.0 – 1.0). The advantage with an FCM is that even if the initial mapping of the problem concepts is incomplete or incorrect, further additions to the map can be included, and the effects of new parameters can be quickly seen. As such, an FCM is a dynamic system model, which thrives on feedback from each concept (i.e. intercommunication). This is a key difference between the FCM and other cognitive maps that have been used frequently in psychology, such as those described by Axelrod (1976), and Mentazemi and Conrath (1986). Another example of an FCM which has been used within business and management, is that of the work by Karderas and Mentzas (1997), in their work on using an FCM for choosing business process metrics. Thus, Figure 0.4 illustrates an FCM of generic investment justification factors, which was developed to demonstrate the inter-relationships between the key dimensions of the conceptual model proposed in Irani (1998).

In the diagram **A** are Strategic considerations, **B** are Tactical considerations, **C** are Operational considerations, **D** are Financial considerations, **+** denotes a causal increase (i.e. "has greater effect upon"), while **–** denotes a causal decrease (i.e. "has lesser effect upon"). The FCM given in Figure 0.4 starts with the application of a suitable appraisal technique, from a financial accounting viewpoint. Practically, this would be in the form of accounting the fiscal benefits available to the company after initiating the project. Each consideration, hereby a fuzzy concept in the FCM, is related to every other concept (i.e. to each fuzzy node) by linking it with an arrow, which shows where a relationship exists. It should be noted that there is no hierarchy between these fuzzy concepts and the letters (A, B, C, and D) which have been represented in the map for brevity.

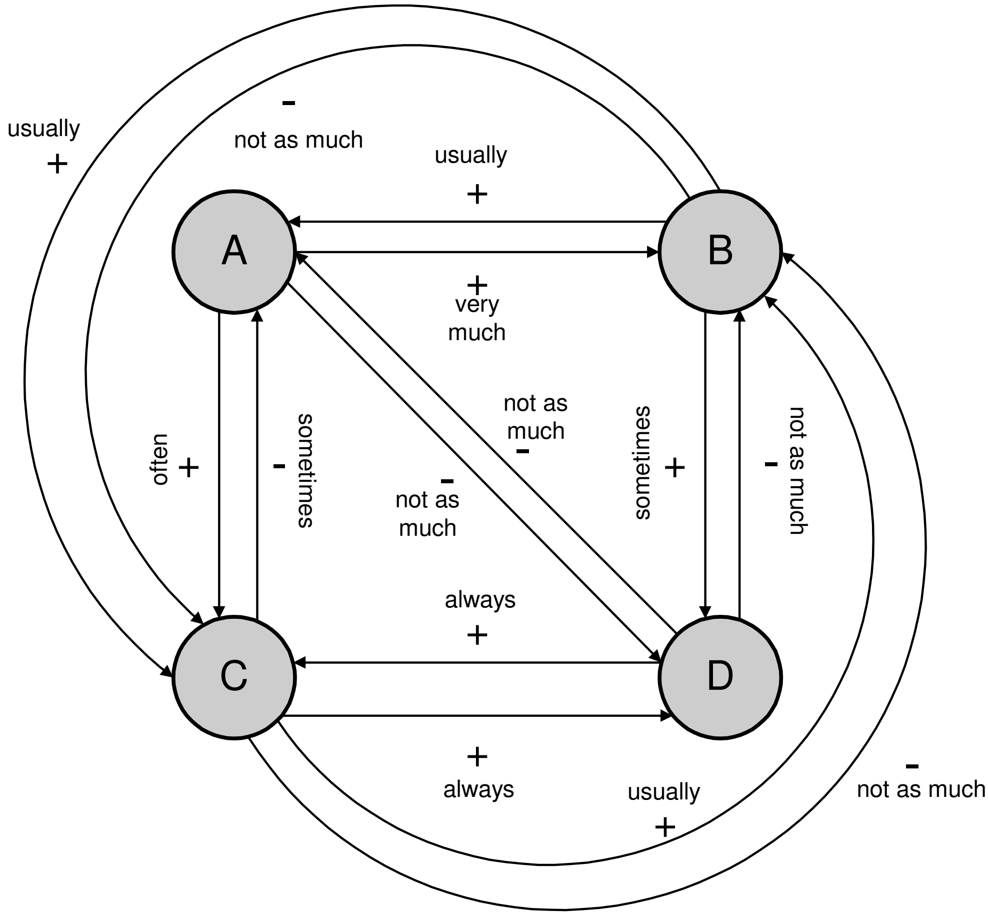


Figure 0.4 A generic, conceptual FCM for Investment Appraisal (Irani *et al.*, 2002)

Further, the '+' and '-' signs situated above the lines connecting the encircled variables are not numerical operators or substantiators, in that they do not show (absolute) scalar quantity increases or decreases between each system concept. Instead these signs denote causal relationships in terms of descriptors, which in this case mean 'has greater effect on', and 'has lesser effect on' respectively. Additional fuzzy terms can also be used to delimit the meaning of these operators e.g. '+ often' would be read as 'often has greater effect on', etc. The map can be read in any direction and relationships can be viewed in terms of any root concept, as it is a non-hierarchic flow diagram (as stated earlier). However, in order to clarify and highlight pertinent relationships between the key variables in the map, it is often easier to begin from a starting/root concept. The map is read by seeing which concept is linked together with another one, and uses the '+' or '-' signs above each arrowed line to provide a causal relationship between them. For brevity in what follows, the author denotes such relationships in the following manner: '<concept_1> <concept_2> [+ or -]'. For example, 'AB-' would mean an arrowed line connects 'A' to 'B' and would be read as "concept A has little effect on concept B". Taking a finance-orientated viewpoint to project justification ('D'), the map shown in Figure 0.4, can be read as follows.

Justifying a project purely on financial terms has little effect on the strategic considerations ('A'). This has been read as the arrow going from ('D') to ('A') and taking the '-' sign above the line to mean 'has less effect on', i.e. 'DA-'. Similarly, strategic considerations have little impact on the financial justification process as many of the benefits are largely qualitative and hence not financially quantifiable (i.e. 'AD-');

Justifying a project based upon tactical considerations, is more quantitative than assessing a project based upon strategic investment criteria (but less so than an operational investment) (i.e. 'BD+');

Operational considerations can be appraised financially without much difficulty as 'day-to-day' operations can be quantified in terms of current resources and operational CSF's (i.e. 'DC+' and 'DC-');

Strategic issues help to justify investments and substantiate tactical considerations/tactical CSFs and vice versa: since tactical and strategic dimension can be viewed as being long/medium term processes. Appraising a project in terms of any of these two would mean that a tactically based justification would be well suited to meeting the strategic goals of the company eschewed in the corporate mission/vision statement (i.e. 'AB+' and 'AB-');

Since strategic considerations take account of long-term objectives and goals, appraising a project based on operational factors is best suited to traditional methodologies, largely because of their quantitative nature. If an operational project was to be appraised solely on its operational characteristics, the strategic consideration for this would be weak, or rather would not be substantial enough to justify a project by itself (i.e. 'CA-'); and,

In order to justify projects solely on operational or tactical grounds, via a financial project appraisal impetus, it can be argued that operational considerations have greater effect justifying tactical considerations and vice versa. This is due to the fact that operational processes can be accommodated within the slightly longer time scales involved with tactical goals and objectives - this is a similar situation as shown in (v) above (i.e. 'CB+' and 'BC+'). However, these relationships are not always applicable to all types of investment, and can be detrimental to the appraisal of a project by any other means (either strategic or financial) (i.e. 'CB-' and 'BC-').

The above causal route through the FCM is but a single pattern that has emerged from the mapping of the conceptual framework. Other patterns can be found by adopting a similar method of beginning a causal route from a starting concept (i.e. from 'A', 'B', 'C' or 'D' respectively) and seeing how each concept can, potentially, be related to any other. The FCM itself shows a low-level representation of the key considerations of the project evaluation model, as opposed to the much higher-level conceptual framework given in Irani (1998). It should be noted that the FCM is a dynamic modelling tool in that the resolution of the system representation can be increased by applying a further mapping to the strategic, tactical, operational and financial considerations as desired. Further detailing of the exact nature of each consideration would ultimately help develop a more comprehensive map, which would show causal patterns that would not ordinarily have been seen, and even possibly, sought. However, other quantitative/qualitative analysis tools such as $IDEF_0$ (Sarkis and Liles, 1995) have been used to assist in the analysis of the aforementioned considerations, and might be able to give further dimensions to the holistic evaluation of project proposals.

Following on from the previous example given, it can be summised that the relationship between Project Benefits and the other parameters in the following manner. Project Benefits (*PB*) have increasing effects upon a projects' value (*V*), i.e. '+ highly valued'. *PB* also provides an effective input to the assessment of risk (*RF*), i.e. '+ consistent benefits'. The financial appraisal of project (*FA*) is also greatly enhanced by tangible project benefits, i.e. '+

attractive'. A negative causal relationship exists between project costs (PC) and value (V), i.e. '- high PC', which translates to the rising cost of a project decreasing its overall worth.

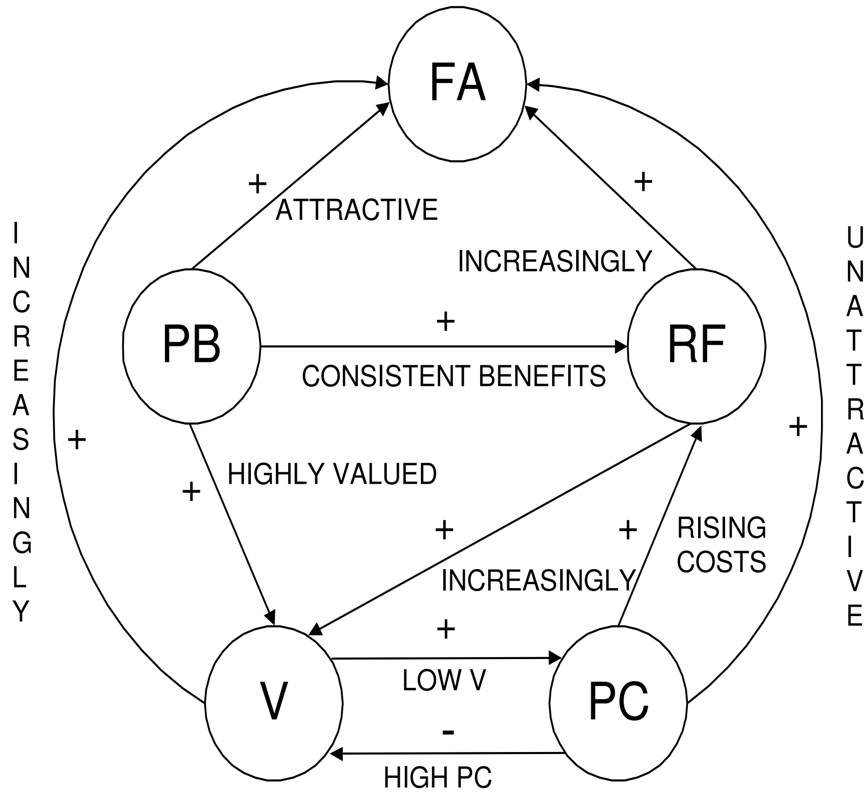


Figure 0.5 An FCM of investment justification criteria for Company B (Sharif and Irani, 1999)

In such a way, the remaining fuzzy concepts can be related to one another by reading and assessing the fuzzy quantifiers between them. This is shown in Figure 0.5. Thus, through using the technique of fuzzy cognitive mapping, it can be seen that there are a multitude of both direct (explicit) as well as indirect (tacit) inter-realationships within the investment appraisal decision-making process. The interplay between these forms of information, and hence knowledge, again shows the contingent differences between those factors which are systemic and environmental (e.g. financial appraisal, FA, and potential costs, PC) and psycho-sociological / behavioural (e.g. risk factor, RF, potential benefits, PB, and value, V) in nature. The author suggests that this further underlines the necessity to understand and define both the context as well as content, behind such decision-making which are rooted (constructively) within human practice and experience. In doing so, the author now progresses the discussion of the case study research findings, in terms of an evaluation of the data against the focal theory.

Comparison with Focal Theory

Given that the author has analysed the case data, the research propositions remain to be evaluated in terms of the research "threads" which were stated earlier in this dissertation, within the focal theory in Chapter 3. To recap, the first thread stated that:

> *An underlying psychological and sociological relationship between Explicit and Tacit knowledge, must exist*

whilst the second thread stated,

> *Tacit knowledge, is reliant upon a-priori assumptions and intuition, and is reinforced through on-going individual experience.*

Based upon the data collected and the resulting analysis and formulation of a conceptual model thus far, were these statements made valid in the light of the research? Taking the first thread, and analysing the results of the data collection the author contends that this statement has been upheld. This is in the sense that in both of the knowledge representation field study cases observed, there was a definite interplay between both articulated (explicit) and inarticulated (tacit) knowledge. Within the CAE modelling and design task, User X tended to give responses which were explicit in the sense of defining and showing his expertise with regards to the *process* of the task he had to perform. In other words, he was very sure of the steps he had to take in order to get the job done and the specific electromagnetic wave theory that he would have to call upon to evaluate the CAE simulation results via the ANISO3 package. But the overriding and very visible facet, though not immediately visible to User X, was observed in terms of how the engineer dealt with understanding and optimising his data model, which appears to support and contextualise the second thread.

Similarly, for the ISE task, the explicit use and representation of knowledge was through the agreement to use a financially based method of investment appraisal of IT/IS of the MRPII system for Company B. As noted within the previous sections, this specific approach was used, for no other reason than for the simple fact that no formal procedures, policies or infrastructure was in place to allow the ISE task to be carried out effectively. Even though it was noted that Manager M and several members of the board of directors, had had success in the past with investment decisions, the scale and importance of this particular investment was outside of their collective and individual working knowledge (especially for Manager M). Again, this is not surprising, as the depth of experience within the board members was relatively shallow, which may be considered a norm for SMEs (Barker, 1999). In a similar light, the tacit knowledge identified within the ISE task, related to the highly subjective viewpoint of Manager M and his adhoc decision-making capability. This was further exemplified through the alleviation of his own responsibility from the task of the MRPII implementation, onto that of the production manager, Manager N. Thus, it appeared that in some sense, that Manager M was able to see that his own personal experience with investment appraisal was not directly applicable to this case, and hence he did not wish to be involved with the process anymore. This is upheld by the research undertaken by Ordonez de Pablos (2002) within Spanish manufacturing organisations, where she found that ultimately, internal knowledge creation and learning strategies influence the success of competitive advantage initiatives. Taken in this light, the author contends that Manager M was perhaps in a sense, leveraging his own knowledge strategy in order to exert influence on the rest of the firm, which in some cases may be seen as being a highly political act:

> *"…individuals both identified and sustained notions of their own self interest in relation to the innovations to be implemented, and pursued courses of action relatively consistent with these interests."*

(Hislop *et al.*, 1998, pp.27)

whilst in other cases may be seen as being part of the skill and experience of senior management (Bennett, 1998). Thus, the ISE task study data also upholds the notion of the second thread given too.

Hence, in both cases, it can be said that the case-specific "threads" or research questions raised were supported and contextualised in terms of the findings of this research. In order to encapsulate and provide closure to the analysis, the stated goal of defining a frame-of-reference for knowledge representation within these manufacturing IS environments, is now shown.

Re-synthesising the concept of Knowledge: a frame-of-reference

Within this chapter, the author has so far shown that the observed cases show a vibrant mixture of both explicit and tacit knowledge types, which in their own right have been represented by the research subjects respectively. The remaining objective to be completed within this research, is therefore to develop a conceptual frame-of-reference for this analysed data. This frame-of-reference which will be able to provide a reference point for defining and the transformation point, or point at which explicit knowledge is exchanged for tacit knowledge, within each of these scenarios. In achieving this goal, the author expands the focus from that of specific organisational settings to a more generic organisational context. This will allow the conceptual frame-of-reference to be grounded in a wider, enterprise setting.

The challenge posed by representing knowledge within organisations as perceived by researchers such as Sveiby, is to channel and harness the information requirements of people and manage technology in such a way as to transfer codified knowledge more effectively (Sveiby, 2001). But simply expanding the accessibility and breadth of information will not necessarily enhance the understanding of the human perspective any further. What is potentially required, is a deeper understanding of the nature of the interaction between information, knowledge and the end-user and the bounds within which each of these factors operate, in order to make best use of these structures (such as for example, approaches to integrate knowledge and information within the components of the enterprise, Badii and Sharif, 2002; Badii and Sharif, 2003).

It is well understood that the traditional notion knowledge management, consists of a series of approaches to leverage the sharing, creation, approval and deployment of knowledge within an organisation. As Earl (1995), and Sveiby (2001) and many others in the field have repeatedly noted, there are at least three core components to this concept: knowledge systems; networks of knowledge communities; and a learning organisation which is amenable to continuous change. What these comparable processes lack however, is the Semiotic and Symbiotic dimension thus far discussed. Whilst many knowledge management implementations have succeeded in highlighting learning organisation (in)efficiencies and realising the worth of explicit and tacit knowledge (Davenport and Prusak, 1998; Nonaka and Takeuchi, 1995; Von Krogh *et al.*, 1999), such approaches so far have been limited to codification and representation issues. This is in the sense of finding acceptable strategies for creative as well as ingrained organisational information, which requires greater distribution amongst co-workers.

Kluge *et al.* (2001), define some of these aspects in terms of an evaluative framework (the knowledge management 'scanner'), which encompasses notions of transferability, perishability and spontaneity (to name but a few). However, these considerations still attempt to deal with a situation where existing or newly generated knowledge is meant to be classified according to some form of classification grammar. This is of course, a knowledge context, but in its loosest sense.

But what of the key forms of knowledge espoused previously within the background theory? Explicit and Tacit knowledge has so far been grounded within the Evaluative form of knowledge, quite simply because the implementation of such concepts has largely been due to the procedural nature of knowledge work and codification, in this regard. This thesis so far, has not made any attempt to reference the Interpretive and Structural forms of knowledge. However, given that it has been suggested that these forms of knowledge are in some way mutually exclusive of each other, can all of these types of knowledge be related and understood somehow? Through viewing knowledge within an organisational / enterprise context, as well as providing a model to integrate both behavioural and psycho-sociological aspects of knowledge and adapting concepts and philosophies form the school of human-centered (or interface design), a conceptual model is thus formed of the inter-relationship or interface between explicit and tacit knowledge and how it relates to knowledge forms thus discussed.

A Semiotic and Symbiotic view of Knowledge

Essentially the development of any knowledge-based information system relies upon the effective realisation of an interface (a method for manipulating knowledge); a knowledge context (a structure for mapping knowledge); and a navigation standard (a process or technique for navigating knowledge). In other words, those components of knowledge that have been described and defined by the author in Chapter 2, as being Structural, Interpretive and Evaluative knowledge respectively. The author now introduces the joint concepts of Semiotics and Symbiotics, in order to further delineate and define the interface between these three states, within a knowledge-dependent IS. The facets of usability and interface, can be thought of as being Symbiotic in nature (having a relationship with the interface), and navigability can be thought of as being Semiotic (providing a grammar of navigability, for instance): both existing within a contextual state.

The basis for this thinking has arisen out of the so-called orthodox school of industrial engineering design, where the role of the designer is seen to be that of a conversationalist, as part of the creative process (Axelrod, 1976). There have been many variations on this concept of design, one of the most crucial being interaction-based design (Alger and Hays, 1964; Bahrami and Dagli, 1994). These approaches attempt to place an emphasis on understanding the interface between technology, usability and information, and how it relates to the design process (Cooper, 1995). The interaction with technology tools to carry out the process of design, becomes part of the user's ontological view. It is argued that no clear distinction can be made between the designer and the designed (the person who interacts with their design creation). Indeed, Tang and Gero (2001), note that the basis of most design tasks involves a combination of human practice, sensitisation to the environment that the designer is in and the usage of metaphors to capture and transmit information within a designed artefact.

Thus, these ideas can be extended towards the IS field where it can be said that the successful interpretation of the interface between man and machine, is dependent upon the ability to link human processes with artificial constructs (i.e. the IS), which mimics how humans think and structure knowledge. The usage of technology in this way, is implicit in many knowledge-based tasks and is at the heart of the development of systems such as information-dependent communities (Scherer, 2000). Kock and McQueen (1998) also define the interaction with information systems in this light, whereby the methods of communication with them, involve a cycle of continuous interpretation and change. Another example of this Semiotic and Symbiotic effect can be seen in the way in which Nokia, one of the world's most dynamic mobile telecommunication companies, has based the design of it's telephone handsets in terms of this interaction between form, function and process (Steinbock, 2001). Nokia have single-handedly managed to define a desirable and definable standard for information navigation, most visible when enabling the device features. The navigation through the hierarchy of menu's, along with functionality linked to keypad layout (select options appear on the left of the screen, exit options on the right), have meant that users of such phones have not only gotten used to such an information architecture but also have begun to expect other devices to have similar tightly integrated features available through loosely coupled navigation hierarchies. In this case, the relationship through the interface with the user is based upon a limited word set vocabulary hierarchy of items, which have some meaning: key menu items such as "Messages", "Settings", "Services" being supplemented with at most a sub-menu hierarchy of upto 6 selectable options, for example "Inbox", "Phone Settings", "Voicemail Settings". The effect produced by interacting with this device is inherently linked to the representation of the functions available in the phone: if the menu options are represented with stylised yet instantly recognisable symbols and wording, the interaction behaviour will also similarly follow, through a much deeper understanding and hence knowledge of the workings of the mobile phone. Hence, it is becoming apparent that the real benefits of exploiting technology, exist in understanding the language of signs and symbols (Semiotics) and the relationship between technology and those factors, such as ourselves, which interact with it (i.e. a Symbiotic relationship). Thus, the author presents a model which defines knowledge in terms of Semiotic and Symbiotic effects, which is presented within Figure 0.6.

This is a realisation of those philosophical concepts outlined within the focal theory in Chapter 3 (see Table 3-1 in Chapter 3): the recapitulation of Nonaka and Takeuchi's SECI model in terms of decision-making within IS, between "form" (Systemic and Environmental) and "feeling" (Behavioural and Psycho-Sociological) factors; the formation of the conceptual focal theory threads as a result of defined key explicit and tacit knowledge transformation drivers, i.e. the assumptional and social threads (see Figure 3.7 in Chapter 3); and finally the contextualization, of all of these factors with respect to the classification of Structural, Interpretive and Evaluative knowledge (from Figure 2.3 in Chapter 2).

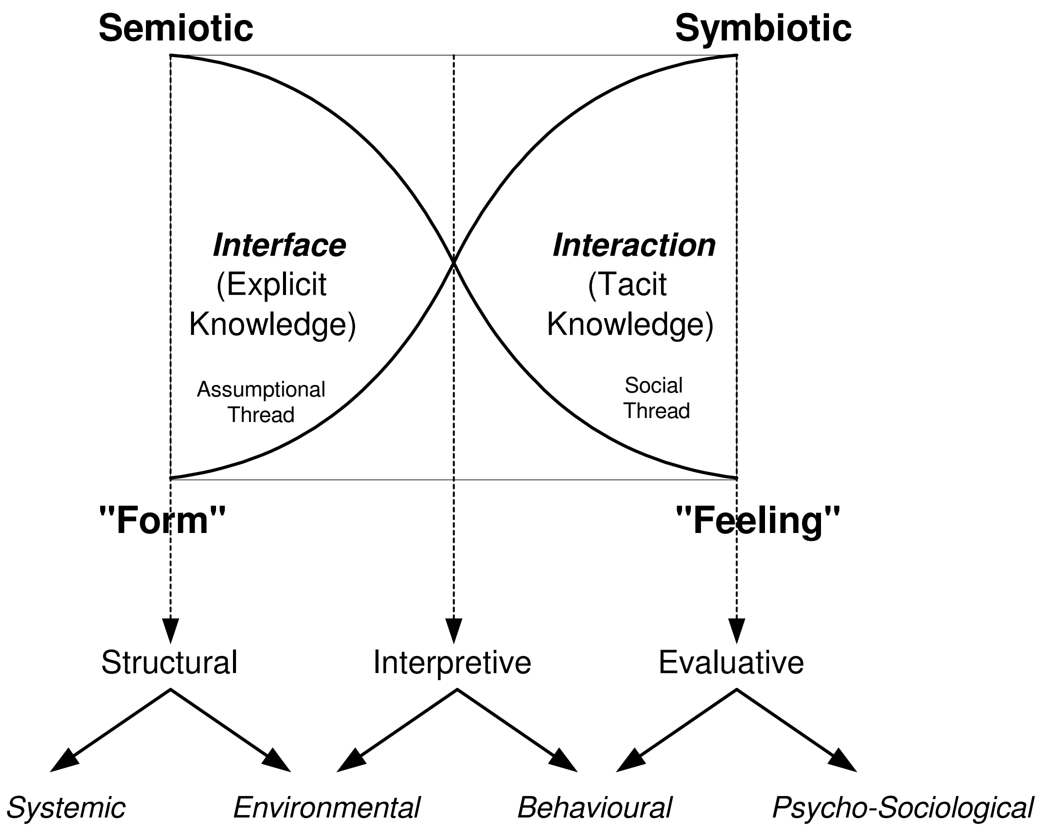


Figure 0.6 Mapping interface and interaction : Semiotic and Symbiotic effects

The author suggests in the diagram in Figure 0.6, that the transition between Semiotic and Symbiotic states consist of aspects of the interface and the interaction between "form" and "feeling" (i.e. a transition between Structural through to Evaluative knowledge). This is shown in the diagram, as the curve rising from the bottom left of the rectangle to the top right and the curve falling from the top left to the bottom right of the rectangle, respectively. The curves shown in this diagram attempt to highlight the non-linear and transient nature of the transformation, or rather reliance, of explicit knowledge on tacit knowledge (and vice-versa). As such as shown and described in case Company A, explicit knowledge was used primarily as a basis for the decision-making task within the CAE process. After which, the actual decisions taken by User X and corroborated through observing similar practices undertaken by members of his team, were based more upon heuristic or tacit knowledge, moving from left to right along the curve, from the Semiotic form of the interface, to the Symbiotic, feeling of the resulting knowledge within the enacted decision.

The opposite was true of Company B and Manager M, wherein ultimately tacit decisions, based upon behavioural or psycho-sociological premises were backed up by explicit assumptions and beliefs (for example, using financial appraisal and cost accounting methods to underpin and satisfy the almost intuitive decision to carry out an investment project). Philosophically, the construct within Figure 0.6, has been derived in the guise of what Polanyi terms, the proximal and distal essence of knowledge (hence for Figure 0.6 explicit, these are the assumption-based and tacit, social knowledge respectively). Contextuality is inferred in this diagram in the sense of Nonaka and Takeuchi's concept of "Ba" or place of being. In other words, knowledge cannot exist without some context and cannot be transmuted into human action, without a transformation between the unknown and known (Nonaka and Takeuchi, 1995), which is implied by the legend Structural, Interpretive and Evaluative at the bottom of the diagram. Also, this diagram attempts to pay homage to those schools of design who view knowledge as not only being a sign of the existence of some information construct and its related significance (Barthes, 1998), but also a representation of a relationship with the knowledge artefact (Anthes, 2001; Sowa, 2000). The overlap between the curves is therefore a transmutation point where knowledge has some particular contextual significance (Heylighen, 1990), knowledge being generated in some part due to an autopoeitic or self-organising nature (Merali, 2002), as a result of interaction between both explicit and tacit forms (the left and right hand side of the diagram respectively).

This mapping therefore seeks to reinforce the notion of context as being part of the interaction between the structure of information (the Semiotic) and the method by which information is related and consumed (the Symbiotic). This means interaction with information should not only be reliant upon codified and Semiotic knowledge (e.g. spreadsheets and documents held in a knowledge repository database), but also reliant upon the Symbiotic relationship associated with it (e.g. usefulness and relevance of knowledge to a particular task). Corner *et al.* (2000), also discuss similar concepts within their paper on dynamic decision-making models whereby they bring together concepts of Recognition-Primed Decisions (decisions which consist of explicit alternative options which influence decision goals) and Image Theory (where new, implicit or tacit decision options are created the decision maker based upon their experience). Hence by placing Structural, Interpretive and Evaluative forms of knowledge along this continuum therefore, the author presents the fact that there may exist a very wide range of features and characteristics which can inhibit and accelerate, the adoption and usage of knowledge within individuals and organizations (i.e. from explicit to tacit knowledge). In terms of the organisational IS aspect, knowledge workers typically expect both breadth of information, as well as depth (KPMG, 1998). By introducing this Semiotic context and relevancy of information alongside a multiplicity of Symbiotic associations between data sources and content, a more effective realisation of the concept of knowledge within IS can be grasped. In order to extend these notions of representational and relational knowledge structures, the author now presents the development of a frame-of-reference siting these particular components of knowledge, with reference to the case data collected and the focal theory developed.

A frame-of-reference for Knowledge Representation within Manufacturing IS

The thesis presented so far, has primarily dealt with understanding the fact that there should be equal importance given to both the contextual representation and causal relationship, as given to the consumer / stakeholder of that knowledge. However, taking into account that the analysis highlights the importance of the behavioural and psycho-sociological aspects with respect to explicit and tacit knowledge, how can this be framed within an organisational context? To address these issues, the author proposed to highlight both the contextual requirements for knowledge within the enterprise as well as the semiotic and symbiotic aspects of knowledge. This is now shown in further detail.

Knowledge Integration within the enterprise

As noted by the author in previously published research, the context of IS within the organisation, or more specifically, the enterprise, needs to encompass concepts of the integration of information and the manner by which such information (or knowledge) is represented and abstracted (Badii and Sharif, 2002; Badii and Sharif, 2003). The components of such an approach, in terms of a framework model, are now outlined in Figure 0.7 order to facilitate the generation of the frame-of-reference later. This model builds upon other work by Badii which involves assessing the impact of knowledge and information overload on organisational decision makers, using mediated IT/IS (Badii, 1999; Badii 2000a-e; Badii, 2001). The model in Figure 0.7 also makes use of the C-Assure and Return-on-Relationship (ROR) approach to knowledge integration, which is a set of models, tools and techniques for integrative IS evaluation to facilitate re-negotiability, holistic in-situ evaluation and located accountability (Badii 2000a-e; Badii and Rolfe, 1996).

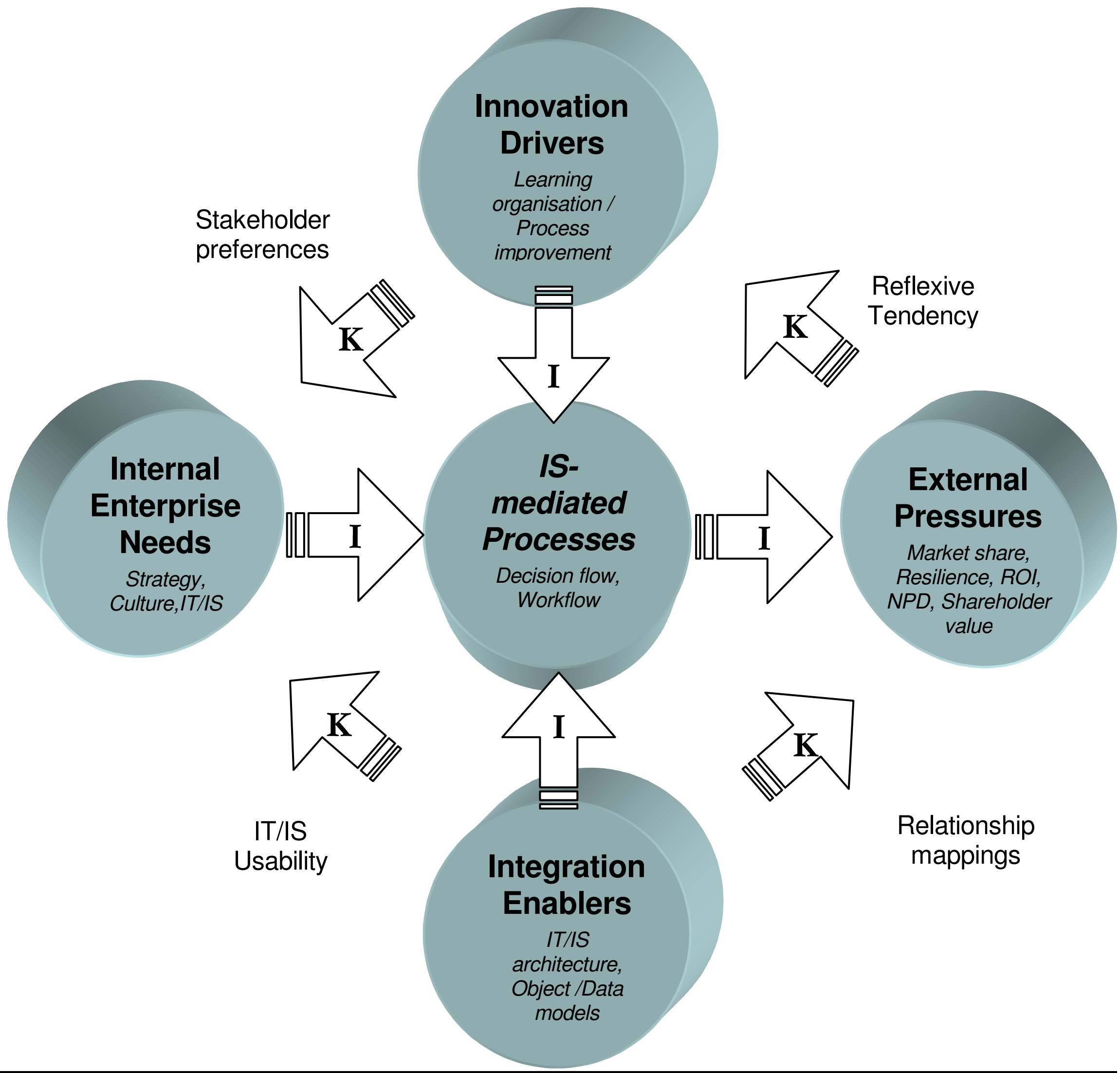


Figure 0.7 An integrated Enterprise Information Integration and Knowledge framework (Badii and Sharif, 2003)

As such C-Assure, harnesses psycho-social, psycho-physiological and other patterns of personal and social memory, actability and preference. This is aided by exploiting such theories in order to elicit and continuously refine models of stakeholder preferences thus exposing deeper customer values and usability knowledge (Badii, 2001a). Accordingly C-Assure supports, both data-driven and model-based analysis of user/customer value judgements and decision making throughout various interacting lifecycles. The C-Assure meta-methodological framework comprises an enquiry / knowledge methodology, a knowledge integration architecture and a set of business process monitoring tools. In light of this context of the C-Assure model, the paper by Badii and Sharif (2003) therefore sought to support the requirement for integrating knowledge with organisational decision making and learning, at each step within the company.

The C-Assure Effects-Affects matrix (Badii 2000a,c), provides the backdrop to this framework where a matrix of both spoken and unspoken, but nonetheless measurable benefits, dis-benefits, side-effects and affects are associated within the enterprise environment (i.e. enterprise context). This is shown in the diagram as the feedback between external competitive pressures and internal, enterprise requirements, based upon information (I) and knowledge (K) dependencies. As such, the representation of knowledge in this form at this higher enterprise level allows the author to begin to place the semiotic and symbiotic relationship of explicit and tacit knowledge, in terms of specific knowledge forms which the organisation would typically encounter. That is to say, the definition of any frame-of-reference model, also requires a *holistic* understanding of the significance of knowledge to the organisation.

Hence, the concepts behind the basis of this model are introduced into this dissertation, in order to allow a deeper understanding of the representation of knowledge within a manufacturing IS environment, which is now henceforth formulated.

The TAPE frame-of-reference

Assessing the model presented in Figure 0.7 which shows the context of knowledge within the enterprise, the author now proposes highlighting specific components of this organisational-centric view, as well as the specific Semiotic and Symbiotic stance taken earlier. The author suggests that by analysing and thereby grouping the constituent parts of the information and knowledge integration framework in Figure 0.7 and the Semiotic and Symbiotic model shown in Figure 0.6, (i.e. placing the research questions within the context of enterprise-level knowledge requirements), the author presents a mapping of those characteristics of Technology, Accessibility, Psychology and Enforceability within Figure 0.8. This figure shows the TAPE frame-of-reference in relation to components of the knowledge transformation framework shown in Figure 3.7 and Table 3-1 in Chapter 3 earlier (namely aspects of Environmental, Systemic, Behavioural and Psyco-Sociological drivers). Essentially the development of the TAPE frame-of-reference, relies upon the latter framework in Figure 3.7, which defined a contextualisation of the case data in terms of the research objectives.

As such, in terms of the first of these characteristics, using current information technologies, it is not unfeasible to produce tools, techniques and services that allow both mappings between Semiotic and Symbiotic knowledge sources, as well as mechanisms for the interpretation of such information. The appropriate use of technologies as diverse as intelligent agents / avatars, thematic community knowledge repositories, content management delivery platforms, expert systems and contextual search engines is a necessary step in allowing knowledge to be used, based upon causal relationships and relevancy to particular knowledge tasks.

Secondly, in terms of the Accessibility component, in order to map the extent of knowledge in an organisation, the output of any knowledge management-based process, should be to also monitor and report on usage trends of that knowledge. In other words, does, for example, the generation of working papers in a university department depend more on the revision of existing knowledge, or the discovery of new ideas? Fundamentally, this will also help to define the depth of knowledge culture and the effect that Semiotic and Symbiotic interaction has on modifying and altering stored information.

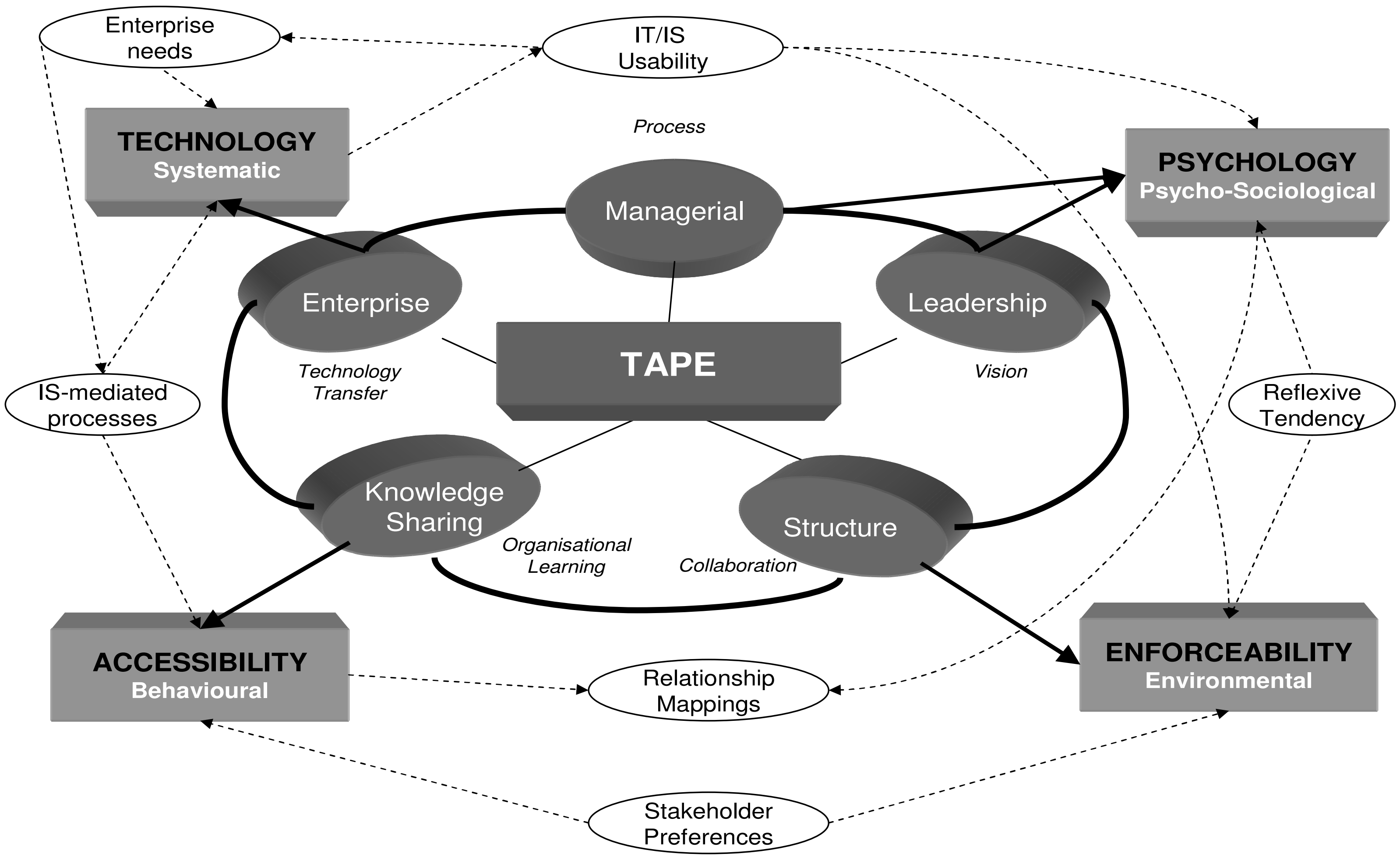


Figure 0.8 Development of the information and knowledge integration framework towards the TAPE frame-of-reference

Thirdly, organisations and individuals, need to define and understand the best interaction methods for certain types of knowledge and map them accordingly : for example, is it more realistic to provide access to documents and reports within a knowledge repository based upon structure and hierarchy (a semiotic approach), or based upon relevancy to a knowledge worker's business process (a symbiotic approach)? This encompasses the third characteristic, that of the Psychological aspect.

Finally, organisations need to investigate shifting the emphasis from the storage of knowledge to better approaches for knowledge retrieval. This concept manifests itself through the design of information hierarchies and architectures (much like how libraries organise books), in order to access information and knowledge in the most efficient and intuitive way possible. Through doing this, the usage behaviour and interaction with knowledge can be enforced. Further, these four key enablers (henceforth known through the acronym, TAPE) can be put in the context of a traditional knowledge management strategy: identifying the most relevant knowledge pertinent to a task and understanding the appropriate usage for it.

The components shown typically revolve around a largely structural or organisational aspect, whereby changes to both representation (knowledge sharing and structure), creation (entrepreneurship or enterprise), and processes (managerial and leadership) are required. Where the components of the TAPE frame-of-reference are introduced into this strategy, then the inherent inter-relationships between structure, context, interaction and inference are more clearly discernable, through the introduction of a language and relationship schema for the required knowledge. The use of a semiotic as well as a symbiotic frame of reference to a particular source of knowledge, appears to be a more pragmatic way to represent and understand knowledge.

Hence, Figure 0.9 shows the author's proposed TAPE frame-of-reference which presents the view that codification of knowledge and its resulting taxonomical categorisation, should be considered as part of a holistic view of organisational knowledge requirement needs and processes.

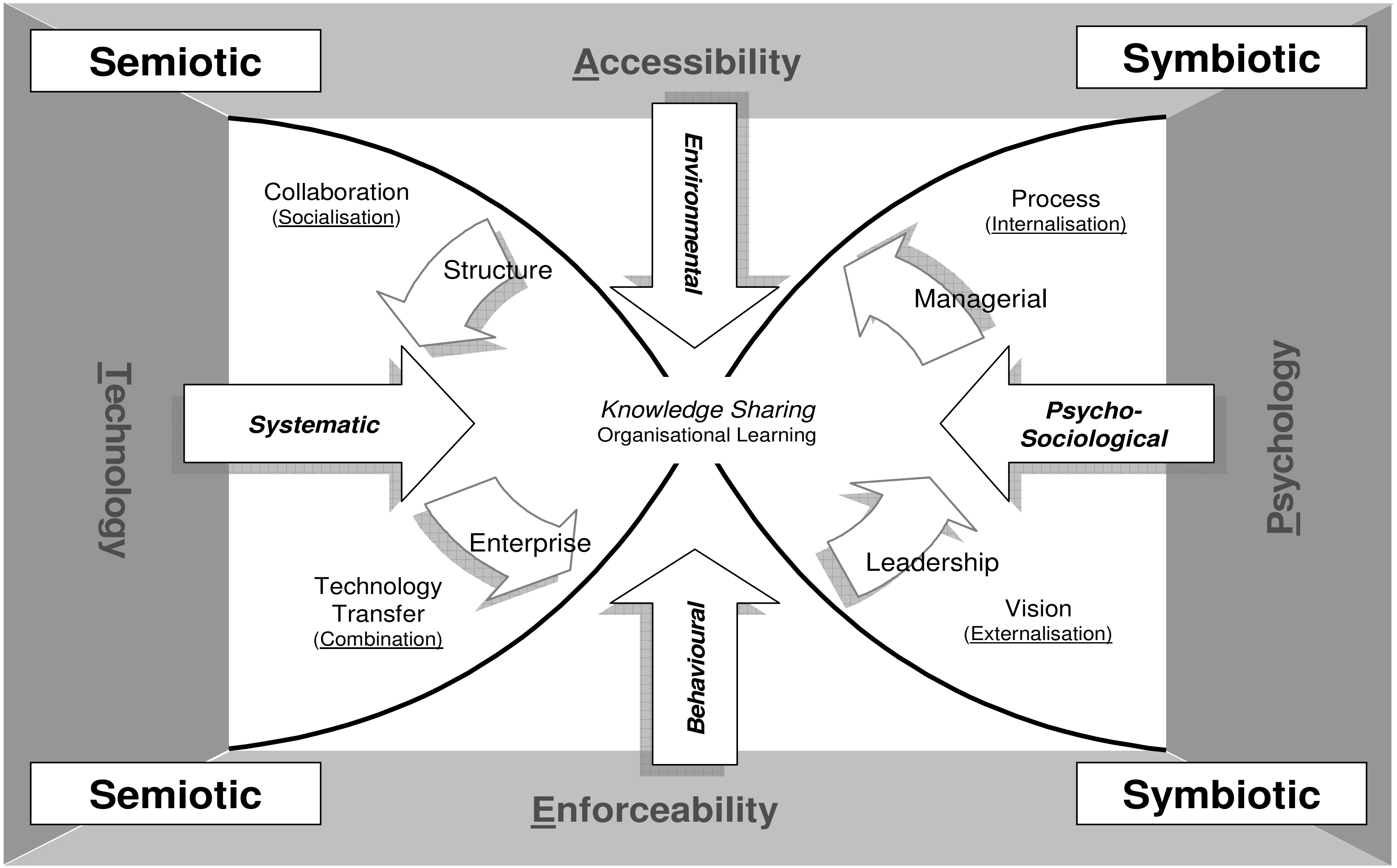


Figure 0.9 The TAPE frame-of-reference in relation to explicit-tacit knowledge transfer factors

By considering the effects of the relationship between *consumers* of information and that of the usage of knowledge, the author suggests that the advantage of introducing a Semiotic and Symbiotic view of explicit and tacit knowledge, improves our understanding of the interplay between the known and unknown factors which drive knowledge representation and use.

Thus, Figure 0.9 shows those specific organisational, and IS-dependent factors which highlight and support notions of knowledge creation and transfer (sic, explicit and tacit knowledge). This figure shows the culmination and aggregation of a number of concepts and ideas which have been presented within this dissertation by the author. Principally, Figure 0.9 has been derived as a result of the analysis of the interplay between explicit and tacit knowledge (via Figure 0.6, Figure 0.7, and Figure 0.8), as a result of the explanatory, descriptive narrative analysis of the case data, against the focal theory model of knowledge transformation (shown in Figure 3.7 and Table 3-1, within Chapter 3 earlier).

Hence Figure 0.9 also highlights those aspects of Nonaka and Takeuchi's SECI model within the context of both Semiotic (i.e. explicit) and Symbiotic (i.e. tacit) knowledge. Once again, as in the case of Figure 0.6, the dark-lined curves linking both Semiotic and Symbiotic phases, attempt to show the non-linear and changing nature of this interrelationship. However, in the context of this diagram, these IS-specific organisational influences are also shown: Collaboration (Structure), Technology Transfer (Enterprise), Vision (Leadership) and Process (Managerial).

In such a way the TAPE frame-of-reference so derived by the author provides a holistic interpretation of these fundamental aspects of knowledge, and allows for an interpretation of both the human, social and technological facets of decision-making behaviour. Given the case studies discussed and presented in this thesis, the author suggests that for the case of Company A and User X (i.e. knowledge used within the CAE task), this fits at the left hand side of the diagram. In other words, the CAE task was derived and based upon Semiotic or Structural / Enterprise, explicit, knowledge. This culminated in a manifestation of knowledge which was Symbiotic or Managerial / Leadership, tacit, knowledge in essence.

So even though User X based his initial decisions upon a systematic approach, the actual outcome of this actions were driven by behavioural and environmental factors, which lead to a Psychological (Process or Vision-centred) application of that knowledge (i.e. heuristic domain knowledge). The opposite is true for Company B and Manager M (knowledge within the ISE task), whereby seemingly Symbiotic or psychological decisions were taken which were underpinned and driven by wholly Semiotic or environmental concerns. This amounted to Manager M attempting to base his "gut feel" IS-related decisions upon so-called traditional or orthodox financial cost accounting methods and reasoning.

Thus, the TAPE frame-of-reference can be used in order to understand this interplay between and all of these knowledge components, and can potentially also serve as a tool for assessing and analyzing the scope and impact of IS organisational change, through the mapping of stakeholders and their interactions with processes and technology.

Evaluation of the research approach

The author now turns to the issue of assessing the nature of the validity and reliability of the research carried out within this dissertation and its effects on the research findings and generation of the TAPE frame-of-reference. As noted in the development of the research methodology in Chapter 4, Validity is defined in terms of whether changes to the temporal or spatial relationship of the observer and observed affect the outcome of the elicited data. Similarly, Reliability is defined as a measure of quality or trustworthiness of the methods employed to capture the said data, and whether or not the data can be consistently captured. Hence in viewing and understanding the case study data and noting that all research is fallible, the author suggests that the research was valid purely as a result of the fact that the experiences and behaviours of the interviewed participants in Company A and Company B, was a true representation of the state of these organisations and of their culture, *at a particular moment in time*.

However, the author also notes that the research approach and subsequent data collected could have been reinforced and made more reliable, by interviewing and observing additional participants, particulary within Company A (the CAE knowledge task case study). Since only a single expert user, User X, was principally observed (though in relation to and noting the work practices of the other team members he lead), the responses elicited had to be taken even more on trust than in the Company B. This was because in the case of Company B, Manager M's behaviours and responses were upheld by the responses and behaviours of Manager N. Therefore construct validity was maintained in this case which also implied some level of reliability could be confirmed (as highlighted in such circumstances by Patton, 2001). In addition, because User X was responsible for the development and maintenance of the

ANISO3 CAE system himself, this introduced a dependent biasing variable, which may have indirectly or directly have affected his responses.

Validity of the research data could have been improved in Company A, by increasing and varying the number of observations of CAE users across the organisation (or even observing users at similar companies, within the same given knowledge task). Also reliability of responses may also have been improved by eliciting further and deeper responses from additional CAE users, rather than merely cursory comments and views expressed by members of User X's team. In order to limit and control the effects of this bias, a methodological triangulation approach was still employed using overlapping participant observation, semi-structured interviews and verbalisation techniques. This was also true for case Company B participants, although in that particular context, it was noted by the author that the participants were more vocal and gave more in-depth, rich answers consistently (more than Company A). In both cases, since the principal manner of the triangulation was methodological, it could be argued that in itself, even this may have been insufficient to ensure validity and reliability given one of the cases observed was weaker than the other. As such, it may have been prudent to apply a mixed or hybridised approach, using theoretical as well as methodological triangulation, in order to site the data with respect to previously published interpretivistic, epistemological research in the area of this dissertation.

However, as discussed in the review of the literature and the resulting novel taxonomy presented by the author in Figure 2.14 in Chapter 2, there has been very little or no research within the purely IS area of knowledge representation (as opposed to the computer science view of knowledge representation in terms of an AI approach). Moreover, the existing literature within CAE evaluation, was limited in itself in terms of quantity (only a few key papers were found to be of pertinent value, being published in the late 1990's – for example Babuska, 1996; Liker *et al.*, 1992; Szabo and Actis, 1996). In contrast to this though, Company B case data (the ISE knowledge task) could also have been validated further in a theoretical sense against other strategic decision-making texts, in the field of manufacturing and operations management. Notwithstanding the fact that these additional approaches may have taken further time and planning to implement within the course of this doctoral research, the author notes that it is unusual for interpretive, qualitative IS research to employ theoretical triangulation in such a manner. This is because, social science thinking and philosophy which IS research is heavily based upon, contends that to hold a theoretically-based view when analysing case study data is difficult, as sociology has to employ a particular ontological stance which, when using or contrasting against multiple theories, becomes meaningless.

Thus, as Massey notes, the credibility of applying triangulation in a social reality setting can become stretched itself, if it is hoped that by a rigourous application of multiple views and methods it will be able to make the view of reality more certain (Massey, 1999, Section 4). Furthermore, it is also important to note that the application of any triangulation approach, is purely judgment-based on behalf of the researcher (which implies an indirect, implicit though nonetheless important bias yet again).

In this vein, Dick and Swepson (1994) as well as Robinson (1997) and also Sterman (2002), agree that absolute validity is difficult to achieve within interpretive research : rather validity of data gathered should be proved *incorrect* in some sense first, for it to be verified as being a valid representation (or rather in relation to the data that has *not* been found or questions which have been left unanswered). Blaikie (1991), Jick (1983) and Morgan (1986) all individually stress this facet too in terms of the subjectivity of such validities, in terms of the appropriate and inappropriate use of a combination of research protocol methods. Travis (1999), who echoes the work of Levy (1991), argues in addition that interpretivist research should be evaluated rationally with respect to the criteria of the research context (i.e. the usage of appropriate and conditioned research methodologies relative to the research questions posed).

Taking these points into account, how reliable and or valid are the resulting models presented within this dissertation and the TAPE frame-of-reference so derived from this analysis and synthesis?

Subjectively, these constructs are valid in terms of the manner and context within which they have been derived: based upon a classification of knowledge (within Figure 2.3), the resulting knowledge transformation drivers highlighted (within Figure 3.7 and Table 3-1), and the model of Semiotic and Symbiotic knowledge interplay (within Figure 0.6). Objectively, on the other hand, one can take the view of Box (1979) and in some sense, the systems thinking view propounded by Ackoff (1989), Checkland (1981) and Sterman (2002), that such constructs may, at best, be incomplete since they do not model the richness of the human real-world view in a holistic sense. These authors take the view that the generation of models and artifacts which represent the world around us are perfect and imperfect at the same time.

Hence, when George P.E. Box mentioned that "All models are wrong – but some models are useful" (Box, 1979), he was alluding to the fact that decision makers sometimes have to make decisions with incomplete information, which may be only explained by the best *available* models. Ultimately the aim of any decision-making or knowledge intensive task is to make decisions that balance competing goals using both complete and incomplete information. Therefore the accuracy needed from developed models of the world, is dependent upon the way in which the model itself is used and interpreted. In such a way, decision-making tasks themselves tend to adapt to the models that they are based upon – the so-called exogenous / endogenous effect of the influence of a system on the individual, and of the individual on the system (Sorensen and Kakihara, 2002; Sterman, 2002). Subsequently, achieving accuracy within a representation of the real world becomes increasingly difficult, as the level of complexity of the model increases to accommodate an ever finer granularity of representation.

Sterman commented that the systems science view of the world has always favoured on the process of modelling systems rather than on the results of such efforts, in the quest for achieving validity through simulation and testing (Sterman, 2002, pp. 521). As Sterman suggests:

> *"…we stress that human perception and knowledge are limited, that we operate from the basis of mental models, that we can never place our mental models on a solid foundation of Truth because a model is a simplification, an abstraction, a selection, because our models are inevitably, incomplete, incorrect – wrong".*
>
> Sterman (2002), pp. 525

Essentially, what Sterman and others mean when they say models are wrong is that any model should yield a fundamental kernel of knowledge at its core, about the context within which it exists. But at the same time, this model should allow us to understand its imperfections and the limitations of the world it is trying to represent, through the inclusion of human, social, systemic and process flows and other impinging factors. A natural consequence of this approach, means that if better, detailed or more complex representations of reality are defined, the accuracy of our predictions and quality of decisions should also increase. Conversely however, providing decision makers with ever more complex models and choices inevitably leads to the use of heuristic rules, that tend to *reduce* the complexity to a manageable level (as has been seen in the case of User X within the CAE modelling task). Interestingly, yet unfortunately, such simplifications are achieved by excluding the complicated and subtle alternative options, which are required in order to make balanced and holistic judgements (Meadows and Robinson, 1985). This occurred in the case Manager M in Company B, where a limited number of financial factors were used to ultimately drive the ISE decision. So, reducing the number of management options may make the decision and knowledge requirements much simpler, though not necessarily, that much better.

As such, any conceptual artefact which attempts to model the range of knowledge and information options available within a decision-making task based upon either a complexification or simplification of reality, may be limited in its expression due to a lack of definition of the boundary and legitimacy of its overall context. If the boundaries of a model are known, then the resulting boundaries of any decisions and interpretations of that model can also be restricted and understood better. Consequently, the derivation of the TAPE frame-of-reference has deliberately evolved as a result of a multitude of models and decision-making considerations spanning both the case study contexts (CAE and ISE knowledge dependencies). By introducing these additional views of not only the SECI approach of Nonaka and Takeuchi (1995), but also the author's previously published research (Baddi and Sharif, 2003; Irani *et al.*, 2002; Sharif, 1997; Sharif and Irani, 1999; Sharif *et al.,* 2004), the dissertation has attempted to bound the intricacies of knowledge representation within the limits of those factors which relate to both key individual and organisational factors. In doing so, it is hoped that the representation of knowledge within TAPE, is sufficiently fertile in order to cultivate further interest and work within the area. As such, the next section defines some pertinent avenues for future research in this context.

Recommendations for Further Work

The research presented and discussed thus far, has established that understanding how knowledge is used and represented within organisations is a difficult and complex task. This is principally due to the fact that the human element to the definition and representation of knowledge is inherently composed of both tacit and explicit parts. The author feels that this is a universal research initiative which needs to be addressed in order to overcome what has been termed within this dissertation as the knowledge conundrum.

Any model or representation is valid and reliable, but only at the time it was generated. The problem encountered by being involved in the generation of such concepts, is that it is difficult to validate any model until *after* it has been suggested and presented. This is true for the TAPE frame-of-reference developed by the author and presented within this thesis also. Therefore in order to validate and verify a model's reliability, a continual assessment must be carried out dynamically to see if it represents reality accurately. Time and space constraints on researcher's resources mean that this requires continuous effort also.

For this reason, any research needs to be an iterative inquiry into the changing nature of the observed phenomenon, relative to the research design and protocol instruments used.

Thus, it is the author's view that in order to further substantiate and refine the frame-of-reference developed for these particular IS cases, further research is indeed required. This would be not only in terms of a validation of the case data found, at similar organisations, but also perhaps a comparison with organisations of different sizes and structures. This dissertation also did not consider the full impact of organisational culture upon knowledge. This is a much wider topic, and as such, was specifically not included within the remit of the thesis, as this would constitute the basis for an action research methodological approach (Zuber-Skerrit, 1991). However, as noted from the synthesis of the collected case data, some of the tacit aspects of the IT/IS decision-making task (notably the internal politik and effect of networking amongst senior management), would also be a useful avenue of research enquiry. In terms of the research methodology employed, this was typical of traditional information systems research projects. The use of case study success and failures has been well documented – however, taking an impartial view on this suggests that additional research approaches within this field, should perhaps employ an ethnographic, or maybe even action research approach to gathering the field data. Analysing and synthesising the temporal effects of how knowledge is used and represented within these types of cases, would also be of interest to the research community, through a combination of a mixed-methods approach using multiple methods of triangulation.

The usefulness of the TAPE frame-of-reference and resulting models and frameworks so derived within this thesis, provides the research field with an expanded range of options in terms of how knowledge is represented within the particular IS environments observed. Yet there is still an opportunity to quantify the resolution and complexity of the author's derived approaches, with decision tools and processes that can transform purely theoretical conjectures into actual information required for decision-making. Therefore another avenue for research is to hybridise the representation of knowledge with tools and processes that will allow researchers and practitioners in MIS to explore the holistic nature of knowledge use within IS organisations and cultures.

This could potentially be achieved by viewing the knowledge representation problem through different research lenses, respecting differences within how knowledge is used and manipulated by different stakeholders. By integrating representations of the real-world with appropriate decision tools and processes, can also allow a timely opportunity to make concepts such as the TAPE frame-of-reference more useful to decision makers within not only within manufacturing, but within other business sectors also.

Hence, research within and along the lines of organisational knowledge can be extended in any manner of directions, both technical and non-technical in scope, and it is hoped that the contribution within this dissertation will add to the body of knowledge within information systems in this regard.

Summary

This chapter has sought to carry out an analysis of the case findings via a narrative approach to the qualitative case data. By comparing the case data with the focal theory model which was presented within Chapter 3 earlier, the author showed that there appeared to be a significant overlap and mixture of both explicit and tacit knowledge forms. This contrasted with the expectation that the externalisation (understanding and translating tacit knowledge into an explicit form) aspect would be more explicit, i.e. more visible in nature.

However, the research finding for the CAE task, found both this aspect and the internalisation aspect (converting explicit knowledge into a tacit form), to be inarticulated (thus, tacit in nature itself). This was due mainly to the fact that the CAE process in this case was highly specialised, and as such required domain expertise in its context. This expertise was at times difficult to articulate and hence in terms of User X, had an impact on communicating the effects of adhoc optimisations to waveguide designs, to the upstream Team B. Similarly, for the ISE task within Company B, the finding was that since the organisation did not use any formalised or holistic approaches to evaluating investments in IT/IS, the totality of the decision-making capability rested solely in the hands of Manager M.

Moreover, the externalised or psycho-sociological nature of the knowledge used by the evaluation team under the responsibility of this manager, meant that there was a lack of involvement and communication to other stakeholders of the MRPII system chosen. This resulted in the negation of responsibility from Manager M to Manager N, wherein it was also found that this lack of focus in order to use the correct information and knowledge, led to the somewhat disastrous implementation of the MRPII system.

In order to supplement and understand these aspects of the case study data, and in order to assist in the formation and development towards a frame of reference for knowledge representation within these IS environments, the author also presented alternative models to augment these gaps in knowledge. In terms of the CAE task, this was to show how artificial intelligent systems approaches could be used not only to automate, but also to guide and highlight the knowledge deficiencies and dependencies within the CAE and FEA tasks.

The ISE task was also analysed in further detail to understand and assess the implications of the managerial decisions taken. In the light of previously published research in the area of manufacturing IS implementations, the author thus proposed that some underlying causal factors were driving the process. These were defined in terms of five technology management factors, which were then contrasted with the given appraisal used within Company B. To model the causal interrelationships therefore within the decision making task, a causal technique, Fuzzy Cognitive Mapping (FCM) was used.

The case-specific "threads" were evaluated against the case data, which were found to be largely bourne out by the analysis : the underlying psychological and sociological relationship between Explicit and Tacit knowledge was shown to exist in terms of the both CAE and ISE tasks not being wholly tacit or wholly explicit; and the Tacit knowledge in each task (CAE model optimisation in Company A by User X and intuitive evaluation of an MRPII package in Company B by Manager M), was analysed and assessed to be based upon *a-priori* assumptions and intuition (largely reinforced through the individual's experience and self knowledge).

It was also discussed that that there was some inherent bias introduced in terms of the case study protocols used for both organisations, and in particular, case Company A (participant observation and semi-structured interviews). This was due to the redundancy of case data which was reliant upon a single source of participant evidence, presented. However, the author noted that the triangulation and data refinement technique used did attempt to highlight this fact through an iterative application of comparison of case responses of User X against his team members. In spite of this, the author contended that rich and in-depth case data (in the sense of Yin, 1994), was still able to be captured and analysed. Notwithstanding these facts, the author also suggested that further triangulation along the lines of theoretical as well as data lenses, should have also been carried out (alongside the methodological form of data triangulation applied within the research presented).

Finally, noting that such models were specific to each case concerned, a frame-of- reference was then developed in terms of an organisational (enterprise) context, and a subsequent relationship mapping between explicit and tacit knowledge forms. This was defined as being a relationship involving Semiotic and Symbiotic aspects of knowledge, where the resulting overlap between explicit and tacit knowledge, defined a point of knowledge transformation. This knowledge transformation point ultimately was said to define the level to which knowledge could be represented within an organisational, IS context. As such, the TAPE frame-of-reference model, included aspects of both the key psycho-sociological (externalisation) and behavioural (internalisation) aspects of explicit and tacit knowledge, aligned to the core components of enterprise processes.

As a result of the derivation of this frame-of-reference, the author has sought to synthesise the background, focal and data theory chapters together. In doing so, this research has highlighted and provided some key contributions to the understanding of knowledge within information systems environments. These are:

- *A novel classification of the forms of knowledge found within the discipline of IT/IS (computing science and information science): Structural, Interpretive, Evaluative forms of knowledge* (shown in Figure 2.3 in Chapter 2)*;*
- *A novel taxonomy which shows the development of knowledge from the fields of economics and management science, towards that of IT/IS* (shown in Figure 2.14 in Chapter 2)*;*
- *A conceptual model which seeks to envelop both the explicit content as well as the tacit context of knowledge in terms of semiotic (form / representational) and symbiotic (causal / inter-related) factors* (shown in Figure 7.6 in Chapter 7)*;*

- *The development of a novel frame-of-reference, based upon the synthesis of both organisational / enterprise knowledge requirements and the relationship between semiotic-symbiotic (explicit-tacit) knowledge forms. The result of which provides a roadmap for how knowledge is represented within these two forms of manufacturing IS context* (shown in Figure 7.8 and 7.9 in Chapter 7).

The analysis of the empirical case data has therefore added to and supported, the literature across both CAE and ISE fields through highlighting the contingent dependencies upon both explicit and tacit knowledge.

CHAPTER 8

Conclusions

This final chapter offers conclusions to the research conducted within this dissertation. This encompasses an outline of the research findings, based upon an analysis of the reviewed literature and of the methodology which was used in order to collect the field study data. Noting that all research is fallible and subject to a finite timescale, an evaluation of the research is made. Key conclusions arising from the thesis are subsequently reported, and, finally, the original contribution to research in the field is also presented.

Conclusions

The intention of this chapter is to conclude the research within this dissertation by addressing the research findings of the study. Hence through highlighting the contribution of the research to the field of knowledge representation within Information Systems, conclusions are drawn from the issues raised via the analysis of the case data and the synthesis and formulation of the frame of reference model for knowledge representation within manufacturing IS environments.

Research Findings of Empirical data and Background theory

The research has found and upheld the research hypotheses or threads supplanted by the background theory in chapter 2 and defined within the focal theory in Chapter 3, that: (i) an intrinsic relationship exists between both the explicit as well as tacit forms of knowledge; (ii) tacit knowledge is reliant upon *a-priori* assumptions and intuition, and is reinforced through on-going individual experience.

The relationships underpinning these statements exist in terms of what the author has classed as being a semiotic, or purely communicable structure of the knowledge; along with a symbiotic, or purely transitive and intuitive application of knowledge, in order to carry out decision-making tasks. These tasks have been extensively evaluated and analysed within the synthesis chapter, Chapter 7, via a narrative discourse and description of the case study data.

Hence, through the evaluation of this case study data, a frame-of-reference for knowledge representation within manufacturing IS environments was formed, as shown in Figure 7.9 in Chapter 7. This was carried out by the author, based upon the development of a conceptual framework which defined Environmental, Behavioural, Systemic and Psycho-Sociological components of the well known SECI model of Nonaka and Takeuchi (see Table 3-1 and Figure 3.7 in Chapter 3); a semiotic and symbiotic model of the relationship and interaction between explicit and tacit knowledge (Figure 7.6 in Chapter 7); and finally the interrelationship between organisational information and knowledge within these contexts (Figure 7.8, also within Chapter 7).

Research Evaluation

This dissertation has attempted to highlight the importance and relevance of knowledge within two manufacturing IS environments, or IS scenarios. Through the review of the published literature on the subject of knowledge and IT/IS within manufacturing, it was generally found that at the very least, the definition and implementation of concepts of knowledge within organisations is highly complex. This is due in parts both to the numerous definitions of knowledge itself; and the wealth of research in the areas of computer aided engineering as well as IT/IS evaluation. Thus, the author was of the view that in order to comprehend the *nature* of knowledge within these contexts, some form of navigational mechanism to discern between the various types of knowledge, was required. This was in direct contrast to adopting atypical approaches to this subject, in terms of applying a purely computational approach (so-called Structural knowledge); an enquiry or information science approach (so-called Interpretive knowledge); or an appropriate knowledge management / procedural approach (so-called Evaluative knowledge).

In order for the research hypotheses and case data to be empirically sourced, analysed and validated, an appropriate research methodology was required. As is the case with any form of research, the selection of a suitable methodology and an execution plan, in terms of an overall research design is crucial. For this reason, the author chose to adopt the strategy of defining the thesis and dissertation, in terms of the Phillips and Pugh (1994) approach of Background Theory, Focal Theory and Data theory (and subsequent synthesis / rehypothesis). This approach allows a highly structured and objective view of the research to be presented, even though the contents of the dissertation may be subjective in the sense of a contextualised view of the research data. The overall methodological stance taken was in terms of an empirical qualitative case study research strategy, in the guise of that proposed by Mumford (1985), Walsham (1993) and Yin (1994). Although Yin suggests that the case study approach is positivist in nature, the author took the view that due to the highly narrative and unquantifiable form of data that would be sourced (from interview and participant observation subjects), such a stance would not be supportable or analyseable easily. Therefore, the interpretivistic stance was taken – and in an epistemological sense, this approach proved to be easier to handle in terms of the data collection and analysis. As such, it is now also vital to assess the particular research approach taken, and to highlight aspects of the research design which could have been executed differently, in an ideal research context.

Research Design and approach

The approach taken with regards to the choice of research methodology and the research design, can be said to have been successful in the sense that the case data collected did assist in the development of the conceptual framework for knowledge transfer, as outlined in Figure 3.7 in Chapter 3. This data further upheld some of the key indicative aspects of knowledge usage and representation within the CAE and ISE tasks (experienced engineers tend to expose heuristic decision making behaviour, which is supplanted by regularly upholding explicit theoretical knowledge with tacit knowledge; explicit investment evaluation and appraisal criteria, defined by senior manufacturing management, can be greatly influenced by tacit psycho-sociological, and intuitive knowledge).

However, in providing closure to the research presented herein, and assessing how the research was actually carried out in the field, the author accepts that the research approach could have been executed to yield perhaps better and more insightful results. Firstly, the remit of the research questions raised could have focussed entirely on simply the tacit component of knowledge representation, without considering explicit factors (or at least understanding explicit knowledge aspects were given). Secondly, the number of cases chosen for analysis could have either been reduced to a single specific example, in order to focus on a particular aspect of the explicit – tacit representation issue; or indeed broadened to provide a wider platform for generalising the framework proposed. This notion could also have been extended to including regional or even national / international quotients of the same research problem. It may also have been advantageous to restrict the expertise of each manufacturing organisation to the same sub-field of manufacturing – for example, both compare and contrast two companies in the hi-technology electronics sector (as opposed to comparing a discrete manufacturing jobbing shop with the R&D department of an electronics company).

Another aspect, which could have been normalised in the similar respect, may have been to restrict the research investigation towards analysing a particular component of the manufacturing cycle only, as opposed to disparate components (the design phase in the case of the CAE task, and the production planning phase in case of the ISE task). Taking this one stage further, it may also have been useful to assess the impact of knowledge representation and usage within the different levels of the organisational hierarchy also. From the current research carried out within this dissertation, it can be seen that User X was at the production and R&D level of the organisation, although was not a member of the board of directors, senior management – as was definitely the case with Manager M in the second case study.

This may also have assisted in situating and assessing the “soft” components of the TAPE frame-of-reference suggested, in terms of the effect of both behavioural (leadership) and psycho-sociological (managerial) factors.

In other words aligning both of these tacit knowledge factors with traits of certain organisational character types, such as middle or senior management. Allied to this, is the fact that the participant sample size for each case study should have been similar. In the case of the CAE task, only 1 key participant’s responses were used, while in terms of the ISE task, up to 6 participant’s responses were used. The reason for the single source approach used in the Company A case study, was largely dictated and driven by the fact that User X was perceived to exhibit some of the knowledge components to be searched for. There was a potential bias in the selection and analysis of the data gathered, because of the emphasis on this single participant’s views and experience. However, in attempting to triangulate the data so gathered, the author applied a combination of data, theory and methodological triangulation to the recorded case information in order to substantiate the observed and recorded phenomenon. Also, although User X was seen to provide sufficiently rich, in-depth data.

In concluding this dissertation within this chapter, the author returns to the aim of this research, which was to develop a frame-of-reference in order to distinguish between different forms of knowledge, within two manufacturing IT/IS scenarios. In so doing, provide an outline of the boundaries between both explicit and tacit knowledge in the context of the given decision-making tasks of CAE and ISE.

This aim has been achieved, wherein the TAPE (Technology, Accessibility, Psychology and Enforceability) frame-of-reference developed by the author, is shown in Figure 7.9 in Chapter 7. This was generated as a result of the development and analysis of the case data with respect to a realization of Nonaka and Takechi’s SECI model within the context of the reviewed literature (i.e. Table 3-1 and Figure 3.7 in Chapter 3). These factors were split up into Environment, Systemic, Behavioural and Psycho-sociological components respectively. The frame-of-reference was also based upon the result of the author’s published work in the joint areas of CAE and ISE (see List of Publications on Page x for further details), from which the underlying fundamental organisational knowledge facets of Enterprise (technology transfer), Knowledge Sharing (organizational learning), Managerial (process), Leadership (vision) and Structure (collaboration) were formed. Thus, through the critique of the extant literature via a taxonomy, the generation of a focal theory, development of a research methodology and design, and the application of interpretivist empirical data analysis techniques to the case data, the objectives of this research have also therefore been satisfied.

Research Contribution

The most important element of a doctoral dissertation is concerned with aligning the importance of the thesis, to the development of the discipline being researched. The contribution that the thesis makes to extend the boundaries of knowledge is now presented. It is important to note that this thesis has not set out to expressly validate or falsify notions of knowledge, knowledge management or other specific techniques and technologies that have been mentioned (such as Artificial Intelligence techniques).

Rather, the focus of the research has been purely explanatory in nature, taking into consideration the contextual requirements for decision-making tasks within information systems, and related stakeholder responsibilities within a manufacturing setting. Thus the outcome of the research has been to highlight those key knowledge dependencies in each case study analysed. As a result, this thesis has offered a contribution to the field of knowledge within information systems, through the following aspects:

- *A novel classification of the forms of knowledge found within the discipline of IT/IS (computing science and information science): Structural, Interpretive, Evaluative forms of knowledge* (shown in Figure 2.3 in Chapter 2)*;*
- *A novel taxonomy which shows the development of knowledge from the fields of economics and management science, towards that of IT/IS* (shown in Figure 2.14 in Chapter 2)*;*
- *A conceptual model which seeks to envelop both the explicit content as well as the tacit context of knowledge in terms of semiotic (form / representational) and symbiotic (causal / inter-related) factors* (shown in Figure 7.6 in Chapter 7)*;*
- *The development of a novel frame-of-reference, based upon the synthesis of both organisational / enterprise knowledge requirements and the relationship between semiotic-symbiotic (explicit-tacit) knowledge forms. The result of which provides a roadmap for how knowledge is represented within these two forms of manufacturing IS context* (shown in Figure 7.8 and 7.9 in Chapter 7).

These contributions can also be viewed in the context of published research in the field, which has continuously attempted to highlight the importance of justifying and realising the importance of knowledge, its capture, codification and usage within organisation (the reader is referred to the front of this thesis, to the section denoted as "Publications arising from this thesis" on Page x, which highlights published and refereed papers in relation to this dissertation).

However, given that this research was primarily focussed upon two separate though contextually relevant aspects of the manufacturing cycle, it is important to note that the scope of the research and its original remit could be developed, and as such, this has several implications. These factors are now discussed in more detail in the following, final section.

Conclusions based upon the research

This dissertation has attempted to outline and investigate, the dynamic interplay between both explicit (formalised) and tacit (intuitive) knowledge, by observing participants with regard to two particular information systems within the manufacturing sector. Through analysing the nature of computer aided engineering (CAE) as well as manufacturing resource planning (MRP) tasks, the research has sought to provide a frame-of-reference for the effective representation of knowledge in these specific terms cases.

Within the background theory (Chapter 2), the author highlighted the inherent complexity and difficulty associated with defining knowledge, given that there are a variety of sources of definition of this concept. Through characterising knowledge in terms of Structural, Interpretive and Evaluative forms, the author also sought to define the importance of context as well as content, of knowledge. Noting that in the majority of the published literature within the field of IT/IS the prevalence has been towards that of manifesting knowledge within organisations in terms of a process (in terms of knowledge management approaches), the Evaluative form of knowledge was chosen as especially suitable to this field. The importance of explicit and tacit knowledge within such a knowledge form was then defined and discussed in detail within the focal theory (Chapter 3).

Using the organisational knowledge factors within Nonaka and Takeuchi's SECI model, the author recapitulated the fundamental components of this model in order to realise those factors which were pertinent to both the CAE and ISE decision-making tasks. This framework was developed in order to be used in the analysis of Computer Aided Engineering (CAE) and IS Evaluation (ISE) tasks within an manufacturing IT/IS environment.

The methodology required in order to capture the empirical data was outlined in Chapter 4. This entailed defining an Empirical qualitative case study approach, which employed participant observation, verbalisation (the "Think Aloud" protocol) and semi-structured interviews, within its design, to gather information from the case study companies and research subjects chosen. The potential for bias within the data was addressed by triangulation techniques based upon theoretical (literature-based), methodological (task- or business process-based) and data (observation-based) techniques. Following this, the case study data itself was presented for both the CAE and ISE tasks in Chapter 5 and 6 respectively. The focus of the research field studies, being to show that an overlap between explicit and tacit forms of knowledge exists within the CAE and ISE decision-making tasks. Finally, a synthesis of the analysed field study data in the form of narrative description and comparison against the focal theory derived earlier was presented within Chapter 7.

As a result of this penultimate chapter, a conceptual frame-of-reference was derived, which highlighted the explicit (semiotic) as well as tacit (symbiotic) factors involved in representing knowledge within manufacturing IS environments. This frame-of-reference allows for the identification of those organisational factors which impinge upon knowledge-intensive decision-making tasks. As such, the contextual relevance of the underlying models and framework (in Figure 7.6, 7.7 and 7.8 within Chapter 7), provides an insight into the relative importance of both explicit and tacit knowledge in terms of knowledge creation and transfer within firms (in the guise of Nonaka and Takeuchi, 1995). The chapter also discussed the inherent limitations of the concepts of validity, reliability and triangulation in terms of interpretive research. Essentially, the author suggested that in order to control and limit the bias within the research presented within this dissertation (especially in the case of Company A data regarding the observation of User X in terms of the CAE task), a systems thinking, rationally-grounded, perhaps even ethonographic or longitudinal research approach could have been taken. This would have allowed the researcher to become more immersed within the organisational environment, and could have potentially alerted the author to biases and dependent variables as part of the elicited field data. The chapter concluded with a discussion of recommended areas for further study within the area of knowledge in information systems. Such work to extend the presented research and validate the findings may also include the generation of tools and processes to realise and test the efficacy of the TAPE frame-of-reference developed by the author, in similar or dissimilar organisational contexts and / or cultures.

Appendix A - Research Methodology Protocol

This appendix details the research methodology and associated protocols used in order to gather the data for the research presented within this dissertation. As defined within Chapter 4, the approach used is that of Empirical Qualitative Case Study research, which is supported by Quantitative collection of data from the defined research subjects as set out below, via Participant observation, Think-aloud recording protocol and Semi-structured interview techniques.

Participant Observation: key informants

For each case study, the following research subjects were observed via a direct overt observation approach:

Case Study Organisation	*Subject*	*Position*	*Experience and years in organisation*
Company A	User X	Senior Electrical Engineer	15 years experience in field ; 5 years within the organisation, 10 years within academia; Chartered Engineer
Company B	Manager M	Managing Director	Owner and Director of company for 10 years
Company B	Manager N	Production Planning and Control	15 years experience in bespoke manufacturing ; Chartered Engineer

		Manager	

The observations carried out were in terms of being directly situated with each research subject for a period of time – from a few hours to a number of days on each occasion.

Think-Aloud protocol

This protocol was not always used as it depended mainly on the system of responses from the research subject. An example of the discourse typically gathered is shown below for case Company A:

Interviewer	Can you tell me what steps are involved in designing this particular waveguide? How do you know how to evaluate and understand the results that the ANISO3 package provides you?
User X	Well, that is both an easy and a difficult question to answer. First, it is easy in the sense that we can obviously see what geometry of guide we have. Then it is quite easy to just draw it on screen – so let's just do that (*runs the CAE package on his machine*). Ok, we just have to wait a second while it loads – there. Ok, so firstly I need to tell it what sort of problem I want to solve – do I need to solve a boundary value problem or one with a singularity involved. For this problem, we have quite a simple guide – so I click BVP (*selects option on screen*). I can then go on and draw the guide – it's quite simple.
Interviewer	So how do you know what to make of the simulation results?
User X	Ok, that is in somewhat difficult. I use my judgement obviously. But I tend to rely on the code to guide me, after all the guys who wrote it knew something about what we are trying to do here! No, I think that when I am looking at the screen, I tend to be trust the results given. It has a quite good record of delivering the results. It doesn't take too long. On the other hand, it really does depend on the problem – singularities and the one I told you about earlier, the infinite wall case? Then I will have to start looking at how I need to

	modify the parameters that I put in, to model, to get that phenomenon accurately.

Semi-structured interviews: Question guides

The following are the interview guides used for each of the cases presented within this dissertation. These questions served as a rough guide to carrying out the interviews with each of the participants concerned, and were not necessarily asked in the order presented, due to the level and depth of responses gathered.

Generic / Filter questions

Interviewee's background: name, job description, background, work history and experience with the organisation

- Can you describe your role within the company?
- Can you describe your day-to-day work?
- What sources of information / knowledge do you require in order to carry out your work?
- Who / what other teams or individuals do you work with in order to carry out your duties?
- What do you understand by the word knowledge? How would you define the knowledge in terms of the work that you do?
- What is the role of IT/IS within your work?
- Does knowledge of IT/IS help or hinder your decision-making capability?
- Do you face any specific issues with accessing knowledge in order to make decisions? If so, what are they?
- How do you think making access to knowledge within your organisation would affect the way you make decisions within your working tasks?

- Can you describe an example of where you have had to use knowledge to carry out a particular task?

Company A Specific questions

- Can you describe and define what a waveguide is and where it is used?
- What is involved in designing one?
- Can you tell me more about the design process within this organisation?
- What role does IT/IS play in the design task?
- Can you describe how the ANISO3 package works?
- What are the strengths and / or limitations of this software?
- When modelling waveguide designs, what other information and knowledge sources do you need to access?
- How do you know when and if you design is correct – i.e. how much faith do you have in the software?
- Is there any part of the design process you would change in order to make better use of your own or your team's knowledge?
- Can you take me through the design of a waveguide? (prompt for Thinking-aloud verbalisation and observation of task by subject)

Company B specific questions

- Can you describe how Company B manufactures products for its customers?
- Can you describe the role that IT/IS plays within the organisation?
- What do you know about the production planning and control process in Company B?

- What do you know about the production planning and control, MRP II, system within Company B? Could you describe how it works within the manufacturing lifecycle?

- How does the MRP II impact and affect you?

- Who are the main stakeholders and owners of the system?

- Do you know how this part of the manufacturing IT/IS infrastructure was chosen? Were you involved in the evaluation of the implemented system?

- Can you describe and take me through the evaluation process? (trigger for thinking-aloud verbalisation of the task)

- What factors governed the evaluation of the MRP II system?

- What sources of information / knowledge were used to evaluate the product?

- Was the implementation successful? What are the key issues, if any, with the resulting system?

- What information / knowledge would have helped or assisted in the evaluation of the MRP II package?

Appendix B - Data models used by User X in Company A

The following diagrams show specific waveguide designs that were designed and optimised by User X, as defined in the first case study (data theory), Chapter 5.

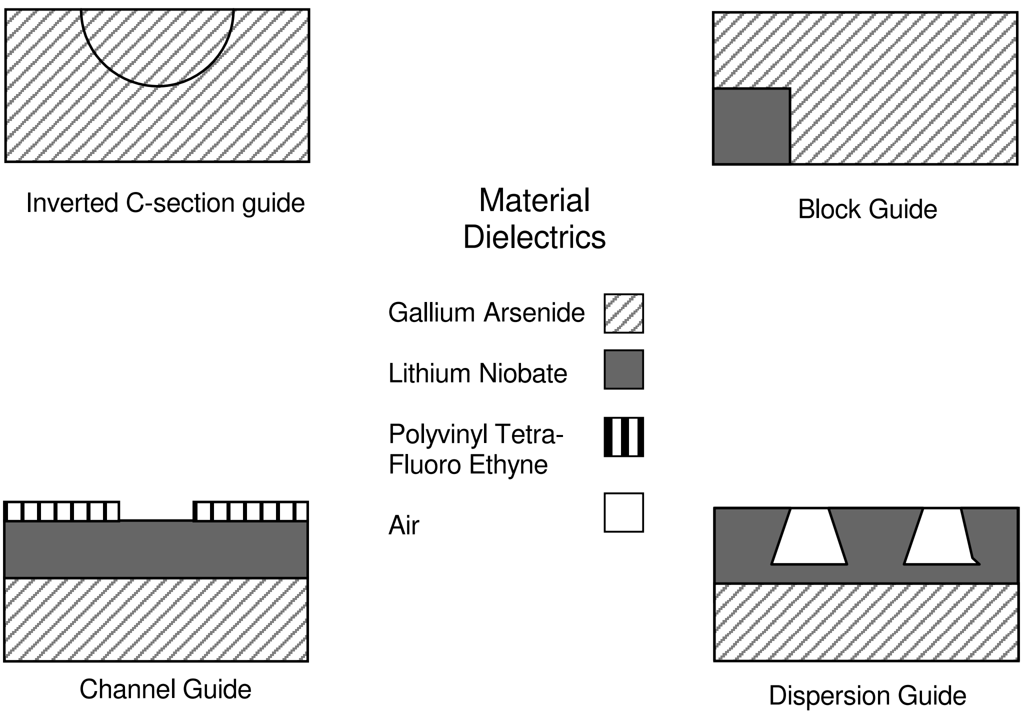


Figure B.1 Cross-sectional Waveguide geometries used in optoelectronic applications (Fernandez and Lu 1996; Hunsperger 1991 ; Silvester and Ferrari 1996)

References

Abdullah, M.S., Benest, I., Evans, A., and Kimble, C. (2002). Knowledge Modelling Techniques for developing Knowledge Management Systems. In *Proc. 3rd European Conf. Knowledge Management*, Dublin, Ireland, September 2002, pp. 15-25.

Ackoff, R. (1989). From data to Wisdom. *Journal of Applied Systems Analysis*, **16** : 3 – 9.

Ahn, C.H., Lee, S.S, Lee, H.J., and Lee, S.Y. (1991). A Self-organizing Neural Network Approach for Automatic Mesh Generation. *IEEE Transactions on Magnetics,* **27** (5) : 4201 - 4203.

Aleksander, I, and Morton, H. (1990). *An Introduction to Neural Computing*. London : Chapman and Hall.

Alfonzetti, S, Coco, S., Cavalieri, S., and Malgeri, M. (1996). Automatic mesh generation by the Let-It-Grow Neural-Network. *IEEE Transactions on Magnetics,* **32** (3) : 1349 - 1352.

Alger, J.R.M., and Hays, C.V. (1964). *Creative Synthesis in Design.* Englewood Cliffs, NJ : Prentice-Hall.

Al-Hawamdeh, S. (2002). Knowledge Management : re-thinking information management and facing the challenge of managing tacit knowledge. *Information Research*, **8** (1), Paper number 143. Available [on-line]. http://InformationR.net/ir/8-1/paper143.html. (20th September 2002)

Al-Mashari, M., and, Zairi, M. (2000). Supply-chain re-engineering using enterprise resource planning (ERP) systems: an analysis of a SAP R/3 implementation case, *International Journal of Physical Distribution and Logistics Management,* **30**(3-4) : 296 - 313.

Andrews, A.E. (1988). Progress and challenges in the application of Artificial Intelligence to Computational Fluid Dynamics. *American Institute of Aeronautics and Astronautics Journal,* **26** (1) : 40-46.

Ansoff, I.H. (1979). *Strategic Management*. Macmillan.

Anthes, G. H. (2001). Symbiotic Intelligence. Available [On-line, October 2001]. http://www.computerworld.com/managementtopics/management/story/0,10801,64912,00.html

Argyris, J.H. (1960). *Energy Theorems and Structural Analysis*. London : Butterworth.

Argyris, J.H., Doltsinis, I. St., Frik, G., and Tenek, L. (1994). Computational Structures Technology in Europe. *IEEE Computatational Science and Engineering.* Spring 1994, pp.43-54.

Arora, J. (1989). *Optimum Design*. New York, NY : McGraw-Hill.

Atluri, S.N. (1991). The Finite Element Method in the 1990's : A Personal Perspective, *The Finite Element Method in the 1990's : A book dedicated to O.C. Zienkiwicz* (Eds. E. Onate, J. Periaux and A. Samuelson), Springer-Verlag / CIMNE, pp.479-486.

Augier, M., Shariq, S.Z., and Vendelo, M.T. (2001). Understanding Context: its emergence, transformation and role in tacit knowledge. *Journal of Knowledge Management.* **5** (2) : 125 – 136.

Avison, D.E., and, Fitzgerald, G. (1998). *Information Systems Development: Methodologies, Techniques and Tools (2nd Ed.).* McGraw-Hill, London.

Axelrod, R. (1976). *Structure of Design.* New York, NY : Princeton University Press.

Babuska, I. (1996). New problems and trends in the Finite Element Method. In (Ed. J.R. Whiteman). *Proc. Conf. on the Mathematics of Finite Elements* (*MAFELAP '96)*, Brunel University, United Kingdom, 23-27th June 1996.

Babuska, I., and Miller, A. (1984). The post-processing approach in the Finite Element Method - Part3 : *A-posteriori* error estimates and adaptive mesh selection. *International Journal on Numerical Methods in Engineering,* **20** : 2311 - 2324.

Babuska, I., and Rheinboldt, W. (1977). Computational Aspects of the Finite Element Method. In (Ed. John R. Rice). *Mathematical Software III.* New York, NY : Academic Press, pp.225-255.

Bäck, T., and Schwefel, H.-P. (1995). Evolution Strategies I : Variants and their computational implementation. In (Eds. G. Winter, J. Periaux, M. Galan and P. Cuesta). *Genetic Algorithms in Engineering and Computer Science.* Chichester, England : John Wiley, pp.111-126.

Badii, A. (1999). The BSIRM_MB SmartProject Best Practice Framework. In Proceedings of the special Research and Technology Development Project Management Workshop, Sponsored by the European Directorate General of the Fifth European Research Programme, DGX111, EU-FP5 IST, Brussels October 1999, published November 1999.

Badii, A. (2000a). Summary Proceedings of UKAIS (Midlands) Research Seminar Series, UKAIS Newsletter June 2000.

Badii, A. (2000b). Design of architectures for forum management and re-negotiability in virtual environments: Proceedings of the 1st EnCKompass International Research Network Workshop, University College Northampton, July 2000.

Badii, A. (2000c). On-line point-of-click web usability mining with PopEval_MB, WebEval_AB and the C-Assure methodology, Proceedings of AMCIS 2000, University of California, Long Beach, August 2000.

Badii, A. (2000d). Man, Machine and Mutuality: Cross-cultural interoperability in Dynamic Web Design, 7th ECITE, Dublin September 2000.

Badii, A. (2000e). Man-machine mutuality and semiotics, evolving web pages as re-adaptive social stereotypes with attitude, Proceedings of the 2nd EnCKompass International Research Network Workshop Trinity College Dublin September 2000.

Badii, A. (2001). Information Systems Integration, P3ie-EnCkompass Workshop, Proceedings of United Kingdom Academy of Information Systems 6th Annual Conference, Portsmouth University, April 2001.

Badii, A., and Rolfe, H. (1996). Boundary sensitised (electronic) relationship management. *Proceedings of UKAIS'96*, Cranfield University., April 1996.

Badii, A., and Sharif, A.M. (2002). Enterprise Challenges: Information Management, Knowledge Integration & Deployment . In *Proc. International Conference on Systems Thinking in Management 2002 (ICSTM 2002),* Salford University, UK.

Badii, A., and Sharif, A.M. (2003). Integrating Information and Knowledge for Enterprise Innovation. Logistics Information Management, **16** (2) : 145 - 155.

Bahrami, A., and Dagli, C.H. (1994). Design Science. In (C.H. Dagli and A. Kusiak), *Intelligent Systems in Design and Manufacturing.* New York, NY : ASME Press, pp.7-25.

Bali, R., and Cockerham, G., and Bloor, C. (1999). MISCO: a conceptual model for MIS implementation in SMEs. *Information Research*, **4** (4), Paper 61. Available. [on-line]. http://InformationR.net/ir/4-4/paper61.html (11th May 1999)

Barr, P.S., Stimpert, J.L. and Huff, A.S. (1992). Cognitive change, strategic action and organisational renewal. *Strategic Management Journal,* **13** : 15-36.

Barthes, R. (1988). *The Semiotic Challenge.* Hill and Wang : New York, NY, USA..

Beale, R. and Jackson, T. (1992). *Neural Computing - an introduction.* Bristol, England : Institute of Physics.

Belkin, N.J. (1980). Anomalous state of knowledge as a basis for information retrieval. *Canadian Journal of Information Science* **5** : 133–43.

Belkin, N.J., and Kwasnik, B.H. (1986). Using structural representations of Anomalous states of Knowledge for choosing document retrieval strategies. In (Ed. F. Rabitti). *Proc. 1986 ACM Conf. on Research and Devleopment in Information Retrieval*, Pisa, Italy, pp. 11 – 22.

Bennett, R.H. (1998). The importance of tacit knowledge in strategic deliberations and decisions. *Management Decision*, **36** (9) : 589 – 597.

Bhatt, G. D. (2000). Organizing knowledge in the knowledge development lifecycle. *Journal of Knowledge Management*, **4** (1) : 15 – 26.

Bijlsma-Frankema, K.M., and Van De Bunt, G. (1994). In search of parsimony: a multiple Triangulation approach to antecedents of trust in Managers.

Binney, D. (2001). The KM Spectrum – understaning the KM landscape. *Journal of Knowledge Management,* **5** (1) : 33 – 42.

Biren, B. (2000). Xerox: Building a corporate focus on knowledge. 06/2000-4891. *INSEAD Working Case 06/2000-4891*, INSEAD, Fountainebleau, France.

Blackler, F. (1995). Knowledge, knowledge work and organizations: An overview and interpretation. *Organization Studies*, **16** (6) : 1021.

Blaikie, N. (1991). A critique of the use of Triangulation in Social Research. *Quality and Quantity*, **25** : 115 – 136.

Borowski, E.J., and Borwein, J.M. (1991). *Collins Dictionary of Mathematics (2nd Edition).* Glasgow, Scotland : Harper-Collins.

Bova, S.W., and Carey, G.F. (1995). Mesh Generation / Refinement using Fractal Concepts and Iterated Function Systems (IFS). *International Journal of Numerical Methods in Engineering,* **33** : 287 - 305.

Box, G.E.P. (1979). Robustness in the Strategy of Scientific Model building. In (Eds. R.L. Launer and G. N. Wilkinson). *Robustness in Statistics*. New York : NY, Academic Press, pp. 202.

Braglia, M., and, Petroni, A. (1999). Shortcomings and benefits associated with the implementation of MRP packages : a survey research. *Logistics Information Management*, **12** (6) : 428 - 438.

Brachman, R.J. (1977). What's in a concept: structural foundations for semantic nets. *International Journal of Man-Machine Studie*s, **9** : 127 - 52.

Brajnik, G. (1999). Information Seeking as Explorative learning. In (Eds. S. Draper and K. Van Rijsbergen). *Prof. Conf. MIRA'99,* Glasgow, UK, 14 – 16 April 1999.

Brown, S.L., and, Eisenhardt, K.M. (1998). *Competing on the Edge: Strategy as Structured Chao*s. Harvard Business School Press, Boston, MA.

Cagan, J., and Genberg, V. (1987). PLASHTRAN : An Expert consultant on Two-Dimensional Finite Element Modelling techniques. *Engineering Computations*. **2** : 199 - 208.

Capurro, R. (1985). Epistemology and Information Science. In (Ed. S. Schwarz). *Report TRITA-LIB-6023*, Royal Institute of Technology Library, August 1985, Stockholm, Sweden.

Capurro, R. (1992). What is information science for? A philosophical reflection. In (Eds. P.Vakkari, B.Cronin). *Conceptions of Library and Information Science. Historical, empirical and theoretical perspectives*. pp. 82 - 98. Taylor Graham : London.

Capurro, R. (2000). Hermeneutics and the Phenomenon of Information. *Research in Philosophy and Technology*. **19** : 79-85.

Carcaillet, R., Dulikravich, G.S., and Kennon, S.R. (1986). Generation of Solution-Adaptive Computational grids using optimization. *Computer Methods in Applied Mechanical Engineering,* **57** : 279 - 265.

Carlson, A.B., and Soderberg, K. (2001). *Perspectives on Knowledge Management* : *A small case study*. Viktoria Institute, Goteborg, Sweden.

Carrier, L. (1999). Managing at light speed. *IEEE Computer* July, pp.107-109

Chalmers, A.F. (1982). *What is this thing called Science ?*. Open University Press, Buckingham, UK.

Chartier, G. (1981). Fabrication of Surface Optical Waveguides. *Proc. 8th Int. Conf. NATO Adv. Study Inst. Integ. Optics : Physics and Applications, Erice, Italy*. New York, NY : Plenum Press. pp.49-72.

Chauvel, D., and Despres, C. (2002). A review of survey research in Knowledge Management 1997 – 2001, *Journal of Knowledge Management*, **6** (3) : 207 – 223.

Checkland, P. (1981). *Systems Thinking, Systems Practice*. John Wiley, London.

Cheung, Y.K., Lo, S.H., and Leung, A.Y.T. (1996). Finite Element Implementation. London : Blackwell Science, pp.81-127.

Ciborra, C., and Jelassi, T. (1994). Knowledge as Strategy. In (M.J. Earl, Ed.). *Strategic Information Systems – A European Perspective*. Wiley, New York.

CIMA/IProdE. (1987). *Justifying Investments in Advanced Manufacturing Projects*. Kogan Page, UK.

Clarke, R.B., and Robinson, D.J. (1985). Effective use of Finite Element Analysis techniques within an integrated CADCAM system. *Effective CADCAM 1985*. London : IMechE, pp.33-38.

Coats, P.K. (1991). A critical look at expert systems for business information applications. *Journal Information Technology*. **6** : 208-216.

Cohen, P.R. (1995). *Empirical Methods for Artificial Intelligence*. Cambridge, MA : MIT Press.

Cohen, L., and Marrion, L. (1994). *Research Methods in Education*. Routledge, London.

Commission of the European Communities (1996). *Commission Recommendation of 3 April 1996 concerning the definition of Small and Medium-size Enterprises*. Directive OJ L 107. European Commission, Brussels, Belgium.

Cooper, A. (1995). *About Face : The Essentials of User Interface Design*. John Wiley and Sons.

Corner, J., Buchanan, J., and Henig, M. (2000). A dynamic model for Structuring Decision problems. *Proceedings of the 35th Annual Conference of the Operational Research Society of New Zealand*, December 2000, Wellington, New Zealand, pp. 189 – 198.

Csendes, Z.J., and Silvester, P. (1970). Numerical solution of Dielectric Waveguides. *IEEE Transactions on Microwave Theory and Technology* **18** (12) : 1124-1131.

Cuesta, P. (1992). *Adaptive Mesh Generation in non-convex domain and applications*, Doctoral Dissertation, University Las Palmas de Gran Canaria, Spain.

Cvetkovic, S.R., Fernandez, F.A., Zhao, A.P., Ettinger, R.D., Sewell, G., and Davies, J.B. (1994). Comparison of two interactive Finite-Element programs for analysis of Optical and Microwave devices. *Journal of Lightwave Technology,* **12** (7) : 1112 - 1120.

Davenport T., Järvenpää, S., and, Beers M. (1996). Improving Knowledge Work Process. *Sloan Management Review*, Summer, pp.53-65.

Davenport, T. (1996). Some principles of Knowledge Management. *Strategy and Business*, **1** (2) : 34 – 40.

Davenport, T. (1998). Putting the Enterprise into the Enterprise System. *Havard Business Review,* Jul-Aug 1998, pp.121-131.

Davenport, T. H. and L. Prusak (1998). *Working knowledge : how organizations manage what they know*. Harvard Business School Press : Boston, MA, USA.

Davies, J.B. (1993). Finite Element analysis of Waveguides and cavities - a review. *IEEE Transactions on Magnetics.* **29** : 1578 - 1583.

Davis, R., Shrobe, H., and Szolovits, P. (1993). What is a Knowledge Representation? *AI Magazine*, **14** (1) : 17-33.

Denzin, N.K. (1984). *The research act: A theoretical Introduction to Sociological Methods*. New York, NY: McGraw-Hill.

Department of Trade and Industry (DTI). (1993). *Inside UK Enterprise: Managing in the '90's*, C/O Status Meeting Limited, Festival Hall, Hampshire, UK, p.53.

Dervin, B. (1999). On studying information seeking methodologically: the implications of connecting metatheory to method. *Information Processing and Managemen*t, **35** : 727-50.

Dick, B., and Swepson, P. (1994). *Appropriate validity and its attainment within Action Research: an illustration using Soft Systems Methodology.* Available. [on-line]. http://www.scu.edu.au/schools/gcm/ar/arp/sofsys2.html.

Dilts, D.M, and Turowski, D.G, (1989), Strategic investment justification of advanced manufacturing technology using a knowledge-based system. In *Proc. 3rd Int. Conf. Expert Systems and the Leading edge in Production and Operations. Management*, University of South Carolina Press, pp. 193-206.

Dolsak, B, Jezernik, A. (1991). Mesh Generation expert system for engineering analyses with FEM. *Computers in Industry,* **17** (2-3) : 309 - 315.

Dolsak, B., and Jezernik, A. (1994). A Knowledge Base for Finite Element Mesh Design. *AI in Engineering.* **9** (1) : 19 - 27.

Donaldson, G., and Lorsch, J.W. (1983). *Decision-Making at the Top: the shaping of Strategic Direction*. Basic Books.

Donnelly, W. (1995). Success Through People. In *Proceedings of the 30th Annual Conference of the British Production and Inventory Control Society*, Birmingham, UK, pp.185-190.

Doorly, D. (1995). Parallel Genetic Algorithms for optimisation in CFD. In (Eds. G. Winter, J. Periaux, M. Galan and P. Cuesta). *Genetic Algorithms in Engineering and Computer Science.* Chichester, England : John Wiley, pp.251-270.

Dreyfuss, H., *What computers still cannot do*, Reading, MA, MIT Press, 1972.

Drucker, P. (1993). *Post-Capitalist Society*. Harper Collins : New York, NY, USA.

Drucker, P. (1999). Beyond the Information Revolution. *The Atlantic Monthly*, October, 47 – 57.

Dyck, D.N., Lowther, D.A., and McFee, S. (1992). Determining an approximate Finite Element Mesh density using Neural Network techniques. *IEEE Transactions on Magnetics,* **28** (2) : 1767 - 1770.

Earl, M. J. (1995). *Strategic Information Systems – A European Perspective*. Wiley, New York.

Eisenhardt, K.M. (1989). Building Theories From Case Study Research. *Academy of Management Review*, **14** (4) : 532 - 550.

Emson, C.R.I., Simkin, J., and Trowbridge, C.W. (1994). A status report on Electromagnetic Field Computation. *IEEE Transactions on Magnetics,* **30** (4) : 1533-1540.

Ericsson, K.A., and Simon, H.A. (1993). *Protocol Analysis : Verbal Reports as Data*. Cambridge, MA : MIT Press.

Ettinger, R.D., Fernandez, F.A., Rahman, B.M.A., and Davies, J.B. (1991b). Vector Finite Element solution of saturable nonlinear strip-loaded Optical Waveguides. *IEEE Photonics Technology Letters,* **3** : 147 - 149.

Ettinger, R.D., Fernandez, F.A. and Davies, J.B. (1991a). Application of Adaptive remeshing techniques to the Finite Element Analysis of nonlinear Optical Waveguides. In (Eds. H.L. Bertoni and L.B. Felsen). *Directions in Electromagnetic Wave modelling.* New York, NY : Plenum Press, pp.239-249.

Farbey, B., Land, F., and Targett, D. (1993). *How to Assess your IT investment: A study of methods and practices.* Management Today / Butterworth-Heinemann.

Farhoomand, A.D. (1992). Scientific progress of Management Information Systems. In (Ed. R.D. Galliers). *Information Systems Research : Issues, Methods and Practical Guidelines*, pp.92 – 111. London : Blackwell Scientific.

Fernandes, P., Girdinio, P., Molfino, P., Molinari, G. and Repetto, M. (1990). A comparison of Adaptive strategies for Mesh Refinement based on *A-posteriori* local error estimation procedures. *IEEE Transactions on Magnetics,* **26** (2) : 795 - 798.

Fernandez, F.A., and Lu, Y. (1996). *Microwave and Optical Waveguide analysis by the Finite Element Method.* Chichester, England : Research Studies Press / John Wiley.

Fernandez, F.A., Ettinger, R.D., Davies, J.B., and Rahman, B.A. (1991). Accurate Finite Element Software for Microwave and Optical Waveguides. *Proc. IEEE International Conference on Computation in Electromagnetics*. pp.14-17.

Fernandez, F.A., Yong, Y.C., and Ettinger, R.D. (1993). A simple Adaptive mesh generator for 2-D finite element calculations. *IEEE Transactions on Magnetics,* **29** (2) : 1882 - 1885.

Ferneley, E., Berney, B., and Rezgui, Y. (2002). Information Retrieval Algorithms for Knowledge Management – the challenge continues. In *Proc. eSMART / CISEMIC*, University of Salford, Salford, Manchester, UK, 2002.

Filipiak, M. (1996). *Mesh Generation* (Technology in Focus document). [On-line]. Available : http ://www.epcc.ed.ac.uk/epcc-tec/documents.html

Finn, D.P. (1993). A Physical modelling assistant for the preliminary stages of Finite Element Analysis. *Aritifical Intelligence in Engineering Design, Analysis and Manufacturing.* **7** (4) : 275-286.

Fletcher, C.A.J. (1991). *Computational Techniques for Fluid Dynamics Vol.2, Specific Techniques for Different Flow categories* (2nd Ed.). Berlin : Springer-Verlag, pp.81-127.

Fort, J.-C., and Pages, G. (1996) About the Kohonen Algorithm : Strong or Weak self-organisation?. *Neural Networks*, **9** (5) :773-785.

French, M.J. (1988). *Invention and evolution : Design in nature and engineering.* Cambridge : Cambridge University Press.

Fruchter, R., Gluck, J., and Gold, Y.I. (1987). Application of AI Programming techniques to the analysis of structures. *The Application of Artificial Intelligence techniques to Civil and Structural Engineering (Proc. 3rd Int. Conf. Civil and Struct. Eng. Comp., CIVIL COMP '87).* Edinburgh : Civil-Comp Press, pp.99-103.

Furner, J. (2002). Shera's Social Epistemology recast as Psychological Bibliology. *Social Epistemology. Social Epistemology*, **16** (1) : 5-22.

Gago, J.P.S.R. (1985). Importance of Self Adaptive Finite Elements and A-Posteriori Error Analysis. In (Ed. T. Kant). *Proc. Int. Conf. Finite Elements in Computational Mechanics (FEICOM '85)*, Bombay, India, 2-6 December 1985, Vol.1. London : Pergamon Press, 15-21

Galante, M. (1996). Genetic Algorithms as an approach to optimize Real-World Trusses. *International Journal of Numerical Methods in Engineering,* **39** : 361-382.

Galliers, R.D., and Newell, S. (2000). Back to the future : from Knowledge Management to Data Management. *Department of Information Systems, Working Paper 92, London School of Economics and Political Science*, London, UK.

Gallopoulos, E., Houstis, E., and Rice, J.R. (1994). Computer as Thinker / Doer : Problem-Solving Environments for Computational Science, *IEEE Computational Science and Engineering,* Summer 1994, pp.11-23.

Gao, F., Li, M., and Nakamori, Y. (2002). Systems thinking on Knowledge and its management. *Journal of Knowledge Management*, **6** (1) : 7 – 17.

Genesereth, M.R., and Fikes, R.E. (1992). Knowledge Interchange Format, version 3.0 reference manual. Technical Report Logic-92-1, Computer Science Department, Stanford University.

Genesereth, M.R., and Nilsson, N.J. (1987). *Logical foundations of Artificial Intelligence*. San Francisco, CA : Morgan Kaufmann.

Gengdong, C., and Zeng, Y. (1992). Strategies for Automatic Finite Element modeling, *Computers and Structures,* **44** (4) : 905-909.

Gennari, J.H., Langley, P., and Fisher, D. (1992). Model of Incremental Concept Formation. In (Ed. J. Carbonell). *Machine Learning*. Cambridge, MA: MIT Press / Elsevier, pp.11-63.

George, P.L. (1991). *Automatic Mesh Generation*. London : John Wiley

Gero, J.S. (1994). Evolutionary learning of novel grammars for design improvement. *Articial Intelligence in Engineering Design and Manufacture,* **8** : 83 - 94.

Gero, J.S., and Kazakov, V.A. (1996). Evolving Building Blocks for Design using Genetic Engineering : A Formal Approach. In (Eds. J.S. Gero and F. Sudweeks). *Advances in Formal Design Methods for CAD : Proc. IFIP WG5.2 Workshop on Formal Design Methods for Computer-Aided Design*, June 1995, Cornwall (UK) / London (UK) : TJ Press / Chapman and Hall, pp.31-50.

Gloudeman, J.F. (1986). Future Finite Element software systems. *AMD (ASME Symposia Series).* **75**, pp.449-458.

Golafshani, N. (2003). Understanding Reliability and Validity in Qualitative Research. *The Qualitative Report*, **8** (4) : 597 – 607. Available. [on-line].

http://www.nova.edu/ssss/QR/QR8-4/golashani.pdf.

Goldberg, D.E. (1989). *Genetic Algorithms in Search, Optimisation and Machine Learning*. Reading, MA : Addison Wesley.

Goldberg, D.E. (1991). Genetic Algorithms as a computational theory of Conceptual Design. In (Eds. G. Rzevski and R.A. Adey). *Applications of Artificial Intelligence in Engineering VI*. Southampton, England / New York, NY : Computational Mechanics Publications / Elsevier, pp.3-16.

Goldman, S.L., Nagel, R.N., and Preiss, K. (1995). *Agile Competitors and Virtual Organizations, Strategies for Enriching the Customer*. New York, N.Y., Von Nostrand Reinhold.

Goonatilake, S., and Khebbal, S. (1994). *Intelligent Hybrid Systems*. Chichester, England : John Wiley.

Grecu, D.L., and Brown, D.C. (1996). *Dimensions of Learning in Agent-Based Design*. [On-line]. Available http://cs.wpi.edu/~dcb/AID96/AID96-MLinD.html.

Grierson, D.E, and, Cameron, G.E. (1987). A knowledge based expert system for computer automated structural design. *The application of artificial intelligence techniques to civil and structural engineering : Proceedings of the 3rd international conference on civil and structural engineering*, Civil Comp. Press, 93-97.

Griffiths, C. and Willcocks, L. (1994). Are major IT projects worth the risk ?. In A. Brown and D. Remenyi (editors.). *Proc. 1st European Conference on IT Investment Evaluation*, City University, London, UK. pp. 256-259.

Gruber. T. (1993). A translation approach to portable ontology specifications. *Knowledge Acquisitio*n, **5**(2):199–220.

Guarino, N. and Giaretta, P. (1995). Ontologies and knowledge bases: Towards a terminological clarification. In (Ed. N. Mars). *Towards Very Large Knowledge Bases: Knowledge Building and Knowledge Sharin*g, pp.25–32. IOS Press, Amsterdam.

Gubrium, J.F., and Holstein, J.A. (2002). *Handbook of Interview Research*. Thousand Oaks, CA: Sage Publications.

Guha., R.V. (1991). *Contexts: A Formalization and Some Application*s. PhD thesis, Stanford University, California, USA.

Gupta, U. (1996). *Management Information Systems: a managerial perspective*. West Publishing.

Hahen, G. and Griffiths, C. (1996). A quantitative model for Technological Risk Assessment in the process of IT Transfer. In A. Brown and D. Remenyi (editors). *Proc. 3rd European Conference on the Evaluation of Information Technology*, Bath University, Bath, UK, 29th November 1996. pp. 35 -42.

Hameyer, K., Belmans, R. (1996). Design and Optimization of Electrotechnical Devices. *Journal of Engineering Design,* **7** (3) : 235 - 251.

Hammer, M., and, Champy, J. (1993). *Reengineering the Corporation*. Harper Business : New York, NY, USA.

Hammond, P., and Davenport, J.C. (1994). Eliciting and modelling the design knowledge of multiple experts, *Dept. of Computer Science & Information Systems, Brunel University, Technical Report CSTR-95-4, pp1-15*.

Handy, C. (1990). *Understanding Organisations*. Penguin, UK.

Haupt, R.A. (1995). An introduction to Genetic Algorithms for Electromagnetics. *IEEE Antennas and Propagation,* **37** (2) : 7 - 15.

Hayes, R.M. (1991). Measurement of information. In (Eds. P.Vakkari, B.Cronin). *Conceptions of Library and Information Science. Historical, empirical and theoretical perspectives*. pp. 268-285. Taylor Graham : London.

Hedestrom, T., and Whitley, E. (2000). What is meant by tacit knowledge? Towards a better understanding of the shape of actions. *Department of Information Systems Working paper 87, London School of Economics and Political Science,* London, UK.

Heflin, J.D. (2001). *Towards the Semantic Web : Knowledge Representation in a Dynamic, Distributed Environment.* PhD Dissertation, Department of Computer Science, University of Maryland, College Park, Maryland, USA.

Herschel, R.T., Nemati, H., and Steiger, D. (2001). *Journal of Knowledge Management,* **5** (1) : 107 – 116.

Heylighen, F. (1990). *Representation and Change. A Metarepresentational Framework for the Foundations of Physical and Cognitive Scienc*e, (Communication & Cognition, Ghent, Belgium).

Heylighen, F. (2001). Bootstrapping knowledge representations – from entailment meshes via semantic nets to learning webs. *Kybernetes*, **30** (5/6) : 691 – 722.

Hirscheim, R., and, Klein, H.K. (1998). Four paradigms of Information Systems Development. *Communications of the ACM*, **32** (10).

Hislop, D., Newell, S., Scarborough, H., and Swan, J. (1998). Networs, Knowledge and Power : Decision making politics and process of Innovation. *Proceedings of the 1st International Conference on Critical Management Studies,* University of Manchester, July 1998, UK.

Hjertzen, E., and Toll, E. (1999). *Measuring Knowledge Management at Cap Gemini AB*, Masters Thesis (1999-02-22, LiTH IDA-EX-99/19), Linkoping Institute of Technology, Linkoping, Sweden.

Hjorlund, B. (2002). Domain Analysis in Information Science : Eleven approaches, traditional as well as innovative. *Journal of Documentation*. **58** (4) : 422 – 462.

Hochstrasser, B. (1992). Justifying IT Investments. In *Conference Proceedings: Advanced Information Systems, The new technologies in today's business environment*, 17-19th March, London, UK. Oxford : Learned Information. pp. 17-28.

Hochstrasser, B., and Griffiths, C. (1991). *Controlling IT Investment: Strategy and Managemen*t. Chapman and Hall, London.

Ho-Le, K. (1988). Finite Element mesh generation methods. *CAD* **20** (1) : 27-38.

Holland, J.H. (1992). Genetic Algorithms. *Scientific American*. July 1992, pp.44-50.

Holsapple, C.W., and Joshi, K.D. (1999). Description and Analysis of existing knowledge management frameworks. In *Proc. 32nd Hawaii Int. Conf. System Sciences (HICSS'99)*, Honolulu, Hawaii, USA, December 1999.

Huber, G.P. (1991). Organizational Learning: The Contributing Processes and the Literatures. *Organization Science*. **2** (1) : 88-115.

Hunsperger, R.G. (1991) *Integrated Optics : Theory and Technology*, Springer Verlag.

Ingwersen, P. (1996). Cognitive perspectives of information retrieval interaction: elements of a cognitive IR theory. *Journal of Documentation*. **52** : 3-50.

Institution of Electrical Engineers (1997). Intelligent Design Systems. *Computing and Control Division (Professional Group C4 : Artificial Intelligence), Digest : 97/016.*

Irani, Z. (1998). PhD Dissertation, Department of Manufacturing and Engineering Systems*, Brunel University*, UK.

Irani, Z., Beskese, A., and Love, P.E.D. (2000). Improving Organisational Competitiveness through developing a Corporate Culture. *Proceedings of the 5th International Conference on ISO 9000 and TQM, "Action 2000: Imperatives for improvement"*, School of Business, Hong Kong Business University, Hong Kong, 2000, pp. 238 – 241.

Irani, Z., Ezingeard, J-N, and, Grieve, R.J. (1997). Integrating the costs of an IT/IS infrastructure into the investment decision making process. *The International Journal of Technological Innovation and Entepreneurship (Technovation)*, **17** (11/12) : 637-647.

Irani, Z., Ezingeard, J-N, Grieve, R.J, and Race, P. (1999). Investment justification of information technology in manufacturing. *The International Journal of Computer Applications in Technology*. – In Press.

Irani, Z. and Love, P.E.D. (2000). The Propagation of Technology Management Taxonomies for Evaluating Investments in Information Systems. *Journal of Management Information Systems*. **17** (3) : 161 – 177.

Irani, Z., and Sharif, A. (1997). Genetic Algorithm Optimisation of Investment Justification Theory. In (Ed. J.R. Koza). *Proc. Late Breaking Papers, Genetic Programming 1997*, Stanford University, Stanford, USA, July 13-16th, 1997, Stanford, CA : Stanford University Bookshop, pp..88-91.

Irani, Z., and Sharif, A. M. (1998). A revised perspective on the evaluation of IT/IS Investments using an Evolutionary approach. In (Ed. J.R. Koza). *Proc. Late Breaking Papers, Genetic Programming 1998*, University of Wisconsin, Madison, USA, July 22-25th, 1998, WI, Omni Press, pp.77-84.

Irani, Z., Sharif, A.M., and Love, P.E.D. (2001). Transforming Failure into Success through Organizational Learning: An analysis of a Manufacturing Information System. *European Journal of Information Systems*. **10** (1) : 55-66.

Irani, Z., Sharif, A. M., Love, P.E.D., and Kahraman, C. (2002). Applying Concepts of Fuzzy Cognitive Mapping to model IT/IS Investment Evaluation. *International Journal of Production Economics*. **75** (1) : 199-211.

Irani, Z., and Sharp, J.M. (1997). Integrating continuous improvement and innovation into a corporate culture: A case study. *The International Journal of Technological Innovation, Entrepreneurship and Technology Management (Technovation)*. **17** (4) : 199-206.

Irani, Z., Sharp J.M. and Kagioglou, M. (1997a). Improving business performance through developing a corporate culture. *The International Bi-Monthly for Total Quality Management: The TQM Magazine*. **9** (3) : 206-216.

Irani, Z., Sharp, J.M. and Kagioglou, M. (1997b). Communicating through self-directed work teams in a manufacturing environment. *Journal of Workplace Learning*. **9** (6) : 199-205.

Irani, Z., Sharp, J.M and Race, P. (1997c). A case experience of new product introduction within a once traditional subcontract manufacturing environment. *Production and Inventory Management Journal*. **38** (2) : 47-51.

Jackson, P. (1990). *Introduction to Expert Systems*. New York, NY : Addison-Wesley.

Jacobsen, H.A. (1998). Generic architecture for hybrid intelligent systems. In *Proceedings of the 1998 IEEE International Conference on Fuzzy Systems*, Part 1 (of 2), Anchorage, USA, May 4-9 1998, pp.709-714.

Jadid, M.N., and Fairbairn, D.R. (1994). The application of Neural-Network techniques to Structural Analysis by implementing an Adaptive Finite Element Mesh Generation. *AI in Engineering Design Analysis and Manufacturing*, **8** (3) : 177 - 191.

Jambunathan, K., Lai, E., Hartle, S.L., and Button, B.L. (1992). Development of an intelligent front end using LISP. *Applications of Artificial Intelligence in Engineering*. Southampton, England / Heidelberg, Germany : Computational Mechanics Publications / Springer-Verlag. pp.228-243.

Järvenpää, E. and Immonen, S. (1998) Quality of working life in knowledge and information work: Implications for information society. In (Eds. P. Vink, E.A. P. Konigsveld and S. Dhondt). *Human factors in organizational design and management – VI*. Elsevier : Amsterdam, Netherlands.

Jayaratna, N. (1994). *Understanding and Evaluating Methodologies*. McGraw-Hill : Maidenhead, UK.

Jick, T.D. (1983). Mixing qualitative and quantitative research methods: Triangulation in action. In (Ed. J. Van Maanen). *Qualitative Methodology*. Beverley Hills : CA. Sage Publishing.

Johannessen, J.-A., Olaisen, J., and Olsen, B. (2001). Mismanagement of tacit knowledge: the importance of tacit knowledge, the danger of information technology and what to do about it. *International Journal of Information Management*. **21** : 3 – 20.

Johnson, Claes. (1985). *The Finite Element Method*. Academic Press : London.

Kang, E., and Haghighi, K. (1995). Intelligent Finite Element Mesh Generation. *Engineering Computations*. **11** (2) : 70 - 82.

Kang, K.T., and Kwak, B.M. (1997). Optimization of Finite Element grids using shape sensitivity analysis in terms of nodal positions. *Finite Elements Analysis and Design*, **26** : 1-19.

Kaplan, R.S. (1985). *Financial justification for the factory of the future*. Working Paper, Harvard Business School, USA.

Kaplan, R.S. (1986). Must CIM be justified on faith alone. *Harvard Business Review*. **64** (2) : 87-97.

Kaplan, R.S. and Norton, D.P. (1992). The balanced scorecard – measures that drive performance. *Harvard Business Revie*w, January-February, pp. 71-79.

Karderas, D., and Mentzas, G. (1997). Using Fuzzy Cognitive Maps to model and analyse Business Performance Assessment. In (Eds. J.G. Chen and A. Mittal). *Proceedings of the 2nd International Conference on Advances in Industrial Engineering and Applications Practice*, pp.63 – 68.

Kardestuncer, H., and Norrie, D.H. (1984). *Finite Element Handbook*. New York, NY : Mcgraw-Hill.

Khan, A.I. and Topping B.H.V. (1993). Parallel training of Neural Networks for Finite Element Mesh Generation. In (Eds. B.H.V. Topping and A.I. Khan). *Neural Networks and Combinatorial Optimization in Civil and Structural Engineering*. Edinburgh, Scotland : Civil-Comp Press, pp.81-94.

Kim, J., Lee., H.B., Jung, H.K., Hahn, S.Y., Cheon, C., and Kim, H. (1996). Optimal design technique for Waveguide device. *IEEE Transactions on Magnetics,* **32** (3) : 1250-1253.

King, W.R., Marks, P.V., and McCoy, S. (2002). The most important issues in Knowledge Management. *Communications of the ACM*, **45** (9) : 93 – 97.

Klein, H.Z., and Myers, M.D. (1999). A set of principles for conducting and evaluating Interpretive Field Studies in Information Systems. *MIS Quarterly*, **23** (1) : 67 – 94.

Kluge, J., Stein, W., and Licht, T. (2001). *Knowledge Unplugged*. Palgrave, Basingstoke.

Knafl, K.A., and Breitmayer, B.J. (1989). Triangulation in qualitative research: issues of conceptual clarity and purpose. In (Ed. J.M. Morse). *Qualitative Nursing Research as Contemporary Dialogue*. Rockville : MD, Aspen Publishing.

Knupp, P., and Steinberg, S. (1994). *Fundamentals of Grid Generation*. Boca Raton, FL : CRC Press.

Kock, N., and McQueen, R. (1998). Knowledge and information communication in organizations – an analysis of core, support and improvement processes. *Journal of Knowledge and Process Management,* **5** (1).

Kogelnik, H. (1981). Integrated Optics Devices for Optical Communications. *Proc. 8th Int. Conf. NATO Adv. Study Inst. Integ. Optics : Physics and Applications, Erice, Italy*. New York, NY : Plenum Press, pp.1-9.

Kosko, B. (1990) *Fuzzy Thinking : The new science of Fuzzy Logic*. London : Flamingo Press.

Kowalski, R. (1979). *Logic for Problem Solving*. New York, NY : North-Holland.

Koyamada, K. and Takayuki, I. (1998). Seed specification for displaying a streamline in an irregular volume. *Engineering With Computers*. **14** (1) : 73 - 80.

Koza, J.R. (1992). *Genetic Programming*. Cambridge, MA : MIT Press.

Koza, J.R. (1994). Introduction to Genetic Programming. In (Ed. K.E. Kinnear, Jr.). *Advances in Genetic Programming*. Cambridge, MA : MIT Press, pp.21-42.

KPMG (1998). *The Knowledge Journey – A business guide to Knowledge Systems*. KPMG Consulting, UK.

Kreiner, K. (2002). Tacit knowledge management: the role of Artifacts. *Journal of Knowledge Management*. **6** (2) : 112 – 123.

Krishnamoorthy, C.S., and Krishnakumar, R. (1988). Knowledge-Based Expert Systems for Finite Element Analysis. In (Eds. J.N. Reddy, C.S. Krishnamoorthy and K.N. Seetharamu). *Finite Element Analysis for Engineering Design (Lecture Notes in Engineering #37)*. Heidelberg, Germany : Springer-Verlag, pp.842-859.

Kucza, T., and Komi-Sirvio, S. (2001). Utilising Knowledge Management in Software Process Improvement – The creation of a Knowledge Management Process Model. In (Eds. K.-D. Thoben, F. Weber, S. Kulwant). *Proc. 7th Int. Conference on Concurrent Enterprising (ICE 2001)*, University of Nottingham, Centre for Concurrent Enterprising, Nottingham, UK.

Kuhlthau, C. (1991). Inside the search process: information seeking from the user's perspective. *Journal of the American Society for Information Science* **42** (5) : 361–71.

Kurzweil, R. (1992). A Kind of Turing Test. In (Ed. R. Kurzweil). *The Age of Intelligent Machines*. Cambridge, MA : MIT Press, pp.374-379.

Kvale, S. (1996). *Interviews*. Sage Publishing : London.

Labrie, R., Thilloy, C., Tanguy, P.A., and Moll, G.H. (1994). An Expert assistant to monitor Finite Element simulations, *Mathematical and Computatational Simulation,* **36** (4-6) : 413 - 422.

Lai, H., and Chu, T.-H. (2000). Knowledge Management – a review of theoretical frameworks and industrial cases. In *Proc. 33nd Hawaii Int. Conf. System Sciences (HICSS'00)*, Honolulu, Hawaii, USA, January 2000.

Lakhany, A. (1995). *Error estimation and Finite Elements*. Doctoral dissertation, Department of Mathematics and Statistics, Brunel University, UK.

Laug, P. (1994). DOMINO : a Knowledge-based system for the users of a Finite Element library. *Mathematical and Computational Simulation,* **36** : 293 - 301.

Lavraz, N., and Dzeroski, S. (1994). Finite Element Mesh design. In (Eds. I. Bratko and D. Jezernik). *Inductive Logic Programming : Techniques and Applications.* New York, NY : Ellis Horwood, pp.217-225.

Leal, A., and, Roldan, J. L. (2001). Benchmarking and Knowledge Management – a European approach. *OR Insight*, **14** (4).

Lee, A.S. (1989). A Scientific Methodology for MIS Case Studies. *MIS Quarterly*, **13** (1) : 33 – 52.

Lenart, M., and Maher, M.L. (1996). Evolutionary Methods in Design : Discussion. In (Eds. J.S. Gero and F. Sudweeks). *Advances in Formal Design Methods for CAD : Proc. IFIP WG5.2 Workshop on Formal Design Methods for Computer-Aided Design*, June 1995, Cornwall (UK) / London (UK) : TJ Press / Chapman and Hall, pp.51-55.

Leonard-Barton, D. (1995). *Wellsprings of Knowledge : Building and Sustaining the sources of Innovation*. Harvard Business School Press : Boston, MA, USA.

Lethbridge, T. C. (1994). Practical Techniques for Organizing and Measuring Knowledge. *PhD Thesis*. School of Graduate Studies and Research, University of Ottawa, Ottawa, Canada.

Levy, M. (1991). Towards an Evolutionary theory of Information Systems Planning. *Systems Thinking in Europe*. London, UK : Plenum Press, pp. 535 – 540.

Liker, J.K., Fleischer, M., and Arnsdorf, D. (1992). Fulfilling the promises of CAD. *Sloan Management Review*, Spring 1992, pp.74-86.

Liszka, T.J. (1995) An introduction to *h-p* adaptive Finite Element Method. [On-line]. Available http://www.comco.com/main/reports/hp-intro/hpintro.html

Lincoln, Y.S., and Guba, E.G. (1985). *Naturalistic Inquiry*. Beverley Hills : CA, Sage Publishing.

Liu, Y.C., EI-Maraghy, H.A., and Zhang, K.F. (1990). Expert system for forming Quadrilateral Finite Elements. *Engineering Computaions,* **7** (3) : 249 - 257.

Love, P.E.D., Gunasekaran, A., and Li, H. (1998). Improving the Competitiveness of Manufacturing Companies through Continuous Incremental Change. *The International Bi-Monthly for Total Quality Management: TQM Magazine*. **10** (3) : 177-185.

Lowther, D.A., and Dyck, D.A. (1993). A Density driven mesh generator guided by a neural network. *IEEE Transactions on Magnetics,* **29** (2) : 1927 - 1930.

Lu, Y., and, Fernandez, A.B. (1993). Finite Element Analysis of lossy dielectric waveguides. *IEEE Transactions on Magnetics*, **29** (2) : 1609 - 1612.

Lyman, H., and Varian, H.R. (2000). *How much Information?*. Available [on-line]. http://www.sims.berkeley.edu/how-much-info/ (correct as of 10/11/2000 2:11:17 PM).

Mackerle, J., and Orsborn, K.(1988). Expert systems for Finite Element Analysis and design optimisation - A review. *Engineering Computations,* **5** : 90 - 102.

Macneal-Schwendler Corp. (1996). *How do I know its the Right answer ? : what managers need to know about Finite Element Analysis, ('Technology in Action' series)*. Available. [On-line] http://www.macsch.com/tech/wp1.html.

Maher, M.L., Poon, J., and Boulanger, S. (1996). Formalising Design Exploration as Co-Evolution. In (Eds. J.S. Gero and F. Sudweeks). *Advances in Formal Design Methods for CAD : Proc. IFIP WG5.2 Workshop on Formal Design Methods for Computer-Aided Design*, June 1995, Cornwall (UK) / London (UK) : TJ Press / Chapman and Hall, pp.3-30.

Mäki, E., Järvenpää, E. and Hämäläinen, L. (2001) Managing Knowledge Processes in Knowledge Intensive Work. In *Proc. 2nd European Conference on Knowledge Management*. Bled School of Management, 8-9 November 2001, Slovenia.

Maki, E., Järvenpää, E., and, Hamalainen, L. (2002). Analyzing intraorganisational Knowledge Management.

Malitz, I. (1987). The Turing Machine. *BYTE,* November 1987, pp.348-358.

Mania, L., Corzani, T., and Valentinuzzi, E. (1981). The Finite Element Method in the analysis of Optical Waveguides. *Proc. 8th Int. Conf. NATO Adv. Study Inst. Integ. Optics : Physics and Applications, Erice, Italy.* New York, NY : Plenum Press. pp. 335-359.

Massey, A. (1999). Explorations in Methodology. In (Eds. A. Massey and G. Walford). *Studies in Educational Ethnography*, *Vol.2*. Stamford : CO. JAI Press.

Maula M. (2000) Three Parallel Knowledge Processes. *Knowledge and Process Management*, **7** (1) : 55-59.

McCallum, K.J. (1990). Does Intelligent CAD exist? *AI in Engineering*, **5**(2) : 55-65.

McCallum, K.J., and Duffy, A. (1990). Representing and Using Numerical Empiricism in Design. In (Ed. J.S. Gero). *Proc. 5th Int. Conf. Applications of Artificial Intelligence in Engineering V, Vol.1 : Design*, Boston, USA, July 1990, Southampton, England / Heidelberg, Germany : Computational Mechanics Publications / Springer-Verlag, pp.115-136.

McCallum, K.J., Duffy, A., and Green, S. (1989). The Knowledge Cube - A research framework for Intelligent CAD. In (Eds. H. Yoshikawa and D. Gossard). *Intelligent CAD I : Proc. IFIP TC5/WG 5.2 Workshop on Intelligent CAD*, Boston, MA, USA, 6-8 October, 1987, Amsterdam : North Holland, pp.38-44.

McCampbell, A.S., Clare, L.M., and, Gitters, S.H. (1999). Knowledge Management : the new challenge for the 21st Century. *Journal of Knowledge Management*, **3** (3) : 172 – 179.

McCarthy, J. (1993). Notes on formalizing context. In *Proceedings of the Thirteenth International Conference on Artificial Intelligence (IJCAI-93)*, pp. 555 - 560, Los Altos, California, USA. Morgan Kaufmann.

McCullough, J.A. (1990). Issues in Intelligent CAD. In (Eds. H. Yoshikawa and T. Holden). *Intelligent CAD II : Proc. IFIP TC5/WG 5.2 Second Workshop on Intelligent CAD*, Cambridge, United Kingdom, 19-22 September, 1988, Amsterdam : North Holland, pp.225-239.

McLeod, W.T. (1980). *Collins Gem English Dictionary.* (Ed. W.T. McLeod). London : Collins.

Meadows, D.H., and Robinson, J. (1985). *The Electronic Oracle: Computer Models and Social Decisions.* Chichester : UK, Wiley.

Mentazemi, A., and Conrath, D. (1986). The use of Cognitive mapping for information requirement analysis. *Management Information Systems Quarterly*, March.

Merali, Y. (2002). The role of boundaries in knowledge processes. *Eurpoean Journal of Information Systems*, **11** : 47 – 60.

Meredith, J.R. (1987) .Implementing the automated factory. *Journal of Manufacturing Systems,* **6** : 75-91.

Michaeliwicz, Z. (1992). *Genetic Algorithms + Data Structures = Evolution Programs.* New York, NY : Springer Verlag.

Michielssen, E., and Weile, D.S. (1995). Electromagnetic system design using Genetic Algorithms. In (Eds. G. Winter, J. Periaux, M. Galan and P. Cuesta). *Genetic Algorithms in Computer Science and Engineering.* Chichester, England : John Wiley, pp.345-369.

Miles, M.B., and Huberman, A.M. (1994). *Qualitative Data Analysis: An Expanded Sourcebook*. Beverley Hills : CA. Sage Publications

Mills, D.Q., and Friesen, B.G. (1999). Emerging Business Realities : A new paradiogm for Consultants Pt 1. *Journal of Management Consulting*, **10** (4).

Minsky, M. (1975). A framework for representing knowledge. In (Ed. P.H.Winston). *The Psychology of Computer Vision*. McGraw-Hill : New York, NY, USA.

Minsky, M. (1985). *The Society of Mind.* New York, NY : Simon and Schuster.

Minsky, M. (1992). Thoughts about Artificial Intelligence. In (R. Kurzweil). *The Age of Intelligent Machines.* Cambridge, MA : MIT Press, pp.214-219.

Moens, M-F. (2000). *Automatic indexing and abstracting of document texts*. Kluwer.

Mohammed, O.A., Merchant, R., and Uler, F.G. (1994). An Intelligent system for design optimisation of electromagnetic devices. *IEEE Transactions on Magnetics,* **30** (5) : 3633-3636.

Montgomery, M., and Fleeter, S. (1995). A locally analytic technique applied to grid generation by elliptic equations. *International Journal of Numerical Methods in Engineering*, **38** (3) : 421 - 432.

Morgan, G. (1986). *Images of Organisation.* London : UK. Sage Publications.

Morse, J.M. (1991). Approaches to Qualitative-Quantitative methodological Triangulation. *Nursing Research*, **40** (1) : 120 – 123.

Mumford, E. (1985). *Research methods in Information Systems*. North-Holland : Netherlands.

Naganarayana, B.P., and Prathap, G. (1992). Expert Systems and Finite Element Structural Analysis - A review, *Sadhana Academy Proceedings in Engineering Sciences, Vol.17, #2*, National Aeronautics Lab., Bangalore University, India, pp.275-298.

Nakao, T., Noguchi, M., Yonezawa, Y., Sakata, M., and Suzuki, A. (1996). Automatic Mesh Generation based on skilled knowledge by Genetic Algorithm. *Proc. 1997 IEEE Int. Conf. Evolutionary Computation (ICEC'96), Nagoya, Japan, May 20-22, 1996*. Piscataway, NJ : IEEE. pp.861-866.

Newman, B., and Conrad, K.W. (1999). A Framework for characterizing Knowledge Management, methods, practices and technologies. In *Proc. Documation '99,* Toronto, Canada.

Niiyama, A., Koshiba, M., and Tsuji, Y. (1995). An efficient Scalar Finite Element formulation for Non-linear Optical Channel Waveguides. *Journal of Lightwave Technology,* **13** (9) : 1919 - 1925.

Nonaka, I., and Takeuchi, H. (1995). *The Knowledge-creating Company : How Japanese Companies Create the Dynamics of Innovation.* Oxford University Press: Oxford, UK.

Numata, J. (1996). Knowledge Amplification : An Information System for Engineering Management. In (Eds. H. Kanaumi, T. Ohkawara, Y. Iwashita, C. Doeden). *Sony's Innovation in Management Series*, **17**, Sony Corp., Japan.

Numata, J. and Taura, T. (1996). Case study: a network system for knowledge amplification in product development process. *IEEE Transactions on Engineering Management.* **43** (4) : 356-367.

Numata, J., Hane, K., Bangyu, L., and Iwashita, Y. (1997). Knowledge Discovery and sharing in an Information System. In *Proc. Portland International Conference of Management of Engineering and Technology (PICMET '97)*, Portland, July 27-31st 1997.

Olesen, K., and Myers, M. (1999) Trying to Improve Communication and Collaboration with Information Technology. *Information Technology & People.* **12** (4) : 317 - 332.

Onions, P.E.W., and Orange, G. (2002). The Three K's : a model for knowledge that supports Ontology and Epistemology. *Proceedings of the 6th World Conference on Systemics, Cybernetics and Informatics*, July 14th – 18th 2002, Orlando, Florida, USA.

Ordonez de Pablos, P. (2002). Knowledge Management and Organistional Learning: typologies of Knowledge Strategies in the Spanish Manufacturing Industry from 1995 to 1999. *Journal of Knowledge Management*, **6** (1) : 52 – 62.

O'Shea, J., and Madigan, C. (1998). *Dangerous Company.* Nicholas Brierly / Random House, London.

Ovum (1999). *Knowledge Management : Building the Collaborative Enterprise.* Ovum Ltd., London, UK.

Owen, D.R.J., and Hinton, E. (1980). *A simple guide to Finite Elements.* Swansea, England : Pineridge Press.

Parmee, I.C. (1996). Towards an Optimal Engineering Design Process using Approprate Adaptive Search Strategies. *Journal of Engineering Design,* **7** (4) : 341 - 363.

Patel N.V and Irani Z. (1999). Evaluating Information Technology in Dynamic Organisations: A focus on tailorable systems. *Logistics and Information Management.* **12** (1) : 32-39.

Patton, M.Q. (2001). *Qualitative Evaluation and Research Methods (3rd Ed.).* Thousand Oaks, CA : Sage Publishing, Inc.

Paul, R.J. (1994). Why Users Cannot 'Get What They Want'. *International Journal of Manufacturing Design.* **1** (4) : 389 – 394.

Paul, R.J. (2002). Is IS an intelligent subject ? . *European Journal of Information Systems.* **11** : 174 – 177.

Peralta, R., and Chen, B. (1995). A Computer Science approach for solving Elliptic Differential Equations. *Numerical Methods with Partial Differental Equations,* **11** : 573 - 590.

Phillips, E.M., and Pugh, D.S. (1994). *How to get a PhD – A handbook for students and their supervisors, 2nd Ed.* Open University Press : Buckingham, UK.

Polanyi, M. (1962). *Personal Knowledge: Towards a Post-Critical Philosophy.* Chicago University Press, Chicago : IL.

Polanyi, M. (1966). *The Logic of Tacit Inference. Philosophy*, **41** (1): 1–18.

Polanyi, M. (1967). *The Tacit Dimension.* Doubleday-Anchor : NY, New York, USA.

Polystanko, S.V., and Lee, J.F. (1995). H_1 (curl) Tangential Vector Finite Element Method for Modelling Anisotropic Optical Fibres. *Journal of Lightwave Technololgy,* **13** (11) : 2290 - 2296.

Porter, M. (1985). *Competitive Advantage* .Collier-MacMillan : New York, NY, USA.

Prahalad, C.K., and Hamel, G. (1990). The Core Competence of the Corporation. *Harvard Business Review*, **68** (3) : 79 – 91.

Prestifilippo, G., and Sprave, J. (1997). Optimal Triangulation by means of Evolutionary Algorithms. *Proc. 2nd Int. Conf. Genetic Algorithms in Engineering Systems, Innovations and Applications (GALESIA '97)*, Glasgow, UK, 2-4 September 1997. London : IEE.

Probert, S.K. (2001). Modelling using IS Methodologies : Some guidelines based on Authenticity and Contemporary Epistemology. *Proc. Conf. Informing Science : Challendges to Informing Clients: A transdisciplinary Approach*, June 2001, pp.437 – 444.

Probst, G., Raub, S., and, Romhardt, K. (2001). *Managing Knowledge : Building Blocks for Success.* John Wiley : Chichester, UK.

Quillian, M. R. (1967) Word concepts: A theory and simulation of some basic semantic capabilities. *Behavioral Scienc*e, **12** : 410 - 430.

Quinn, J.B. (1992). *Intelligent Enterprise: A knowledge and service-based paradigm for Industry.* New York Free Press : NY, New York, USA.

Quinn-Patton, M. (1986). *How to use Qualitative Methods in Evaluation.* Sage Publications : Thousand Oaks, CA, USA.

Rahman, B.M.A., and Davies, J.B. (1984). Finite Element Analysis of Optical and Microwave Waveguide problems. *IEEE Microwave Theory and Technology,* **32** : 20-28.

Rahman, B.M.A., Fernandez, F.A., and Davies, J.B. (1991). Review of Finite Element methods for microwave and optical waveguides. *IEEE Proceedings,* **79** : 1442 - 1448.

Rank, E., and Babuska, I. (1987). An Expert System for the optimal mesh design in the hp-version of the finite element method, *International Journal of Numerical Methods in Engineering,* **24** : 2087 - 2106.

Ranky, P.G. (1990). *Manufacturing Database Management and Knowledge Based Expert Systems.* CIMWare Ltd : Guildford, Surrey, UK.

Rao, S. S. (2000). Enterprise Resource Planning : business needs and technologies. *Industrial Management and Data Systems*, **100** (2), pp. 81-88.

Rao, L., He, B., and Yan, W. (1994). Novel adaptive generator based on Kohonen's Neural Network model and vector quantization. *Proc. 2nd Int. Conf. Computation in Electromagnetics, Nottingham, UK, Apr 12-14 1994*, (IEE Conference #384). London : IEE, pp.193-197.

Ratnajeevan, S., and Hoole, H. (1990). Eigenvalue and Eigenvector Perturbation and Adaptive Mesh Generation in the Analysis of Waveguides. *IEEE Transactions on Magnetics,* **26** (2) : 791-794.

Reich, Y., Konda, S.L., Levy, S.N., Monarch, I.A., and Subrahmanian, E. (1993). New Roles for Machine Learning in Design. *AI in Engineering,* **8** : 165 - 181.

Reichert, K., Skoczylas, J., and Tarnhuvud, T. (1991). Automatic Mesh Generation based on Expert System Methods, *IEEE Transactions on Magnetics,* **27** (5) : 4197 - 4200.

Remenyi, D. (1991). *The formulation and implementation of strategic information systems*. PhD Thesis, Henley Management College, Brunel University, Uxbridge, UK.

Remenyi, D., and Sherwood-Smith, M. (1999). Maximise Information Systems value by continuous Participative Evaluation. *Logistics Information Management*, **12** (1/2) : 14 -32.

Remenyi, D., Money, A., Sherwood-Smith, M., and Irani, Z. (2000). *The effective measurement and management of IT Costs and Benefits – 2nd Edition*. Butterworth-Heinnemann : London, UK.

Rimmel, K. (2001). *Knowledge Management: A case study of the Volvo Ocean Race*. Masters Thesis (2001:37), Graduate Business School, School of Economics and Commercial Law, Goteborg University, Gothenburg, Sweden.

Robinson, S. (1997). Simulation model verification and validation: increasing the user's confidence. In (Eds. S. Andradottir, K.J. Healy, D.H. Withers and B.L. Nelson). *Proceedings of the 1997 Winter Simulation Conference*, Baltimore, USA, December 1997, INFORMS Press, pp. 53 – 59.

Rose, J. (2002). Interaction, transformation and information systems development – an extended application of Soft Systems Methodology. *Information Technology and People,* **15** (3) : 242 - 268.

Rosenfeld, and Morville (2002). *Information Architecture for the World Wide Web*. O'Reilly and Associates : Boston, MA, USA.

Rosenman, M.A. (1996). *A Hierarchical Evolutionary approach to the generation of Form*. Second Online Workshop on Evolutionary Computation (WEC2), Nagoya University, Japan, March 1996. [On-line]. Available : http://www.bioele.nuee.nagoya-u.ac.jp/wec2/papers/index.html

Rouse, A., and Dick, M. (1994). The Use of Computerized Tools in Qualitative Information Systems Studies. In *Proceedings of the 5th Australasian Conference on Information Systems*, Monash University, Melbourne, Victoria, 1994, pp. 209-220.

Ruggles, R (1997). The State of the Notion: Knowledge Management in Practice. *California Management Review*, **40** (3) : 80 – 89.

Saaty, T.L. (1980). *The Analytical Hierarchy Process, planning, priority setting, resource allocation*. USA : McGraw-Hill.

Sanada, K, Richards, C.W., Longmore, D.K., and Johnston, D.N. (1993). Finite element model of hydraulic pipelines using an optimized interlacing grid system. *Journal of Control Systems Engineering,* **207** (4) : 213-201.

Sandgren, E. (1994). Multicriteria design Optimization by Goal Programming. In (Ed. H. Adeli). *Advances in Design Optimisation*. New York, NY : Chapman and Hall, pp.225-265.

Saracevic, T. (1996). Modelling interaction in Information Retrieval : a Review and proposal. In *Proc. 59th ASIS Annual Meeting*, Volume 33, Baltimore, Maryland, USA, 1996

Sarantakos, S. (1998). *Social Research*, Melbourne, Australia : Macmillian.

Sarkis, J., and, Liles, D. (1995). Using $IDEF_0$ and QFD to develop an organisational decision support methodology for the strategic justification of computer-integrated technologies, *International Journal of Project Management*, **13** (3):177-185.

Scherer, E. (2000). The knowledge network: knowledge generation during implementation of application software packages. *Logisitics Information Management*, **13** (4) : 210 – 217.

Schulz M., and, Jobe, L. (2001) Codification and Tacitness as Knowledge Management Strategies: an Empirical Exploration. *Journal of High Technology Management Research*, **12** (1) : 139 - 165.

Schumaker, L.L. (1993). Computing optimal triangulations using Simulated Annealing. *Computer Aided Geoemetrical Design,* **10** (3-4) : 329 - 345.

Schumpeter, J. (1934). *The Theory of Economic Development : An enquiry into Profits, Capital, Credit, Interest and the Business Cycle.* Oxford University Press : London, UK.

Scott, H., and, Ives, B. (1992). MIS Research Strategies. In (Ed. R.D. Galliers). *Information Systems Research : Issues, Methods and Practical Guidelines*, pp.132 – 143. London : Blackwell Scientific.

Seufert, A., Von Krogh, G., and Bach, A. (1999). Towards Knowledge Networking. *Journal of Knowledge Management.* **3** (3) : 180 – 190.

Sharif, A. (1997a). The Management of Intelligence-Assisted Finite Element Analysis Technology. In (Eds. D.F. Kocaoglu and T.R. Anderson). *Proc. Portland Int. Conf. Management of Engineering and Technology (PICMET '97)*, Portland, Oregon, July 27-31st 1997, Portland, OR : Portland State University / IEEE / Informs, pp. 2550-2555.

Sharif, A., and Ettinger, R.D. (1997b). Finite Element Mesh Generation using Genetic Algorithms. In (Ed. J.R. Koza). *Late Breaking Papers at the Genetic Programming 1997 Conference*, Stanford University, Stanford, California, USA, July 13-16th, 1997, Stanford Bookstore, pp. 219-224.

Sharif, A., and, Irani, Z. (1997). Fuzzy Cognitive Mapping as a Technique for Technology Management. In *Proc. Portland International Conference on Management of Engineering and Technology (PICMET '97)*, Portland, Oregon, July 27-31st 1997, Portland, OR : Portland State University / IEEE / Informs, pp. 871.

Sharif, A.M. (1997). The Management of Intelligence-Assisted Finite Element Analysis Technology. In *Proc. Portland International Conference on Management of Engineering and Technology (PICMET'97)*, Portland, Oregon, July 27-31st 1997, Portland, OR : Portland State University / IEEE / Informs, pp.2550-2555.

Sharif, A.M. (1999a). Neural and Evolutionary Computing in Finite Element Analysis. *Journal of Computing and Information Technology*, **7** (1) : 137-151.

Sharif, A.M. (1999b). Harnessing agile concepts for the development of Intelligent Systems. *New Generation Computing*, **17** (4) : 369 – 380.

Sharif, A.M., and Barrett, A.N. (1998a). Utilising knowledge for optimum mesh design. *IEE Colloquium on Knowledge Discovery and Data Mining*, IEE, London, 7-8 May 1998. Digest No. 98/310, London : IEE, pp.4/1-4/5.

Sharif, A.M., and Barrett, A.N. (1998b). Seeding a genetic population for mesh optimisation and evaluation. In (Ed. J.R. Koza). *Proc. Late Breaking Papers, Genetic Programming 1998*, University of Wisconsin, Madison, USA, July 22-25th, 1998, WI, Omni Press, pp.195-201.

Sharif, A.M., and Ettinger, R.D. (1997). Finite Element Mesh Generation using Genetic Algorithms. In (Ed. J.R. Koza). *Proc. Late Breaking Papers, Genetic Programming 1997*, Stanford University, Stanford, USA, July 13-16th, 1997, Stanford, CA : Stanford University Bookshop, pp.219-223.

Sharif, A.M., and Irani, Z. (1999). Research note : Theoretical Optimisation of IT/IS Investments. *Logistics Information Management.* **12** (2) : 189 - 196.

Shephard, M.S. (1985a). Finite Element Modelling within an Integrated Geometric Modelling Environment : Part I. *Engineering Computations.* **1** : 61-71.

Shephard, M.S. (1985b). Finite Element Modelling within an Integrated Geometric Modelling Environment : Part I and II. *Engineering with Computers,* **1** : 61-85.

Shephard, M.S., Yerry, M.A., and Baehmann, P.L. (1986). Automatic Mesh Generation allowing for efficient A-priori and A-posteriori Mesh refinement. *Computer Methods in Applied Mechanical* Engineering, **55** : 161 - 180.

Sieloff, C.G. (1999). "If only HP knew what HP knows": the roots of knowledge management at Hewlett-Packard. *Journal of Knowledge Management*, **3** (1) : 47 – 53.

Silvester, P. (1969). A general high-order finite element waveguide analysis program. *IEEE Transactions on Microwave Theory and Technology,* **17** (4) : 204 - 210.

Silvester, P. P., and Ferrari, R.L. (1996). *Finite Elements for Electrical Engineers*, *3rd ed.* Cambridge : Cambridge University Press.

Simon, H.A. (1969). *The Sciences of the Artificial.* Cambridge, MA : MIT Press.

Simon, H.A. (1995). Artificial Intelligence : an empirical science. *AI* : **77** : 95-127.

Simpson, P.K. (1990). *Artificial Neural Systems : Foundations, Paradigms and Applications*. San Francisco, CA : Mcgraw-Hill.

Small, M.H., and Chen, J. 1995. Investment justification of advanced manufacturing technology: An empirical analysis. *Journal of Engineering and Technology Management,* **12** (1-2) : 27-55.

Smith, E. (2001). The role of tacit and explicit knowledge in the workplace. *Journal of Knowledge Management.* **5** (4) : 311 – 321.

Soerensen, M., and Boehmler, G. (1985). The Missing link between CAD and FEM - does it exist?. In (Ed. Tarun Kant). *Finite Elements in Computational Mechanics (FEICOM '85), Vol.2*. New York, NY : Pergamon Press, pp.967-984.

Soh, C.K., and Yang, J. (1996). Fuzzy controlled Genetic Algorithm search for Shape optimisation. *Journal of Computational Civil Engineering,* **10** (2) : 143 - 151.

Soo, C.W., Devinney, T.M. and, Midgley, D.F. (2002a). The process of Knowledge creation in organizations. *INSEAD Working paper 2002/30/MKT*, INSEAD, Fountainebleau, France.

Soo, C.W., Devinney, T.M. and, Midgley, D.F. (2002b). Knowledge creation in organizations: exploring firm and context specific effects. *INSEAD Working paper 2002/55/MKT*, INSEAD, Fountainebleau, France.

Sorensen, C., and Kakihara, M. (2002). Knowledge Discourses and Interaction Technology. *Department of Information Systems Working paper 115, London School of Economics and Political Science,* London, UK.

Sowa, J.F. (1994). *Conceptual Structures*. Brooks Cole : Pacific Grove, CA, USA.

Sowa, J.F. (2000). *Knowledge Representation : Logical, Philosophical, and Computational Foundations*. Brooks Cole : Pacific Grove, CA, USA.

Steels, L. (1993). Intelligence - Dynamics and Representations. In (Ed. L. Steels). *Proc. NATO Advanced Study Institute on The Biology and Technology of Autonomous Agents*, Castel Ivano, Trento, Italy, March 1-12. New York, NY : Springer.

Steinberg, L. (1994). Research Methodology for AI and Design. *Artificial Intelligence in Engineering Design Analysis and Manufacture,* **8** : 283-287.

Steinbock, D. (2001). *The Nokia Revolution*. Amacom

Stenmark, D. (1999). Asynchronous brainstorm: an intranet application for creativity. In *Proc. WebNet´99*, AACE Press, Honolulu, pp. 1429-1430.

Sterman, J.D. (2002). Reflections on becoming a systems scientist. *Systems Dynamics Review*, **19** (4) : 501 – 531.

Stewart, T. (1997). *Intellectual Capital.* Currency-Doubleday : New York, NY, USA.

Suchman, L. (1987). *Plans and Situated Actions: The Problem of Human-Machine Communication*. Cambridge University Press : Cambridge, UK.

Svedin, J. (1989). A Numerically Efficient Finite Element formulation for the General Waveguide problem without Spurious Modes. *IEEE Transactions on Microwave Theory and Technology*, **37** : 1708 – 1715.

Sveiby, K.-E. (1997). *The New Organisational Wealth.* Berret-Koehler : San Francisco, CA, USA.

Sveiby, K.-E. (2001). A knowledge-based theory of the firm to guide in strategy formulation. *Journal of Intellectual Capital,* **2** (4): 344-358.

Sveiby, K.-E., and Simons, R. (2002). Collaborative Climate and Effectiveness of Knowledge Work : an empirical work. *Journal of Knowledge Management*, **6** (5) : 420 – 433.

Syed, J.R. (1998). An adaptive framework for knowledge work. *Journal of Knowledge Management*, **2** (2) : 59 – 69.

Szabo, B. A., and Actis, R.L. (1996). Finite Element Analysis in Professional practice. *Computer Methods in Applied Mechanical Engineering,* **133** (3-4) : 209 - 228.

Takahashi, H., and Shimizu, H. (1991). A General Purpose Automatic Mesh Generation using Shape Recognition Techniques, *Computers in Engineering 1991, Vol. 1, (Proc. Int. Conf. ASME Int. Comp. Eng., 1991)*, New York, NY : ASME, pp.519-526.

Takkinen, J., and, Shahmeri, N. (). Are you busy, cool or just curious ? CAFÉ: A model with three different states of mind for a user to manage information in electronic mail.

Tang, H.-H., and Gero, J.S. (2001). Roles of Knowledge while designing and their implications for CAAD. In (Eds. J.S. Gero, S. Chase and M. Rosenman). *Proceedings of CAADRIA 2001*, Key Centre of Design Computing and Cognition, University of Sydney, 2001, pp. 81-89.

Tapscott, D., Lowy, A., and Ticoll, D. (1998). *Blueprint to the Digital Economy – Creating wealth in the era of E-Business.* McGraw-Hill.

Targama, A., and, Diedrich, A. (2000). Towards a Generic Theory of Knowledge and its Implications for Knowledge Management. In *Proc. 7th Workshop on Managerial and Organizational Cognition (ESADE)*, Barcelona, Spain, 2000.

Tarnhuvud, T., Reichert, K., and Skoczylas, J. (1991). Problem-Oriented Adaptive Mesh Generation for accurate Finite Element calculation. *IEEE Transactions on Magnetics,* **26** (2) : 779-782.

Tellis, W. (1997). Application of a Case Study Methodology. *The Qualitative Report*, **3** (3). Available. [on-line]. http://www.nova.edu/ssss/QR/QR3-3/tellis2.html.

Thomas, P.D., and Middlecoff, J.F. (1979). Direct control of the Grid Point Distribution in Meshes Generated by Elliptic Equations. *American Institute of Aeronautics and Astronautics Journal,* **18** : 652 - 656.

Thompson, J.F. (1984). Grid Generation techniques in Computational Fluid Dynamics. *American Institute of Aeronautics and Astronautics Journal*, **22** : 1505 - 1523.

Thompson, J.F., Warsi, Z.U.A., and Mastin, C.W. (1985). *Numerical Grid Generation, Foundations and Applications.* Amsterdam : North Holland / Elsevier.

Toffler, A. (1990). *The Third Wave.* Academic Press.

Topping, B.H.V. and Bahreininejad, A. (1995) Subdomain Generation using parallel Q-state Potts Neural Networks. In (Ed. B.H.V. Topping). *Developments in Neural Networks and Evolutionary Computing for Civil and Structural Engineering.* Edinburgh, Scotland : Civil-Comp Press, pp.65-78.

Travis, J. (1999). Exploring the constructs of Evaluative criteria for Interpretivist Research. *Proceedings of the 10th Australasian Conference on Information Systems*, 1st – 3rd December 1999, Wellington, New Zealand, School of Communication and Information Management, Victoria University of Wellington, New Zealand, pp. 1037 - 1049.

Turcke, D.J., and McNeice, G.M. (1974). Guidelines for selecting Finite Element Grids based on an optimization study. *Computers with Structures,* **4** : 499 - 519.

Turkiyyah, G.M., and Fenves, S.J. (1996). Knowledge-Based Assistance for Finite Element Modelling. *IEEE Expert.* **11** (3) : 23-32.

Turner, M.J., Clouth, R.W., Martin, H.C., and Topp, L.J. (1956). Stiffness and deflection analysis of complex structures. *Journal of the Aeronautical Sciences*, **23** : 805 – 823.

Üler, G.F., and Mohammed, O.A. (1996). Ancillary techniques for the practical implementation of GAs to the optimal design of electromagnetic devices. *IEEE Transactions on Magnetics,* **32** (3) : 1194 - 1197.

United Nations (2001). Knowledge Management for Decision-Making: Tools, Institutions and Paradigms. Distribution paper E/ECA/DISD/CODI.2/10 (*Second Meeting of the Committee on Development Information (CODI)*, Addis Ababa, Ethiopia, 4-7 September 2001), Economic and Social Council, Economic Commission for Africa, United Nations : New York, NY, USA.

Valliapan, S., and Pham, T.D. (1995). Elasto-Plastic Finite Element Analysis with Fuzzy parameters, *International Journal of Numerical Methods in Engineering,* **38** : 531 - 548.

Vakkari, P. (2000). *Conceptions of Library and Information Science. Historical, empirical and theoretical perspectives*. Taylor Graham : London.

Van der Spek, R., and Spijkervet, A. (1997). Knowledge Management: Dealing Intelligently with Knowledge. In (Eds. J. Liebowitz and L. Wilcox). *Knowledge Management and its Integrative Element*s. CRC Press : New York, NY, USA.

Vandenblucke, P., and Lagasse, P.E. (1976). Eigenmode analysis of anisotropic optical fibres or integrated optical waveguides. *Electronics Letters* **12** (5) : 120 - 121.

Vimawala, M.S., and Turkiyyah, G.M. (1995). Computational procedures for topological shape design. *Computer Methods in Applied Mechanical Engineering,* **125** : 257 - 285.

Von Krogh, G., Ichijo, K., and Nonaka, I. (1999). *Enabling Knowledge Creation : How to Unlock the mystery of Tacit Knowledge and Release the power of Innovation.* Oxford University Press, NY.

Walsham, G. (1993). *Interpreting Information Systems in Organisations*. John Wiley and Sons : New York, NY, USA.

Wang, S.S. (1991). Knowledge-Based Diagnostics and Design Systems, *Computers in Engineering 1991, Vol. 1, (Proc. Int. Conf. ASME Int. Comp. Eng., 1991).* New York, NY : ASME, pp.13-22.

Whitley, E. (2002). Tacit and Explicit Knowledge: Conceptual Confusion around the Commodification of Knowledge. *Department of Information Systems Working paper 90, London School of Economics and Political Science,* London, UK.

Wielinga, B.J., Th. Sterner, A., and Breuker, J.A. (1993). KADS : A knowledge approach to Knowledge Engineering. In (Eds. B.G. Buchanan and D.C. Wilkins). *Readings in Knowledge Acquisition and Learning, Automating the Construction and Improvement of Expert Systems*. Morgan Kaufmann : San Mateo, CA, USA.

Wight, O.W. (1984). *Manufacturing Resource Planning: MRPII.* Oliver Wight Ltd, USA.

Wiig, K.M. (1995). *Knowledge Management Methods: Practical Approaches to Managing Knowledge.* Schema Press : Arlington, TX, USA.

Wiig, K.M. (1997). Knowledge Management : An Introduction and Perspective. *Journal of Knowledge Management*, **1** (1) : 6 – 14.

Wiig, K.M. (1999). What future knowledge management users may expect. *Journal of Knowledge Management*, **3** (2) : 155 – 165.

Willcocks, L. (1994). *Information Management – The Evaluation of Information Systems Investments.* Chapman and Hall, London.

Willcocks, L., and, Margetts, H. (1994). Information management - risk and information systems: developing the analysis. In (Ed. L. Willcocks). *Infor-mation Management: The Evaluation of Information Systems.* Chapman & Hall : London, UK.

Wilson, J. (1994). Information Management. In (J. Feather and P. Sturgess, Eds). *Encyclopedia of Library Information*. Routledge, London.

Wilson, T.D. (1981). On user studies and information needs. *Journal of Documentation*, **37** : 3-15.

Winslow, C.D., and Bramer, W.L. (1994). *FutureWork – Putting Knowledge to Work in the Knowledge Economy*. New York Free Press : New York, NY, USA.

Winter, G., Montero, G., Cuesta, P. and Galan, M. (1994). Mesh Generation and Adaptive Remeshing by Genetic Algorithms on Transonic Flow Simulation. In (Eds. S. Wagner, E.H. Hirschel, J. Periaux and R. Piva). *Computational Fluid Dynamics '94 (Proc. 2nd European Computational Fluid Dynamics Conference, 5-8 September 1994, Stuttgart, Germany).* Chichester, UK : John Wiley, pp. 281-287.

Wittgenstein, L. (1956). *Philosophical investigation*s. Basil Blackwell : Oxford, UK.

Wright, D.S., Taylor, A., Davies, D.R., Sluckin, W., Lee, S.G.M. and Reason, T.J. (1974). *Introducing Pyschology : An experimental approach*. Middlesex, England : Penguin, pp.497-510.

Wu, X., Ramakrishnan, S., and Schmidt, H. (1995). Knowledge objects. *Informatica.* **19** (4) : 557-571.

Yagawa, G., Mochizuki, Y., and Yoshimura, S. (1991). Automated Structural Design based on Expert's knowledge and Fuzzy Control. *Computers in Engineering 1991, Vol. 1, (Proc. Int. Conf. ASME Int. Comp. Eng., 1991).* New York, NY : ASME, pp.23-28.

Yagawa, G., Yoshimura, S., and Kawai, H. (1995a). Automatic large-scale Mesh Generation based on Fuzzy knowledge processing and computational geometry (with a new function for Three-dimensional Adaptive remeshing). *Transactions of the Japanese Society of Mechanical Engineers (JSME) Part A,* **61** (583) : 652-659.

Yagawa, G., Yoshimura, S., and Nakao, K. (1995b). Automatic Mesh Generation of complex geometries based on Fuzzy knowledge processing and computational geometry. *Intellient CAE,* **2** (4) : 265 - 280.

Yagawa, G., Yoshimura, S., Soneda, N., and Nakao, K. (1992). Automatic Two- and Three-dimensional Mesh Generation based on Fuzzy knowledge processing. *Computational Mechanics,* **9** (5) : 333 - 346.

Yagawa, G.I., and Okuda, H. (1996). Finite Element Solutions with Feedback Network Mechanism through direct minimization of Energy functionals. *International Journal of Numerical Methods in Engineering ,* **39** : 867 - 883.

Yao, K.T., and, Gelsey, A. (1996). Intelligent Automated Grid Generation for numerical simulations. *Artificial Intelligence in Engineering Design Analysis and Manufacturing,* **10** (3) : 215 - 234.

Yeates, D.A. (1991). *Project Management for Information Systems*, London, Pitman.

Yin, R.K. (1994). *Case study research: Design and Methods – 2nd Ed.* Sage Publications : Thousand Oaks, CA, USA.

Young, Z., and Grosse, I.R. (1990). Rule-based computational system for Automatic Finite Element modeling. *Computers in Engineering 1990, (Proc. Int. Conf. ASME Int. Comp. Eng., 1990).* New York : NY, ASME, pp. 87-94.

Zack M. (1999) Managing Codified Knowledge. *Sloan Management Review*, Summer, 45-58.

Zadeh, L.A, (1965). Fuzzy sets. *Information and Control.* **8** : 338-353.

Zadeh, L.A. (1996). Fuzzy logic = computing with words. *IEEE Transactions on Fuzzy Systems*, **4** (2): 103-11.

Zienkiwicz, O.C. and Taylor, R.L. (1971). *The Finite Element Method in Engineering Science.* London : Mcgraw-Hill.

Zienkiwicz, O.C., and Cheung, Y.K. (1965). Finite Elements in the solution of field problems. *The Engineer*, September 1965, pp.507-510.

Zienkiwicz, O.C., and Zhu, J.Z. (1990). The Three R's of engineering analysis and error estimation and adaptivity. *Computer Methods in Applied Mechanical Engineering,* **82** : 95 - 113.

Zuber-Skerrit, O. (1991). *Action Research for Change and Development.* Aldershot : UK. Gower Publishing.