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Supporting the management of electronic engineering design teams through a dynamic contingency approach

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Supporting the management of electronic engineering design teams through a dynamic contingency approach

Richard David Parsons

November 1997

Abstract

The contribution to knowledge presented in this thesis is the dynamic contingency approach, supported through software, which supports the management of the early, conceptual stages of electronic engineering team design. The term contingency pertains to the design environment being in a *contingent* state, that is "dependent on uncertain issues" (Hayward & Sparkes, 1991). These issues are typically *dynamic*, that is "pertaining to forces not in equilibrium, forces that produce motion" (Hayward & Sparkes, 1991).

The concept for the dynamic contingency approach was developed through a soft systems analysis. This analysis drew upon an ethnographic study conducted in parallel with the present work by another researcher. Both the present work and the ethnographic study were carried out within a multidisciplinary research team in collaboration with an industrial partner (company A). This thesis discusses the evolution of this multidisciplinary research method, including the development of a software prototype (EDAPT), which enabled the requirements for the dynamic contingency approach to be established. Through this research method key issues were identified which affect the ability of design managers, and to a lesser extent design engineers, to adequately perceive the current situation of a design project; and to determine appropriate corrective responses to potential problem situations. The work indicates that this is particularly true when under pressure in such a complex, interdependent and dynamic environment. This thesis illustrates how the environment of design can be dependent upon these key issues which are often uncertain, that is, the environment is in a contingent state. Furthermore, the thesis depicts the dynamic nature of these issues.

The dynamic contingency approach was developed in response to these issues in partnership with the industrial collaborator. The approach synthesises a variety of such issues to support the coordination of interdependencies, provide a view of the current project situation, alert stakeholders to potential problem situations, and present possible responses to potential problem situations. In short, what has been achieved is a design management worldview with sufficient detail to help people expect and anticipate what might happen, and how others may behave in a team design environment, together with the foundations for a system which enables and supports this perspective. In essence the approach provides a way of conceptualising the design environment which should enable improvements in the management of design teams at the early, conceptual stages of electronic engineering design projects.

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"Let us, then, be up and doing,
With a heart for any fate;
Still, achieving, still pursuing,
Learn to labour and to wait."
(from A Psalm of Life, H. W Longfellow)

What began as a route to a qualification in pursuit of a chosen career, became an integral element of my life. As a consequence the work described in this thesis has affected everyone connected with me. I must therefore thank all of those people, who have in varying degrees, enabled me to complete this work. In particular I owe much to my wife Alli for her understanding and support, and so much more than I could express here; I hope that we get along as well once this work becomes less of a presence in our lives! I must also thank my Father and Mother (and even my two brothers Michael and Robert) for their encouragement and support, especially during the last six years; and Gina and Roy Ball for their support and thoughtfulness.

Within the University of Plymouth, of the many people who have provided assistance I would like to thank my main supervisors Dr Peter Jagodzinski and Dr Fraser Reid for their guidance, support and hard work in helping me to complete and produce this work. My thanks must also go to the other key members of the research team Dr Phil Culverhouse and fellow researcher Caroline Burningham. I would like to say a special thank you to Mr Jim O'Brien who as both a friend and colleague, provided distractions from work and a devils advocate for my sometimes tortured thinking. I would also like to thank Tom, Rachel & Tammi for their help and coffee drinking abilities.

Obviously none of this work would have been possible without the support of the School of Computing, University of Plymouth; the EPSRC's funding; and in particular the time and interest of the employee's at company A.

iii) Author's Declaration

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award.

This research has been undertaken whilst the author was employed as an externally funded Research Assistant in the School of Computing, University of Plymouth. The position was funded by the Engineering and Physical Science Research Council (EPSRC) as part of research grant GR/H/43526. Although this position was as a member of a research team, the contributions attributed to the author as described in this thesis, are the results of work conducted solely by the author.

During the course of the work the author attended the following :

- Informing Technologies to Support Engineering Decision Making Conference, London, 11/94;
- Object Technology and its application in Engineering Conference, Glasgow, 3/95;
- The practical application of intelligent agents and multi-agent technology Conference, London, 4/96;
- A variety of IEE colloquia on Engineering Design & CSCW;
- 1st International Engineering Design Debate, Strathclyde, 9/96.

Articles from this work were presented at, and published in the proceedings of, the following :

- 3rd International Conference on concurrent engineering and electronic design automation, Cambridge, 3/96;
- 1st International Engineering Design Debate, Strathclyde, 9/96;
- 11th International Conference on Engineering Design, Tampere, Finland, 8/97.

Elements of the work have also been published as a chapter in "The Design Productivity Debate" (see Jagodzinski, Parsons, Burningham, Evans, Reid & Culverhouse, 1997).

In addition to these public presentations the work have been presented to :

- Other research institutions via correspondence and informal workshops;
- Personnel at company A (the industrial collaborator for this research), from engineers to senior management;
- Various members of the EPSRC steering committee via poster sessions at the University of Plymouth.

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Date: 1/6/98.

1. Introduction

1.1 Thesis' aim & contribution to knowledge

The aim of this work may be termed 'theory building' (Eisenhardt, 1989), with the objective of gaining an appreciation of the poorly understood environment of electronic engineering design teams and determining possible support to its management. This thesis presents a Human Factors perspective, that is '*the analysis and solution of problems relating to people's interactions, as individuals, groups or organisations, with information artefacts, technologies and systems*' (EPSRC, 1996), of a multidisciplinary research project. As suggested by Eisenhardt (1989), to retain theoretical flexibility and avoid bias, the work began without a research question or hypothesis. The approach postulated in this thesis is the result of this theory building exercise.

Many authors (for example Hales 1993, Cross 1994, and Pugh 1996) describe research of design as initially viewing design as a technical process, and more recently as a cognitive process for the individual and as a social process for a team. They argue that design research now needs to integrate these three views into a more systemic approach. That is, " *a framework...within which the design manager has room to move about, fitting together bits of the jigsaw as they come together and applying a variety of techniques to maintain steady overall progress towards a finished product*" (Hales, 1993, page 9). The contribution from the work described in this thesis is a dynamic contingency approach which provides a foundation for developing such a framework. The dynamic contingency approach, supported through software, addresses both social and technical issues to support the management of the dynamic and interdependent socio-technical environment of team electronic engineering design. The term contingency pertains to the design environment being in a *contingent* state, that is "dependent on uncertain issues" (Hayward & Sparkes, 1991). These issues are a variety of situational factors which are typically *dynamic*, that is "pertaining to forces not in equilibrium, forces that produce motion" (Hayward & Sparkes, 1991).

The rationale for the dynamic contingency approach that is presented in this thesis was evolved and evaluated in collaboration with an industrial partner (company A) via :

- A soft systems analysis of the current design environment at company A;
- The evolution of a conceptual model and a prototype socio-technical system entitled EDAPT: Engineering Design Ally for Project Teams, to support the perceived conflicts in this environment;
- The development of the concept of the dynamic contingency approach, supported by EDAPT;
- The evaluation of EDAPT and the concept of the dynamic contingency approach to establish requirements for supporting the management of the design environment.

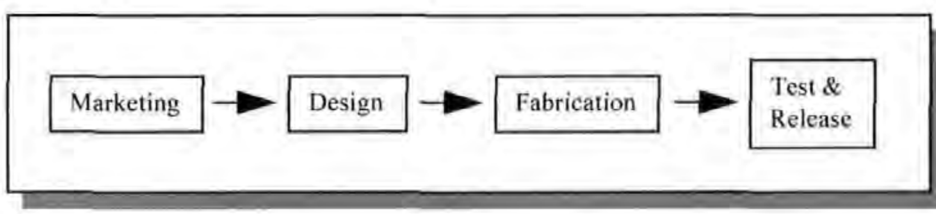
The dynamic contingency approach described in this thesis provides electronic engineering design teams with a worldview in sufficient detail to help people expect and anticipate what might happen, and how others may behave in a team design environment, together with the foundations for a system which enables and supports this perspective. Essentially the approach provides a way of conceptualising the design environment which should enable improvements in the management of design teams at the early, conceptual stages of electronic engineering design projects.

1.2 What is design ?

As the title states, this thesis is concerned with supporting *design*. The term design can be applied in many contexts. Before we begin to delve into the complexities of the thesis, we need to explain what we mean by design in an engineering context, and in particular electronic engineering.

Electronic engineering covers a wide area of application. The most visible to the general public being the production of microchips for use in consumer goods such as computers, videos and televisions. The development of such products can be seen to follow a typical product design life cycle. In brief, the requirements of a market are ascertained and assembled into a product requirement specification, usually by the marketing function. A design for the product that meets these requirements is then developed, usually by design engineers. This design will normally be in the form of schematic diagrams and written specifications of function. These form the basis for a process known as Fabrication, (i.e. the production stage where the physical microchip is produced). The microchip is then tested and released. Figure 1.1, illustrates this process.

Figure 1.1, a simple overview of a product design life cycle.



Thus, the design phase of a product, in a sequential process as shown above, falls between marketing and fabrication. French (1985) has defined design as referring to the conception, invention, visualisation, calculation, marshalling, refinement and specifying of function to determine the form of an engineering product. This definition can be contextualised by distinguishing between science and engineering.

> *" Science attempts to formulate knowledge by deriving relationships between observed phenomena. Design, on the other hand, begins with intentions and uses the available knowledge to arrive at an entity possessing attributes that will meet the original intentions. The role of the design is to produce form or more correctly, a description of form using knowledge to transform a formless description into a definite, specific description. Moreover, design is a pragmatic discipline, concerned with providing a solution within the capacity of the knowledge available to the designer. This design may not be 'correct' or 'ideal' and may represent a compromise, but it will meet the given intentions to some degree."*
>
> *Coyne, Rosenman, Radford, Balachandra & Gero (1990)*

Design should not be considered a linear progression from problem to solution. As Cross (1994) discusses, the solution does not arise directly from the problem. Typically the designer's attention oscillates between the problem and the solution and an understanding of both evolves. So, design can be viewed as a pragmatic discipline concerned with generating a solution within the constraints of the designer's knowledge and access to knowledge, which satifices a problem. This perspective of design does not really consider design as carried out within a team. When design is conducted in a team environment there are different opportunities and problems arising from the dynamics of social interaction and the enhanced availability of knowledge (Cross & Cross, 1995). Our focus has been team design, and our perspective has been that team design is a highly social activity, which we discuss further in section 1.5.

1.3 Background of the University of Plymouth project

The work discussed in this thesis was conducted within a University of Plymouth (UoP) multidisciplinary research project. A succession of projects conducted by the University of Plymouth since 1988, led to the focus of the work discussed in this thesis. Ball (1990) details a psychological study of the cognitive tactics of individual design engineers. Ball's findings identified a number of issues, such as encouraging the formulation of more than one design solution and the need for assisting solution selection, which required support. Such issues provided the basis for a knowledge based support tool for individual designers, as described by Scothern (1991). Ball's work identified the need to consider the organisational and social aspects of design which impact on the cognitive process of design.

Following this work an international survey of industry practice, CAD tool usage and limitations, design theory and process models was conducted. This entailed literature reviews, and visits to eighteen UK and European electronics manufacturing firms and eight leading US, Japanese and Korean electronics companies and research institutes. These companies represented the automotive, aerospace, process equipment and consumer products sectors. As far as possible the companies chosen were held (for example by Department of Trade & Industry) to exemplify good practice in the industry. This study provided insights into the major problems facing product designers, and enabled a set of best practices to be identified. The study revealed a number of widely held views. For example, that whilst concurrent engineering approaches are considered to be more efficient, traditional approaches giving a serial pathway for product development, are more commonly used because they require less sophisticated communication systems, project control and management. More details of this work can be found in Culverhouse, Bennett and Hughes (1991a & 1991b).

1.4 University of Plymouth project intent and structure

The UoP multidisciplinary research project was a workplace based study. Such studies aim to convey the sociality of work by shedding light on the complex actions and interactions that occur (Plowman, Rogers, & Ramage 1995). The UoP project was conducted by a multidisciplinary research team comprising social and cognitive psychologists, electronic engineers, software engineers and HCI practitioners; in conjunction with a leading UK *silicon foundry* (company A), sampled in the previous studies (see section 1.3). Past investigations in the conceptual stage of electronics design have aimed at supporting the cognitive process of the design activity (for example, McNeill & Edmonds 1994, and Harris, McNeill & Sydenham 1991). The intent of the UoP project was that the studies would inform the design of a support system to improve the management of team electronic design. This thesis concerns the provision of this support in the form of an information system. Stowell and West (1994) define an information system as the "*notional whole that manages the provision, manipulation and use of appropriate data to enable decision-making and resulting action in the realm of purposeful human activity*". Stowell and West's argument places emphasis upon understanding decision making activities and potential methods of supporting them. This emphasis determined the structure of the UoP project as follows.

Generous access to design teams in industry coupled with the multidisciplinary research team, provided the opportunity for a thorough study of the technical and social aspects of design practice and problems in industrial settings. The project entailed two interrelated studies, a longitudinal psychology study and a soft systems analysis, both focusing on design teams working on major projects in company A. Briefly these studies, which were conducted by a psychologist and the author respectively, were :

i) a longitudinal social psychology study utilising ethnographic and other qualitative techniques focusing on the social activity within design teams, providing a description of project management, work practices, problems, errors, decision-making events and information pathways from the perspective of team members during the early phases of design.

ii) a soft systems analysis examining the extant socio-technical environment of team electronic engineering design to determine requirements for improving the current situation.

The longitudinal social psychology study, which was conducted by the psychologist, commenced approximately 12 months prior to the systems analysis. This thesis is concerned primarily with the systems analysis, and the conclusions of the UoP project.

1.5 Thesis focus

From the earlier UoP projects it became clear that the management of the team process of design was poorly understood, particularly the early conceptual phases. As Oxman (1995) illustrates due to this poor understanding "*management tools are poorly integrated with the design process, especially in conceptual design*". Thus the management of the design team became the project's focus.

Typically the term management is considered to describe a collection of activities such as planning, organising, directing and coordinating. Kocaoglu (1996) characterises the essence of engineering management as '*making and implementing decisions to provide leadership for a system or its related components*'. Ho & Sculli (1994) discuss the essence of management as dealing with problems, which are effectively social constructs. This perspective may be embellished by Warboys (1995) description of management's three social challenges. These being the development of personnel so that they can achieve their best; how to give personnel the fullest opportunity for contribution; and finally how to unify the various contributions (i.e. the problem of coordination), "*the crux of any organisation*".

Within this thesis it is these issues to which we refer when discussing management. In summary, management is the action to effectively deal with the flux of interacting events and ideas which these tasks encapsulate (Checkland, 1981).

This thesis makes reference to terms such as method and technique which although widely used often have differing connotations. For consistency their use within this work conforms to the definitions of Morris, Evans, Green, and Theaker (1996) [1] where : a method is a systematic way of proceeding with a phase of developing a product, typically composed of a series of steps; and a technique is a way of accomplishing a specific task that forms part of a method.

As discussed above this work has focused upon team design. By team we refer to a set of people who are knowingly collaborating on a common goal, who require communication and coordination among the team members (Olsen, Cutkosky, Tenenbaum, & Gruber, 1993). Further, that each team member may have different responsibilities and roles. Cross (1994), uses the following analogy based upon a football team, to convey the environment in which team design takes place :

> *"The football team's strategy for defeating the opposition [i.e. the design] will consist of an agreed plan to use a variety of plays or moves, to be applied as the situation demands. During the game, the choice of a move, and whether or not it is successful, will depend on the specific circumstances, on the skill of the players, and on the response of the opposition.*
>
> *The repertoire of moves used in a game is partly decided in advance, partly improvised on the field, and also amended at the half-time briefing by the team coach. The coach's role is important because he maintains a wider view of the game than the players can actually out there on the field."*

This analogy provides a useful handle on the task facing the management of a design project. However, where the analogy falls down is that a football coach normally has a good view of who is doing what and when, how the game is flowing, videos of previous games of both their team and the opposition, and a referee and fairly well

[1] It should be noted that the use of the term 'methodology', has been avoided within this thesis as we concur with Morris et al who consider it to be 'much abused'.

established rules for behaviour under certain conditions. As will be discussed throughout this thesis, these aspects are not normally available to design management.

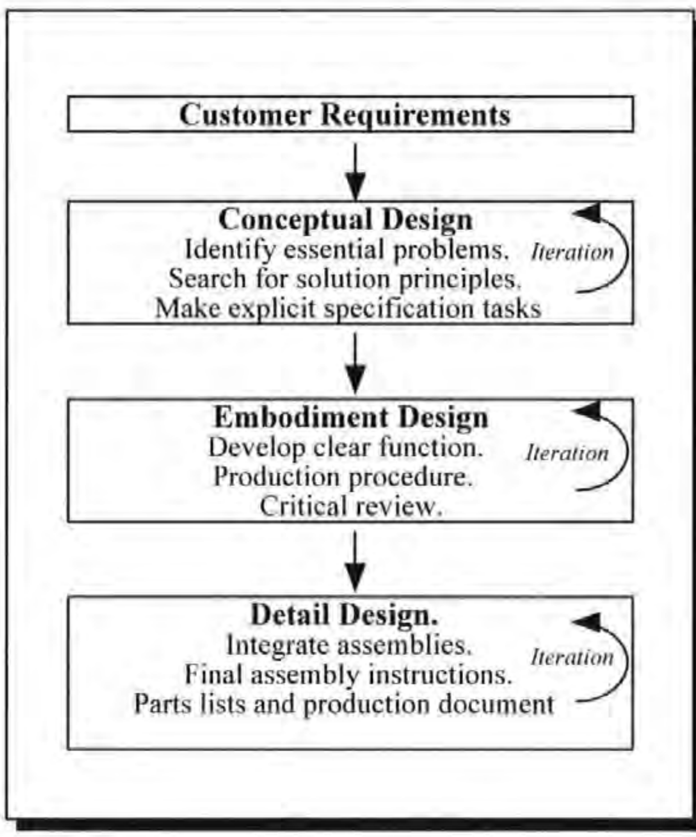
In a seminal paper Bucciarelli (1988) discusses the ethnographic perspective of team engineering design. From ethnographic studies of two companies Bucciarelli describes his view of design as :

> *"...[a design] exists only in a collective sense. Its state is not in the possession of any one individual to describe or completely define, although participants have their own individual views, their own images and thoughts, their own sketches, lists, diagrams, analyses, [etc.] which they construe as the design. ... formal drawings, detailed lists of performance specifications, lists of materials, subcontractor orders, [etc., do not constitute the design] ...these are artifacts of the process, formal productions of participants, parts and pieces of the design, but they ought not to be construed as 'the' design. They serve as a datum, as touchstones to grab hold of as the need arises. ... in [the design] process, different participants point to different sets of artifacts as the design. If all point to the same set of representations you can be sure that the process is over."*

For these reasons Bucciarelli views design as being a social process, a perspective which this project has adopted. This work has taken the view that considering design as a social activity is particularly important for the early stages, where between 50% to 80% of the cost of manufacturing a product may be committed within the first 5% to 10% of the design process (Jenkins 1996, and Sharpe 1995). This part of the process is concerned with turning what can be quite vague and conflicting aims into hard engineering targets. Due to the increasing complexity and size of artifacts this has through necessity become a team process, which must allow a high degree of flexibility and adaptation in the interpretation and exchange of ideas. For this reason it is not amenable to the tight reductionist modelling which has been applied to the later stages of design (for example, Ullman, Dietterich, & Staufer 1988). This situation is further complicated by Concurrent Engineering (CE) '*... the concept of running design activities and reflecting the effect of design influences simultaneously*' (Jenkins, 1996). CE is generally applied by developing and implementing multi-skilled teams supported by appropriate technologies (Greenfield, 1996). This approach moves project structures from hierarchical to adhocracies. This places a greater burden on co-ordination, and the communication and storage of information.

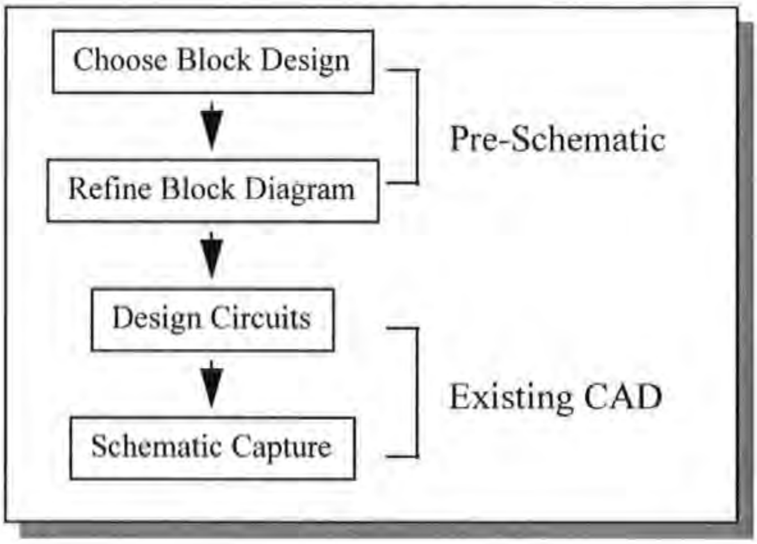
The preceding discussion has illustrated the importance and difficulty of managing team design. In particular this affects the early, conceptual stages. Well established models and theories exist for the later stages of design as described in BS7000 (see Figure 1.2 below, after Pahl & Beitz, 1984).

Figure 1.2. Product Design Process, after Pahl & Beitz (1984)



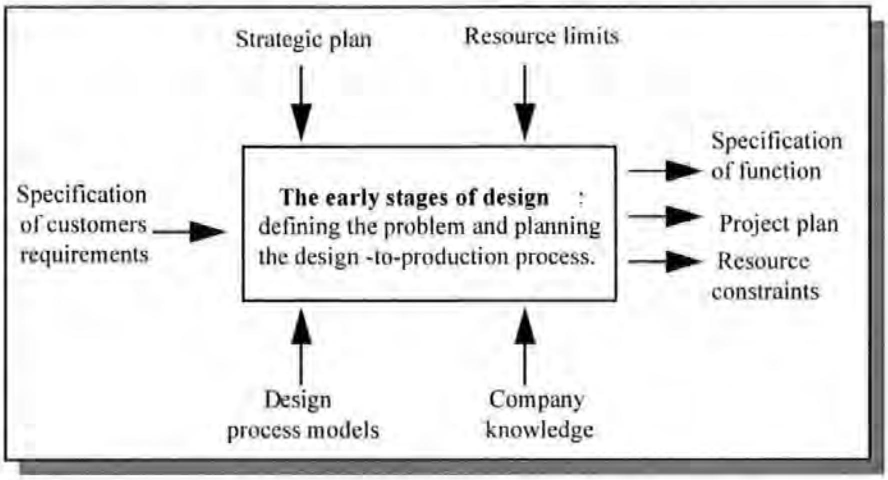
The current project concentrates upon the early conceptual phase of the design process, which is less well defined than the later stages. Using Murray's (1993) definition, electronic engineers may be considered to be '*knowledge-workers*' in that they manipulate information and insubstantial material. In other words their material comprises data, ideas, and concepts which are realised in some descriptive form such as a specification. This is particularly true of the conceptual stage, which has been characterised by Guindon, Krasner and Curtis (1987), as " *identifying and defining what the problem to solve is, [more] than on designing a system to solve the problem*". Within electronic engineering the conceptual design phase typically uses a block representation which ignores the exact details of the circuit and focuses upon a general functional description (Harris et al, 1991). Figure 1.3 below, illustrates an overview of this step within the design phase.

Figure 1.3, electronic design sub steps (after Harris et al, 1994).



As we shall discuss later in the thesis, this stage of design is reliant upon flexibility and adaptability which are achieved by what is primarily a social process of debate and interaction between people. As Hybs and Gero (1992) discuss, typically the earliest stages of this process have little if any external manifestations of the design, that is a specification or schematic. Jagodzinski, Parsons, Burningham, Evans, Reid, and Culverhouse (1997) show how this process is concerned with juggling conflicting aims and constraints to produce an acceptable definition of the problems, as outlined in Figure 1.4 below, which are addressed in the later stages of design.

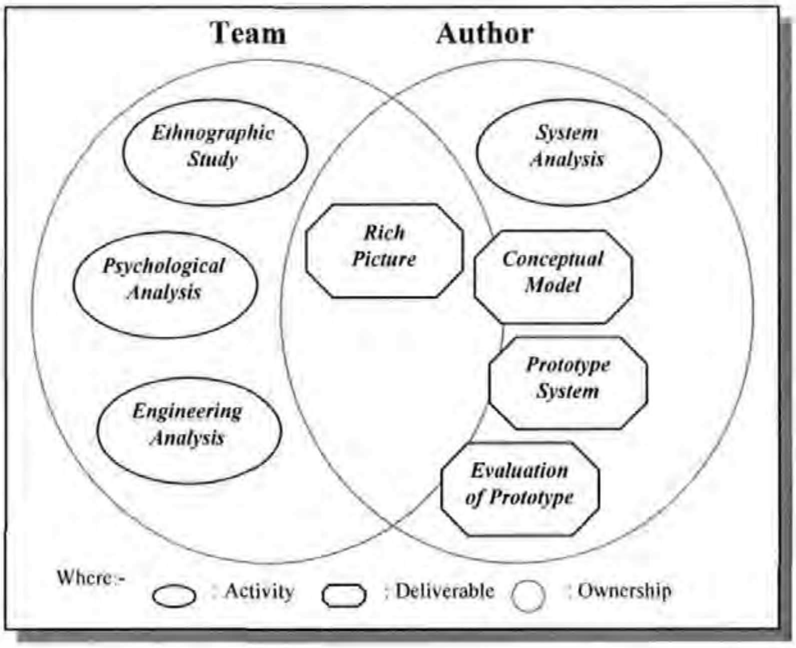
Figure 1.4, The early stages of electronics design (after Jagodzinski et al, 1997).



1.6 Thesis summary and structure

This thesis presents the contributions of the author to the UoP project outlined above. Plowman, Rogers, & Ramage (1995) argue that the use of techniques such as ethnography in systems development make the work of the analyst and the ethnographer difficult to distinguish. Due to the nature of such a collaborative and multidisciplinary project it is difficult to completely isolate any one person's contribution from the work of the other members of the team. To attempt to ignore others' work can remove the context of that which remains. Consequently the input from the team, which informed and constrained the contributions of the author, must be included in this work. In particular, chapter 4 reports in some detail the work of other team members which enabled the evolution of the problem definition. Figure 1.5, below signposts the contributions from the author within the UoP project.

Figure 1.5, The contributions from the author within the UoP project.



The thesis takes the follow structure. Chapter 2 offers a synopsis of research in providing support to the management of engineering design, illustrating the need for synthesising the array of techniques and tools that are available, to enable their selective and effective use by design management. The need for synthesis in such a multidisciplinary project and the potential for utilising an emergent approach determined the methods of research used within the UoP project as a whole, and in particular the present work, which is described in chapter 3. The main work discussed in the thesis has been structured around the definition of the problem, an hypothesis for improving the situation, and the evaluation of the hypothesis. In reality the work was highly iterative between these stages, but is presented in this way to make the material more easily digestible.

The initial stages of the work involved the generation of a rich picture of the problem situation. This picture was formed from three key perspectives of the situation, namely from psychological, engineering and stakeholder viewpoints. A number of interrelated and interdependent issues are identified in this picture. They stem from the sometimes conflicting need for formality and flexibility in the design environment.

The initial stages of the work, the rich picture and these issues are discussed in chapter 4.

The next stage of the work concerned conceptualising the problem situation, and the evolution of potential means to improve the current situation. The crux of the work presented in this thesis involved the synthesis of various requirements for support which had been identified from the rich picture, into one conceptual model of support. Expanding upon the problem situation, chapter 5 discusses the rationale for a dynamic contingency approach which comprehends social and technical influencing factors which achieves this synthesis. The requirements for supporting this environment evolved through the formative evaluation of two conceptual models of support and an exploratory prototype system (EDAPT). Chapter 6 describes the evolution of these models and EDAPT. Thus chapters 5 and 6 provide the rationale and approach for improving the current management of team electronic design.

Due to the nature of the research method adopted, formative evaluation was continuos throughout the work. However, the final stages of this work entailed a more structured evaluation of the proposed approach for supporting the management of electronic engineering design projects. Essentially this involved the comparison of the problem situation presented in chapter 4 against the approach presented in chapters 5 and 6. In addition to this comparison exercise, the human factors of the system were also considered. For example, guidelines for groupware design were incorporated from pertinent literature. The evaluations involved a number of techniques which were suitable for coping with such rich and contextually based requirements. This final evaluation and its findings are discussed in chapter 7.

Collins, Brown, and Newman (1989) suggest that *reflection* is a fundamental aspect of improving understanding. The final chapter reflects upon the work contained in this thesis in terms of the project's aims, the research method adopted, the deliverables, further work and finally the author's reflection upon the work.

The research has been consciously and fundamentally human-centred in that the problem and the approaches to its support comprehend the environment of design as an interrelationship of technical and social issues, achieved through the consensus of the stakeholders at company A. The thesis presents the view that this complex interrelationship of technical and social issues may be better managed through a dynamic contingency approach, supported by appropriate tools, techniques and working practices integrated in an environment such as that outlined in the prototype system EDAPT.

2. A synopsis of approaches to supporting engineering design

2.1 Introduction

This chapter presents a brief synopsis of the approaches to understanding and developing support for engineering design. The scope of design science has been wide, from modelling individual cognitive processes (for example, Ball 1990) to the development of mechanism to support multidisciplinary design (for example, Stacey, Sharp, Petre, Rzevski & Buckland 1996). It is an evolving field, without a recognised taxonomy which includes information regarding the environment and process of design (Ullman, 1992). Due to the interdisciplinary and interdependent nature of much of design research it is difficult to neatly classify the different approaches which have been taken. Oxman (1995) and Cross (1994) present discipline led perspectives of design studies. As Oxman discusses, the application of multidisciplinary approaches is increasing as the benefits from integrating techniques become apparent. A viewed shared by Hales (1993) and Cross, Christiaans and Dorst (1996) who describe design as initially being viewed as a technical process, and more recently as a cognitive process for the individual and as a social process within a team. They argue that design research now needs to integrate these three views into a more systemic approach. The present work may be seen to encompass these perspectives as the support of the management of team design requires such a synthesis. As Cantamessa (1997) states engineering design should be viewed '*as a very complex melting pot of different ingredients: managerial objectives, organizational factors, methodological techniques and technological support'*. The work discussed in chapters 3,4,5 of this thesis has led us to focus upon supporting the management of the dynamic socio-technical environment of the design process. This requires a clear and current 'picture' of the design project's situation at any given point in time and the implications of altering the situation.

A number of authors have categorised approaches to developing support for design (for example Cantamessa 1997, Pallo 1996, Dowlatshahi 1994 & Ullman 1992). Whilst the titles of their categories vary, the concepts are essentially the same. The following chapter discusses the research approaches based on Ullman's (1992) mechanical engineering categories of process, environment, and problem. Where *process* examines the procedures of a design project; *environment* encompasses aspects such as participants and resources; and *problem* looks at the cognitive activity of design itself. The aim of this chapter is to outline the various approaches, and illustrate from a design management perspective, the need for synthesis.

2.2 The design process : what happens in a design project

Formulating a model of any process is normally a key requirement in better understanding and determining improvements for that process. A process model of design is particularly important for team activity as it provides a *formalised,* and *externalised* method (Cross 1994). Formalising the process helps to ensure that necessary issues are considered and that oversights are not made. Externalising facilitates communication between the team about what is, what should, and what might happen. Two categories of design model have been defined, namely descriptive and prescriptive (Cross, 1994 and Finger & Dixon, 1989).

Descriptive models (for example French 1985), describe a sequence of typical activities that occur in design. Cross (1994), defines descriptive models as " *emphasising the importance of generating a solution concept early in the process. ...The process is [regarded] as heuristic, using previous experience, general guidelines and 'rules of thumb' that lead in what the designer hopes to be the right direction, but with no absolute guarantee of success".* As design complexity and market competition increases, so does the necessity for team design, for example due to size of task and issues such as time-to-market. However, as Cross (1994) and Culverhouse (1995a) have noted, descriptive models do not provide the more systematic approach to the design process that facilitate the effective management and coordination of team design, for example knowing at which point particular specialists will be required.

Prescriptive models attempt to define a more systematic procedure to follow, their emphasis being the *"need for more analytical work to precede the generation of solution concepts"* (Cross, 1994). Prescriptive models of the design process are evident in the domains of mechanical engineering (for example Pahl et al 1984, Ullman 1992) and software engineering (for example NCC's *'V' STARTS*, Sommerville 1992). These models provide useful checklists for the sequence of generic activities which need to be carried out. However, prescriptive models do not support the management or control of the process, with regard to problems such as human error, over design, reinvention, communication between phases, appropriate levels of documentation and not reflecting the opportunistic nature of design (Culverhouse, 1995a & Davies, 1993).

The complementary pro's and con's of these types of model reflect the different phases of design. Dorst et al (1995), compare two design paradigms namely, 'problem solving' (Simon, 1981), versus 'reflection-in-action' (Schön, 1983). Simon views design as a rational problem solving process, whereas Schön views design as a *'reflective conversation with the [design] situation'* where any design problem is unique. These two approaches may be viewed as being prescriptive and descriptive, respectively. Dorst et al (1995) conclude that the 'problem solving' paradigm is apt for well defined situations, such as the later stages of design, but that the 'reflection-in-action' paradigm provides a better description of the conceptual, early stages of design. In other words it appears that descriptive models map the reflective, creative activity of the earlier stages, whilst the more reductionist, "scientific" approaches are better suited to the latter stages.

These models of design are fundamentally concerned with sequential design processes. Understanding of the process is further complicated by the adoption of concurrent engineering (CE). The benefits of adopting the philosophy of CE, for example reduced time-to-market, have been argued by many authors (see Hyeon et al 1993, Maddux 1993). CE aims to replace the classical sequential process of design, by simultaneous design. The main vehicle for this approach has been the use of multidisciplinary teams. Models for managing this process have been proposed (for example Duenas et al 1996), but these can compound the problems of an already poorly understood process.

Currently available models do not provide sufficient structural support for both the team activity of design and the reflective paradigm needed at the early stages of design. As Cross (1994) states "*What is needed is a more flexible, strategic approach to designing, which identifies and fosters the right kind of thinking at the right time, and within the context of a particular design*". This means design managers knowing when to apply the most appropriate approach. This is an aim which is central to the present work and will be discussed in more depth as the thesis progresses.

Computer Supported Co-operative Work (Grief, 1984) studies, which are discussed further in section 2.3, have utilised ethnographic techniques to reveal the social nature of the design process. For example, both Hughes (1995) and Pycock (1995) argue that process models guide the process, not enforce it. This is because the models are embedded and situated within organisational settings, making every situation unique and requiring different interpretations. Gaining an understanding of this context and the day to day social negotiation which resolves situations is crucial to providing a resource which guides action and cooperation. This is a view expanded upon by Minneman and Harrison (1997) who, based on work in the mechanical engineering field, characterises design activity as :

> *"In the heat of the moment, interest-relative negotiation is precisely what happens regardless of what processes and tools are in place for a design team to use as resources. Politics, personal and group histories, and complex organizational interactions are the norm...these phenomena.. [are] fundamentally what design is about, not as deviations from a rational ideal."*

The value of methods and models according to Minneman and Harrison (1997), are that they provide a framework for participation and negotiation, *'not blueprints for a specified result'*. As discussed above, models in some form must be available to support the management of design teams. Knowing what to do and when, requires a clear picture of the design process. This means a view of the interrelationships of the social and technical factors. Providing this view has been a key objective for the present work.

In addition to attempts at modelling, techniques and standards are also being developed to support the design process. As Buckroyd (1994) discusses a number of Japanese originated techniques have become popular, for example Design For Manufacturing (DFM), Design For Testability, etc. Generally these techniques, commonly referred to as *DFx's*, introduce additional considerations for functions within the process which aim to improve subsequent production. For example, DFM asks the designer (and possibly the manufacturer) to consider the manufacturing requirements of design solutions. French (1985) describes a design's philosophy as being the basis from which a few key decision are made, arising from a few important considerations, out of which many consequences flow. He argues that frequently this philosophy only emerges when the scheme is complete. In many ways DFx techniques encourage the consideration of design philosophies. Another popular technique for supporting the process has been the use of Quality Functional Deployment (see Lundel & Williams, 1993). Hauser (1988) describes Quality Functional Deployment (QFD) as a '*conceptual map that provides the means for interfunctional planning and communications*'. QFD provides a means of recording marketing's customer requirements, and their associated trade off's and importance. QFD forms a series of descriptions which act as communication tools between each of the functional stages of a product's development. For example, QFD has been used as a tool for communication between design and marketing, and design and production. Within electronic engineering the application of many of these techniques has proven difficult. For example the relationship between form and function in electronics (see Culverhouse 1995 a), makes the use of QFD difficult. Although these techniques can be valuable, their benefits are not additive (Cantamessa, 1997). What is required is a means of understanding the current situation of a project and the appropriate technique to apply at that particular point.

Another obstacle to an integrated view of design has been a lack of accepted standards which has impeded data flow between tools within the design process and throughout product development. Support is being evolved by the ISO through the "STandard for the Exchange of Product model data" (STEP). STEP aims to support the description of the information required to define, manufacture and maintain a product. It is intended to provide a method of evolving a specification which will provide a single definition which may be shared across domains and applications. The core of the standard now exists, and is developing to include model mapping, process mapping, and object oriented methods (Kahn, 1995 & MacRandal 1995). This standard could provide the underlying mechanism which supports a more integrated and flexible design process.

Workflow management systems (WMS) evolved primarily from early office automation and document management systems. Their primary role being the tracking and control of the passage of information from function to function within a process. WMS may therefore be considered a process-centric approach for modelling, executing and monitoring information flows in a process, as opposed to the data-centric approach of more traditional database applications (Kamath & Ramamritham, 1996). Currently implemented WMS lack the ability to track data dependencies between different workflows; fail to control concurrent access to objects managed by non-transactional activities; do not support cooperative activities and have poor recovery support (Alonso, Agrawal, El Abbadi, Kamath, Günthör, & Mohan 1996, and Georgakopoulos, Hornick, & Sheth 1995). Despite these deficiencies WMS promises obvious benefits to any system which seeks to support the control of information flows and work is being undertaken to address these problems. For example, Medina-Mora, Winograd, Flores, and Flores (1992) are developing a design method for supporting the reorganisation of work, commonly described as Business Process Re-engineering (BPR), through workflow management. Their rationale is that whenever technology is introduced the work process is effectively reorganised, this concurs with Sommerville and Rodden (1996). Consequently, Medina-Mora et al aim to carry out BPR whilst introducing a workflow approach. This approaches appears to be a reasonable providing your are able to capture the necessary process model(s) adequately, something which is considerably more straightforward in the more linear and controlled environment of an administrative office than a design team.

Given the current level of understanding of the design process, coupled with the deficiencies described above, engineering design would not be amenable to a rigid

WMS model. However as WMS and STEP develop further and our understanding of the needs of this environment improve (for example Cockburn & Jones, 1993), WMS may provide a useful vehicle for improving the control of information flows between information clients.

2.3 The design environment : a melting pot

This section discusses elements of the design environment and approaches to their support from a management perspective. Hosking and Morley (1991) argue that management adopt strategies which optimise social and technical systems to obtain an optimal fit and healthy overall system. Hales (1993) and Cantamessa (1997) argue that design management involves integrating or synthesising the diverse social and technical factors which comprise the design environment. Broadly, support has taken either a social or technical perspective, not the synthesis of both perspectives.

Design, due to the increasing size and complexity of projects, is through necessity becoming a team process. Much of the current research taking a more social perspective of teams has been based upon experimental studies using techniques such as verbal protocol analysis, for example Cross and Cross (1995). The main findings from such studies tends to lead to the development of sets of roles which supports various group interactions (for example Cross & Cross 1995, Hales 1993 & Sonnenwald, 1996). Whilst such work provides good indicators of potential problem elements, they require further analysis in an industrial setting to enable their findings to be utilised in a support development project such as this. More pertinent work however has come from the complementary studies of Bucciarelli (1994) as discussed in chapter 1, and Lloyd and Deasley (1996 & 1997). Both of these studies utilised ethnographic based case studies of the commercial design process in engineering enterprises, and revealed a number of social based issues which need to be considered when attempting to provide a framework to support design management. For example, Lloyd and Deasley(1996 & 1997) discuss the affect of the amount of trust in the originator of a document to the recipient; and that due to the complex social structure of the design environment and the nature of design problems that the design manager is beset by *contingent* problems. Lloyd et al discuss the resolution of some these problems requires the use of contingent roles. As described in chapter 4, these roles need to be context based, and therefore tailored for the enterprise in question. As Hosking and Morley (1991) discuss it often falls to management attempt to fulfil social needs and nurture these necessary roles.

As Pallot (1996) discusses research into design team formulation has often been discussed within the concurrent engineering paradigm (CE). As discussed above in section 2.1, CE aims to shorten the time-to-market of a product by replacing the classical sequential process of design with simultaneous design. The most widely adopted approach is the creation of specialised teams (Pallot, 1996, and Race & Powell 1994). The teams typically comprise designers from various domains and personnel from other related functional areas for example marketing, manufacturing, etc. The intention is that organisational functional barriers are removed, and that early identification of problems can be made and resolved. O'Grady and Young (1991), conclude that difficulties in effective management of the design team are holding back CE. As discussed in section 2.1, without an adequate model of the team process of design, management of the process is impeded. Furthermore, as Race and Powell (1994) discuss, the application of multidisciplinary teams is not suitable to all projects. For example, in a *repeat* design project where little or no innovation is involved. What is required is a mechanism for knowing when to use approaches such as multidisciplinary teams.

Hosking and Morley (1991) describe teamwork to be the consideration of the collective performance of people who come together to work on projects as members of a team. Their assertion is that team building through 'role development', as mentioned above, is only a thread of this model; and that the essence of managing this situation is to organise the collective process to produce high quality products with minimum process loss. To achieve this, according to Hosking and Morley, requires the activity of design to be '*legible, coherent and open ended*'. They define these terms to mean that the activity's elements are easy to understand, the elements are integrated and work together to give a coherent picture, and that the activity is responsive to change, respectively. This description of the requirements of design, again necessitates the need for a dynamic framework for representing the situation of the design project and guiding decisions.

Hosking and Morley (1991) and Pugh (1996) discuss the information processing of a team to move between two states, namely vigilant and non-vigilant. Characteristics of a vigilant state being the serious consideration of more than one course of action and being sensitive to new information even if it is unpalatable. In contrast a non-vigilant state is characterised by satisificing and limited evaluation of any consequences. As Hosking and Morley discuss under certain conditions, for example when decisions need to be made quickly, can be reversed, and are of limited consequence, the speed of non-vigilant processing can be an asset. However according to Hosking and Morley, non-vigilant processing can be inappropriately applied due to aspects such as personal bias and social processes. They define three such instances of this occurring. Firstly, a strongly cohesive group[2] can evolve such that the group reacts in concert to issues and can "*engage collectively in defensive forms of information processing which mean they are no longer capable of confronting difficulties head on, in an active, open minded way*". Secondly when there are structural faults, that is the way in which the environment of design is configured, for example having an inappropriate team structure. Thirdly, when the decision makers are in "*provocative situational contexts*". Hosking and Morley place the responsibility for structuring the design process, to encourage more or less vigilance as required by the task, upon design management. Clearly, the management of such an environment requires the ability to determine the current project situation as a whole, in conjunction with the social skills of the manager.

Software for supporting group work, commonly referred to as groupware, is increasingly being used within companies. In an Institute of Management survey (IOM, 1996) 45% of UK companies reported using groupware. Much of the recent research on supporting group design has been conducted within the developing and diverse field of CSCW. Olson, Card, Landauer, Olson, Malone and Leggett (1993)

[2] Hosking et al (1991) describe group cohesiveness as the force attracting members, and causing them to remain in, a group.

describe Computer Supported Co-operative Work (CSCW) as focusing upon "... *group work that potentially can be supported by some kind of technology, be it that for communication among group members or support of the conduct of the work itself*". As McCarthy (1994) argues there are a great diversity of definitions and approaches to CSCW, some of which are disjunctive. Within the area of design research, CSCW has generally focused upon either facilitating communication media for multi-site collaborative work (see Jenkins 1994, Newlands 1994, Clarke 1994), or supporting communication within teams which comprise specialists from different domains, for example Architect and Engineer (see Bridges 1994; Favela, Imai & Connor 1994; and Stacey, Sharp, Petre, Rzevski & Buckland 1996). Whilst Edmonds, Candy, Jones and Soufi (1994) suggest a multi-agent support system to support collaborative design, and promote a shared understanding of information amongst a team. The development of these approaches has generally been technology led. Grudin's (1989) work on the problems of scaling up single user to group based applications, indicates that typically workloads are merely shifted because systems developments are too strongly management led. Schmidt and Bannon (1992), demonstrate the need to acknowledge and support what they define as 'articulation work'. That is, compromises that are vital to getting the job done in the event of unanticipated contingencies. This requires a better understanding of the socio-technical environment in which the 'job' is done. Olson et al (1993), considers CSCW to be "*building systems and analysing them to inform theories*". They argue that without theories and models of the nature of group work and communication, and expansion of existing HCI theories to incorporate group issues, CSCW can not progress further. Such work has commenced (for example Cross and Cross 1995), but this technology has been focused at automatic team coordination whereas team management needs support in applying management skills to coordinating teams.

A key area of management activity is the estimate of resource requirements versus the risk of failure. Whilst, within engineering design, most risk assessment techniques tend to be qualitative rather than quantitative (for example see Hales 1993), assessing risk can provide two advantages to supporting design. Firstly, they can guide decision making in the planning stages of a project and during its development. This is particularly important in the earlier stages of design, where conceptual design solutions need to be assessed. However at this stage the elements of the design are unclear and changeable, making risk assessment difficult. To alleviate this situation a number of 'function' based assessment techniques have been developed which aim to provide estimates at an early stage in the development of a project. For example, Function point analysis (Symons, 1988) and Function-costing (French and Widden, 1993) have been successfully applied to software engineering and mechatronics projects respectively. However, their application to electronics is more difficult. French and Widden (1993) state that this is due to *'the difficulties of specifying electronic functions, the great variability of costs, and above all the high level of aggregation costs'*. Secondly, they can provide 'boundaries' for a project. By applying a metric the boundaries of a design classification can be monitored allowing for example, the control of innovation in a project and reassessment if a design has to be reclassified (Culverhouse, 1994). Risk management has been identified as an important issue for management of design projects and will be discussed in more detail in chapter 4. The control of risk and resources requires access to current information regarding many aspects of a project which at present are either not captured or are not sufficiently accessible. As this work will discuss later these attributes are typically interrelated, and support is needed when managing the complex networks of interdependencies that can occur.

Within software engineering to address the capture and accessibility of project information Integrated Process Support Environments (IPSE) have been developed. IPSE typically aim to provide an environment which supports integrated tools, access to information and mechanisms for communication. The common features of an IPSE (for example Logicore Software Engineering Environment), are a database management system, information sharing, data for tool integration, methodology enforcement, and document standardisation and control. Within electronic engineering, software tool suites (for example Cadence) attempt to supply a similar environment, although their aim is to support the activity of design rather than its management. However, as their component point tools improve, users tend to switch to the most advanced design tool suite and thus tend to lose access to previous project data as there is at present no accepted standard for data exchange or storage. Work is being conducted to address this issues. Platt (1994), applies the IPSE concept to the senior management level of civil engineering. Duck, Hall, Pickering and Riley (1994), have developed a dynamic, integrated project management and quality assurance Decision Support System (DSS) for the construction industry, which is independent of its data. Moore (1994), presents a DSS comprising a flexible suite of systems to support the conceptual design of bridges. These works primarily focus on information availability. From the studies discussed later it is shown that design management also require mechanisms which can monitor the interrelationships of attributes and guidance upon situational changes.

This section has described how design management have to attempt to synthesise the social and technical aspects of the design environment to achieve results. The social aspects of the environment can necessitate the need for particular roles in certain situations. The difficult lies in design managers being able to synthesise the various aspects of the environment to perceive an accurate picture of the current project situation. The technical issues within this equation are often grounded in the actual design problem discussed in the following section.

2.4 The design problem : tools for design activity

Whilst our focus is the management of design teams, this necessitates the appreciation of the cognitive activities of design. The work described in this thesis did not directly focus upon the activity of design itself, rather it has drawn from other design research. This section outlines pertinent approaches of developing support for the activity of designing, what Cross (1992) describes as the oscillation between the problem and the solution, until a requirement match is made with an acceptable level of misfit. The approaches have mainly been focused upon the support of creativity, reuse of previous designs and designer's information requirements.

Studies of the conceptual stage of engineering design have been conducted which have concentrated upon supporting creativity in design (Candy & Edmonds 1994, Spence 1994). Candy and Edmonds (1994), have identified some of the needs of an innovative designer from empirical studies of the design of the Olympic LotusSport Pursuit bicycle. Spence (1994), reports the perceived needs for engineering design and for supporting creative design. Although our work is not focusing directly upon the issue of creativity, these studies have indicated that any proposed system must reflect the needs of creativity by allowing the designer freedom to generate new ideas (for example through sketching) issues which are now being addressed in technologies such as CAD (see van Dijk 1995). More pertinent work has been carried out by McNeill and Edmonds (1994), and Harris, McNeill, and Sydenham(1991). Harris et al have developed a pre-schematic electronic circuit design system which, based upon artificial intelligence techniques, supports the designer in moving from a product concept to the schematic stage. Whilst this system has shown success in its intentions, this system relies upon the accuracy and completeness of the requirements specification which as we shall discuss is often inadequate for this purpose. McNeill and Edmonds (1994) report findings from empirical studies of the cognitive aspects of conceptual electronic design. Their intention was to establish areas in which support could be given by a computer based assistant. One of their key findings being that designers need support in the provision of design strategies, especially if tackling a new concept. As we shall discuss this type of metaknowledge is also conditional upon other situational factors, such as the business aims of the project. Whilst the increasing sophistication of design tools such as CAD are important for the activity of design, our focus has been the support of the design team's needs. This focus is being addressed, for example Sharpe (1995) is developing tools to design support multidisciplinary conceptual design, primarily focusing upon the support of creativity and innovation. However, this work does not support the management of the design project.

Another impact of technology has been that developments in computer based information systems which have led to the increase in the accessibility of information. In engineering this has applied to both internal information (for example previous designs, Email), and external information (for example, markets, parts catalogues, methods) . Recent research in this area has concentrated upon information sharing;

enabling reuse of known information (that is, to reduce risk, improve time-to-market etc.); and improving access to new information.

Court, Culley and McMahon's (1993), survey of over 200 engineering designers in the UK, has provided details on information supply and usage in terms of availability, accessibility, applicability, authenticity, and amount. Court et al (1994), suggest that without improvements in filtering, accessing and interfacing techniques, that hard copies and verbal formats will still be preferred and used by design engineers. Research into the structure and requirements of documentation (see Culley, Court & McMahon 1992; Cartnell 1992; and Culverhouse 1994), all make useful contributions that aim to encourage reuse, and improve accessibility to design information. This is achieved through identifying essential information requirements, suggesting standard data storage formats, and utilising techniques such as object orientated databases.

The field of Software Engineering has developed approaches such as object oriented (O.O.) techniques and code libraries to improve reusability and access to information. Cognitive psychology views of reuse in engineering (for example Fischer 1987 & Visser 1992), have suggested that appropriate mechanisms are needed to support reuse. For example, a systems interface requirements for an expert differ significantly from those required by a novice. If this is not reflected in the interface it is likely to discourage reuse. A number of developments have applied O.O. to addressing these issues (for example Culverhouse 1994, Wallace 1995, Donaldson & MacCallum 1995). These studies offer complementary models of information storage to encourage design reuse. The possibility of reusing previous designs has also encouraged developments in the 'case based reasoning' (CBR) paradigm. CBR solves new problems through retrieving and adapting previous solutions to similar problems. Computer based support for CBR has been successful in prototyping (for example Price & Pegler 1994, Wang & Howard 1994), and in industrial applications by Lockheed and General Dynamics (Watson 1994). Whilst these applications demonstrate the possibilities of applying the CBR paradigm, they essentially optimise design parameters in the later stages of the design process (Donaldson & MacCallum 1995), a phase which as we have discussed is better understood. The use of CBR in supporting the management of team design may be more useful with regard to project information (for example previous plans).

The research outlined in this section has indicated that design at times requires flexibility to allow creativity, that access to information must be balanced against information overload and that design reuse mechanisms are likely to vary at each stage of the design. These issues have guided the development of the support that is discussed in the following chapters.

2.5 Conclusions

This synopsis has outlined the emergence of a wide range of highly significant insights into many aspects of engineering design. However much of the work has concentrated on distinct and often separate concerns. There has been a tendency towards reductionism in order to understand better the component issues and activities of design, and no doubt this approach will continue to yield valuable insights.

Relatively few authors have attempted to synthesise the component issues and activities of design into a holistic view which recognises the dynamic interactions between all or even many of the separate components, and the need for these to be reconciled and managed although some (for example Frankenberger & Pabke-Schaub 1997, Minneman and Harrison 1997, and Cantamessa, 1997) recognise the problem.

The focus of the present work takes a holistic view in order to enable better management of design team projects. Supporting engineering design has drawn from many disciplines in the search for solutions. Dym (1994) attempts to synthesise the various representation of design artefact, to illustrate the applicability of certain approaches to certain design situations. From a management perspective the research discussed in this chapter requires a similar synthesis at the design project level. That is, an attempt to provide a unified representation of the current design situation for a project. Different approaches and methods will be required at different times, the difficulty lies in determining which are applicable in a given situation. Cross (1994) describes this need as "*What is needed is a more flexible, strategic approach to* *designing, which identifies and fosters the right kind of thinking at the right time, and within the context of a particular design*". Available models do not support both the flexibility needed by design and the mechanisms needed to manage and control team work, in practice these two issues often conflict. Current understanding of the requirements for support in this context are limited as developing such models requires an understanding of the information needs of design management in the real world, team environment, of social interaction and debate. Thus the aim of this work was to develop models, based upon ethnographic study of the design environment, which integrated social and technical aspects of the situation of design to provide support for its management.

"The greatest invention of the 19th century
was the invention of the method of invention"

(A. Whitehead, Science & the Modern World, 1925)

3. Research method

3.1 Introduction : an integration of perspectives

As discussed in chapter 1 this work has taken a Human Factors perspective with the aim of theory building. This chapter discusses a research model which synthesises a variety of information sources in a multidisciplinary project. As discussed in Parsons Jagodzinski, Reid, Burningham, Culverhouse, and Evans (1997a), due to the innovative nature of this approach, this model evolved through the course of the work.

An innovative approach was adopted in response to three main criticisms of traditional systems analysis approaches, particularly when considering social interactions. Firstly that traditional systems analysis approaches are based upon the underlying paradigm of goal seeking, optimisation, and predict and control, where human factors are treated in a deterministic or mechanical way (Ho & Sculli, 1994). Secondly, for being technology led (Stowell & West 1994; Clegg, Waterson, & Carey 1994; and King & Majchraz, 1996) where traditional computer systems analysis is typically concerned with identifying data processing activities within an organisational setting, and their subsequent enhancement through the application of technology. Thirdly, that traditional systems analysis focuses on the characteristics and structure of the solution rather than the problem (Siddiqi & Chandra Shekaren 1996; Jirotka, Gilbert & Luff 1992; and Bansler & Bodker 1993). This situation can occur because the context of the information may be ignored and as information is situated it is the context that will determine its meaning (Goguen, 1996).

A potential means of alleviating some of these issues has been the utilisation of ethnographic techniques, which attempt to reveal the context of information (Goguen, 1996) and identify issues which are important in that environment (Clancey, 1993). Whilst ethnography has been employed within a variety of systems analysis projects (for example Hughes 1995), there has been no recognised method for integrating the diverse information generated from these dissimilar methods. A problem which arises from a multidisciplinary approach is one which Sonnenwald (1996) describes as *contested collaboration.* In this situation the various participants have pre-existing models of work activities, specialised languages, and differing, sometimes conflicting expectations for assessing the quality and success of the work. To allow support to be developed under these conditions the participants need to integrate the differing approaches and ensure that their contributions do not have a negative impact upon the artefact as a whole. The integration of this type of data and the incorporation of the many perspectives of the situation into a model for support is difficult (Sommerville, Rodden, Sawyer & Bentley, 1993). It requires a method which is capable of being flexible and eclectic to accommodate different perspectives and generate a commonly understood representation to reconcile and integrate the different categories of evidence derived from the ethnographic and systems analytic studies. The Soft Systems Method (Checkland, 1981) offered such an approach as it utilises debate and negotiation to reach consensus and accommodate a number of views of the current situation of interest. Consequently this work has been based upon a Soft Systems approach drawing heavily upon an ethnographic study which was conducted by a fellow researcher.

The development of a fully functional system was beyond the scope of this present work, rather the research focused upon evolving requirements. The project was a bottom-up investigation, with no preconceived solution type to be applied. The task was to identify issues which detract from the management of the design process. The present work can be seen to comprise three classical stages : problem definition; the development of an hypothesis which postulated an approach for addressing the problem; and evaluation of the hypothesis. These phases were not linear and all entailed cycles of elicitation, expression and evaluation for each phase with company A.

3.2 Requirements engineering : identifying and evolving stakeholder's needs

Many models of the process of systems development exist which describe to varying degrees the development of various types of systems, from simple databases to expert systems. However, Morris et al (1996) argue that whatever the application type the process may be regarded as comprising three essential stages, these being :

- Capture and approval of a satisfactory set of systems requirements.
- Generation of a design that satisfies these requirements.
- Realisation of an implementation that conforms to this design.

(after Morris et al 1996)

The focus of this research has been the development of requirements, that is meeting the first stage in the above sequence, which may be termed requirements engineering. Recent trends in systems development have acknowledged a number key issues which support the approach that was adopted by this work; Siddiqi and Chandra Shekaren (1996) discuss three of these issues :

- Firstly, requirements engineering may be regarded as a project in itself with its own life cycle. For example, Jarke and Pohl (1994) propose that the requirements engineering life cycle comprises phases of elicitation, expression and validation. Potts, Takahashi, and Anton (1994), suggest a similar sequence but add that the evolution of the requirements should be accomplished through stakeholders using scenarios to challenge proposed requirements.

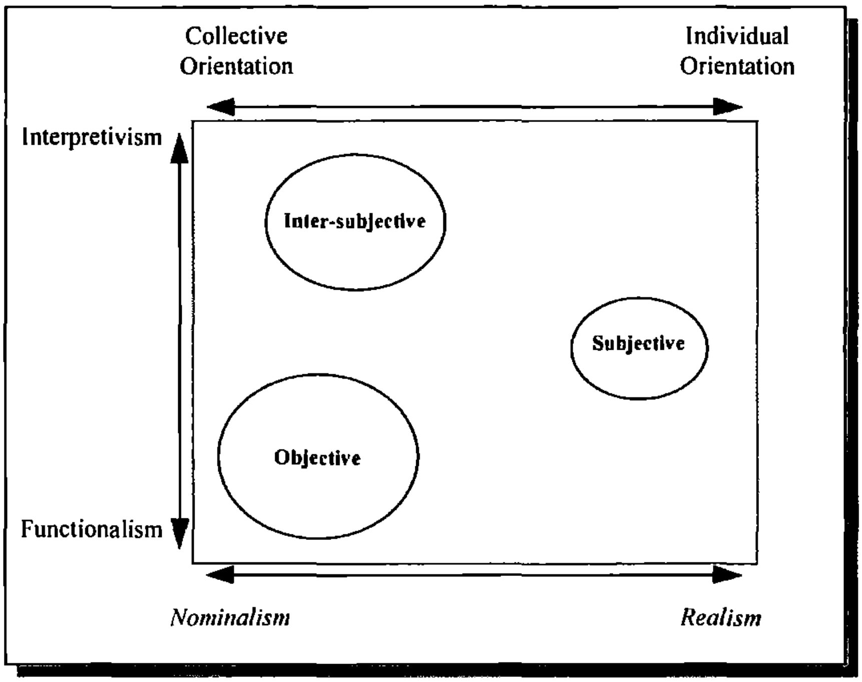
- Secondly, Jackson (1995) and Siddiqi and Chandra Shekaren (1996) criticise current software developments for focusing on the characteristics and structure of the solution rather than the problem. This situation occurs according to Goguen (1996), because the situation of the requirements are ignored. Goguen states that '*requirements are information, and all information is situated*', consequently it is the situation that will determine the meaning of the requirements. He proposes that both social and technical factors must be considered, and that this could be accomplished via ethnographic techniques.

- Thirdly, Siddiqi and Chandra Shekaren (1996) state that '*The oldest and perhaps most widely shared piece of conventional wisdom is that requirements constitute a complete statement of what the system will do without referring to how to do it*'. Siddiqi and Chandra Shekaren (1996) and Goguen (1996) argue that it is impossible to obtain complete requirements in many situations due to the inevitable issues of change and flexibility. Consequently, there must be context to the requirements and change must be accepted and managed.

Identifying the concern of this work as the development of requirements necessitates the definition of what exactly we mean by requirements. Iivari and Hirshheim (1996) distinguish three views of users requirements: objective, subject, intersubjective. The objective view concerns the impersonal features of an organisation. The subjective stresses and reflects the personal characteristics of the user. The intersubjective lies between these others perspectives and concentrates upon establishing a consensus between the stakeholders. As Iivari and Hirshheim (1996) and Goguen (1996) discuss, typically when determining requirements for say a group-based system such as, this most requirements will begin as subjective, and it is the analysts' task[3] to develop subjective requirements into intersubjective requirements. These three views of requirements are compared below in Figure 3.1.

[3] Alternatively, this task may become a shared task utilising the stakeholders if using a SSM approach as discussed in section 3.4.2.

Figure 3.1, A comparison of three views of information requirements (after Iivari and Hirshheim, 1996).



Iivari and Hirshheim state that the inter-subjective view has a nominalist ontology which relies upon voluntarism and emergence of requirements to a large extent. They argue that establishing requirements is essentially a matter of social agreement, as at present the main strategy for eliciting requirements relies upon "*asking*", that is, interviewing. They view information systems as increasing becoming organisational communication systems, which therefore rely upon intersubjective needs. Accepting this view that intersubjective requirements rely largely upon emergence and social agreement, concurs with the third point discussed above, that attempting to deliver *complete* requirements is futile. Adopting this viewpoint, an analysis method was required which embraced these ideas of social agreement and emergence. Iivari and Hirshheim discuss the suitability of a variety of systems analysis approaches which could be used to achieve this, one of which is the Soft Systems Method (Checkland, 1981), which is discussed later in this chapter. To supplement systems analysis Iivari and Hirshheim, and Goguen (1996), propose the use of longitudinal ethnographic approaches to try to capture the emergence of the social issues.

3.3 Ethnography : the emergence and discernibility of issues

Two concerns which face any study applying user participative design are adequate user involvement and human biases. Gaining sufficient access to users and their time can prove difficult in high pressured and competitive environments where expertise is in short supply (Turban, 1993), which is true of the electronics' design sector. Perhaps more important, especially in a socio-technical environment, are issues arising from human factors. For example, users' own agendas lend bias to their perceptions and perspectives, coupled with the limitations of human memory, can lead to 'perfected' processes being recalled (Ball 1990 & Davies 1993). Issues such as these can hinder the gathering of accurate information concerning the actual situation and processes of the system under study. Unsupported, it is difficult for an analyst to capture tacit working practices, for example, ignoring day to day articulation work has led to the failure of systems because they lacked tacit understanding (Schmidtt & Bannon, 1992; and Jirotka, Gilbert, & Luff 1992). Sommerville, Rodden, Sawyer, and Bentley (1992) illustrate the implications of this concept well by pointing out that during industrial action workers will 'work to rule'. That is, that they will only perform tasks as described and directed by their official rules of work. To alleviate these issues the analysis was enhanced through access to a longitudinal ethnographic study. The study, which commenced approximately 12 months prior to the present work, aimed to expand the current understanding of electronic engineering design as a team process. The longitudinal study forms part of a separate social psychology PhD project, but it provided a valuable information source for this work.

The longitudinal study employed ethnographic techniques which aim to provide a better understanding of the nature of work as it is actually carried out. Hughes, King, Rodden, and Anderson (1994) describe the aim of ethnography as "*..to see activities as social actions embedded within a socially organised domain and accomplished in and through the day-to-day activities of participants... ethnography (is able) to describe a social setting as it is perceived by those involved in that setting*". In their purest form ethnographic techniques are typically non-intrusive, naturalistic and long term. They attempt to reveal tacit knowledge and implicit practices which are a natural part of the social system which enable people to work. An observer records not just the details of the formal transactions of work, but also the social devices which enable them to take place, and the significance of such devices (Jagodzinski, Parsons, Burningham, Evans, Reid, & Culverhouse, 1996b).

Reid, Burningham, Jagodzinski, Parsons, Culverhouse, and Evans (1997b) describe how, within the UoP project, the longitudinal study was conducted as follows. The longitudinal study took a multimethod qualitative approach by combining the following three qualitative data gathering techniques; as is evident this process was one of identifying and refining the focus of the study. Firstly, *direct observation and shadowing* resulting in a narrative record of observations on normal working activities of target personnel in selected domains of the company.

Secondly, *depth interviews* which were semi-structured depth interviews were carried out with nineteen preselected personnel, lasting for approximately one and a half hours. These exercises were carried out at the start of the study to identify common themes and issues at that level of management within the company to provide a context for the probe interviews, outlined next. The interviews attempted to identify goals, working practices, interpretative schemes, judgmental and attitudinal responses, etc. This initial work revealed that company A's senior managers did not have a high level of interaction with product development groups, as the project leaders (PL's) fulfilled the main operational design management functions. Examples of such functions being : technical leadership and decision making, group integration and motivation, staff development and appraisal functions, interfacing with senior managers and other departments, customer interaction and product specification. Thus one focus of the studies became the design and management activities of project leaders (PL's).

Thirdly, weekly *retrospective probe interviews* gathered longitudinal data from selected personnel in the selected product teams. These interviews followed a fixed protocol, and gathered attitudinal and judgmental data. The interviews probed for personnel's work role, what it encompassed, and with whom they interacted; work style; communications; project control; design knowledge; the design process and relationships at work. The PLs' occupational background and experience were also discussed and any other area the subject wished to cover. This stage involved the study of two design teams for a period of 40 weeks from the early stages of the design process to completion of the detailed design, as defined in chapter 1. One team was designing a new RISC processor, considered to be an innovative project with high levels of uncertainty both in the level of design knowledge required and software tools used in the design process. The second team was producing a variation of an existing chip to enable consumer product manufacturing companies to customise the chips for their own requirements. The research was therefore able to compare and contrast practices and problems at opposite ends of the continuum of new knowledge versus existing knowledge.

As discussed in Jagodzinski, Parsons, Burningham, Evans, Reid, and Culverhouse (1997), the justification for the use of structured interviews was the intrusiveness of conventional diary keeping methods and the criterion of issue salience. This criterion of issue salience is based on cognitive science theory, and assumes that respondents sample their memories for instances of occurrences triggered by probe questions, and retrieve vivid, recent, personally significant, or otherwise more memorable, instances of these occurrences. In other words, respondents are assumed to produce reports on the most salient occurrences, rather than an exhaustive and unbiased recall of events. As such the study was "*guided by respondents' intuitive judgements of what was relevant and significant, rather than the investigators own presuppositions*". A triangulation reliability check on the identification, interpretation and characterisation of critical occurrences in the design process, was achieved by including another design team member in the data sampling.

As Murray (1993) discusses ethnography has to be bounded; it is impossible to 'view' everything that occurs in the situation of study; and obviously any perspective taken will influence results. As can be seen from the above description, the ethnographic study was progressively focused on key areas within the environment, and conducted in a sequential manner which enabled a time-series analysis to be carried out on the data. To ease the negative affects of focusing the study, the evolution of the system involved input from any stakeholders in the system rather than just the potential users, as discussed in sections 3.4.2 and 3.5.

A key benefit of a longitudinal study is that the ethnographic data can be examined for a large time frame. As Murray (1993) and Sommerville (1992) discuss this can have three implications. Firstly, proper consideration can be given to complete work cycles. For example, the effect of small problems which occur repeatedly can be properly assessed. Secondly, issues tend not to present themselves immediately, but will become evident over the course of a project, that is they are emergent. Thirdly, rare but significant events can occur which may be missed in shorter periods of study.

The collaboration of software engineers and social scientists has been used with some success in projects at Lancaster's CSCW research centre (Hughes 1995). Sommerville et al (1992) describe the benefits of utilising ethnography in a study of requirements for supporting air traffic controllers. Standard systems analysis techniques would not have captured the social interactions on which the current system relies. A current problem with utilising this information is that the outputs from ethnography are typically extremely rich reports which are not amenable to traditional systems analysis, where the context and articulation work discussed above is all too readily lost (Sommerville, 1992 & Murray, 1993). In Sommerville et al's multidisciplinary project team, sociologists became the system analysts and the systems requirements evolved from the ethnographic data that they collected. The software system was developed in parallel with the ethnographic study. The team communicated via monthly meetings between the software engineers and the sociologists. Sommerville et al report that although this approach proved successful, they still found difficulty in extracting the systems requirements from the ethnographic data. Hughes et al (1994), and Bansler and Bodker (1993), argue that the main cause for this problem is that traditional structured analysis and development methods ignore the fact that the system functions within an environment.

The research method adopted for this work has taken a slightly different approach to the use of ethnography from the work at Lancaster. Due to the quantity and richness of the ethnographic data, which is difficult to codify, its integration has relied heavily upon social mechanisms such as negotiation and consensus. The ethnographic data was examined from both an engineering and a psychological perspective. The inclusion of a domain expert, that is, an expert in electronic engineering provided a more objective resource with more time than the expert user's and less task bias. A detailed analysis of the data (see Reid 1997a and Culverhouse 1996b), has produced model(s) of the behaviour of teams in the early stages of design. The social science experts, as well as providing vital input regarding social issues, achieve what Clancey (1993) describes as "*social scientists in effect help to keep the project honest*". These perspectives and the process of consensus were harnessed through the use of a soft systems analysis approach, as described in the following section.

3.4 Systems analysis method

This section discusses the philosophies underlying the system analysis, and approaches which were employed during the course of this work, these include socio-technical, soft systems, and object orientation.

3.4.1 The Socio-Technical paradigm : *the arena*

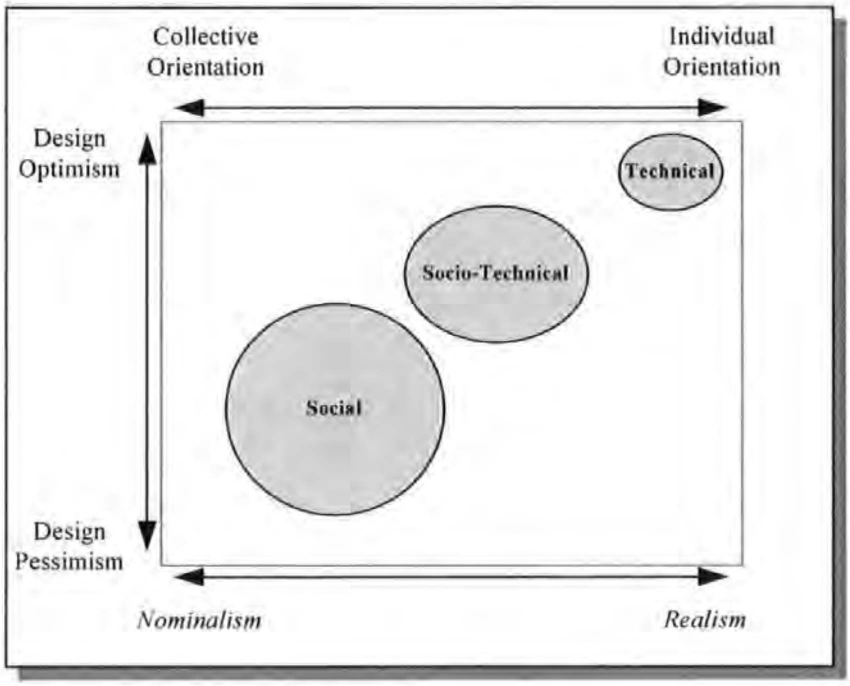
Since the emergence of the socio-technical paradigm in the 1950's, authors have been proposing that systems analysis methods should focus upon supporting 'workers' through technology (Trist, 1981). Previous paradigms attempted to design and impose systems which appeared to utilise technology and people in the most efficient manner. They would generally view human needs and motives as irrelevant to the efficient operation of the system, for example Scientific Management (Taylor, 1947). The socio-technical paradigm was essentially a shift of focus towards finding a goodness of fit between supporting the workers needs and the perceived economic benefits of technology. As such it can be considered more of a philosophical approach than a technical system development method. Its principles include :

- Treating individuals as complementary to technology rather than an extension of it;
- Valuing the discretionary rather than the prescribed part of work roles;
- The work system, which comprised a set of activities that made up a functioning whole, now became the basic unit rather than the single jobs into which it decomposed;
- Consequently, the work group rather than the individual became central.

(*after Trist 1981*)

Trist (1981) describes the socio-technical paradigm as concentrating upon supporting the worker through technology, in a system which acknowledges the social and physical aspects of the work situation. It recognised the need to consider the complexity of the social environment and its human factors during systems analysis. Iivari and Hirshheim (1996) describe the socio-technical paradigm as lying between the social and technical view of the role of an information system within an organisation. A technical perspective paradigm assumes that connections between the system and environment can be reduced to well defined inputs, outputs and ergonomic factors. In contrast the social perspective is that the system is an integral and constitutive part of organisational communications, control, coordination, cooperation and work arrangements. Hence, they define the socio-technical as viewing an organisation as composed of interdependent technical and social subsystems which are treated as equal partners. Figure 3.2 below illustrates where these paradigms lie in terms of the Organisational role of a system.

Figure 3.2, The theoretical underpinnings of the Organisational role of an information system (after Iivari and Hirshheim, 1996).



The perspective of this project lies within the socio-technical paradigm as defined above by Iivari and Hirshheim, although this work would be considered to more heavily weighted towards the social considerations using their definitions. Generally system's development methods which aim to consider socio-technical issues, do so by increasing user participation in the system's development, in a structured manner. For example ETHICS (Mumford, 1986) and Human Factors Guidelines (HUSAT, 1988), which attempt to ensure that the resultant model of the systems analysis reflects the users' understanding, and that the users' understand the model. However as Stowell and West (1994) argue these methods primarily exist to fulfil a technical outcome. They state that if, as in this work, your concern is an information system rather than a computer system, that the users must lead the requirements not just contribute information at an early stage. They argue that an information system within an organisation often involves the product of social interaction, and those best placed to identify requirements and their implications are those involved in this interaction. They label this concept as client led design which they describe as being founded upon "*the notions of hermeneutics and phenomenology*". This idea of being client led concurs with the approach adopted for the longitudinal study discussed above, where to an extent, the interviewees can lead the issues considered through recalling their most salient occurrences.

Whilst this idea of client led design may be valid to an extent, it may also be argued that those within the system may also be too close to the problem to identify some of the issues (Ho & Sculli, 1994). This situation may be resolved through a compromise of developing both a user led and learning environment. This calls for the analyst to become a facilitator, as argued by Iivari and Hirshheim (1996), and Checkland and Scholes (1991), and the need for a more objective information source (for example, via ethnographic techniques).

Thus, the Socio-Technical paradigm has described our arena, and the ideas discussed in this section provide a philosophy for systems analysis. However there is a lack of established methods for analysing work and conceptualising requirements when adopting a socio-technical perspective (Carstensen & Schmidt, 1993). What was required was a method which enabled the consideration and capture of various perspectives, information sources, and established intersubjective socio-technical requirements. As the following section discusses, the soft system approach (Checkland & Scholes 1991) offered the potential to meet these needs.

3.4.2 Soft systems method : a framework

Within software engineering two main approaches to systems analysis currently exist. These are commonly referred to as '*hard*' (for example SSADM, Downs et al 1992) or '*soft*' (for example SSM, Checkland & Scholes 1991) methods. The key difference between these approaches is the intent of the analyst, and the current understanding of the problem situation that exists. Generally the more reductionist hard methods are thought to be best suited to producing a solution for a well defined or understood problem. Conversely more enriching soft methods are thought to be better suited to improving understanding of a problem situation and are targeted at ill defined or poorly understood situations. In other words, soft systems methods can be viewed as an approach for establishing *what needs to be done*, rather than the *how to do it* approach of hard methods (Checkland & Scholes, 1991). In this way Checkland and Scholes argue that SSM is well suited to the creation of information systems, rather than the design of an already understood system. Hence SSM would appear to be well suited to work which aims to theory build.

Soft System Methodology (SSM) was a move away from the 'hard' engineering view of systems, towards a 'human activity system' view. A Human Activity System (HAS) may be considered to be a transformation process, in which humans are actively engaged, where some input is transformed into some output (Wilson, 1984). A HAS comprises a social system and a system of activities. An organisation may be considered to comprise a number of HAS. This concept is illustrated in Figure 3.3 below (after Wilson 1984).

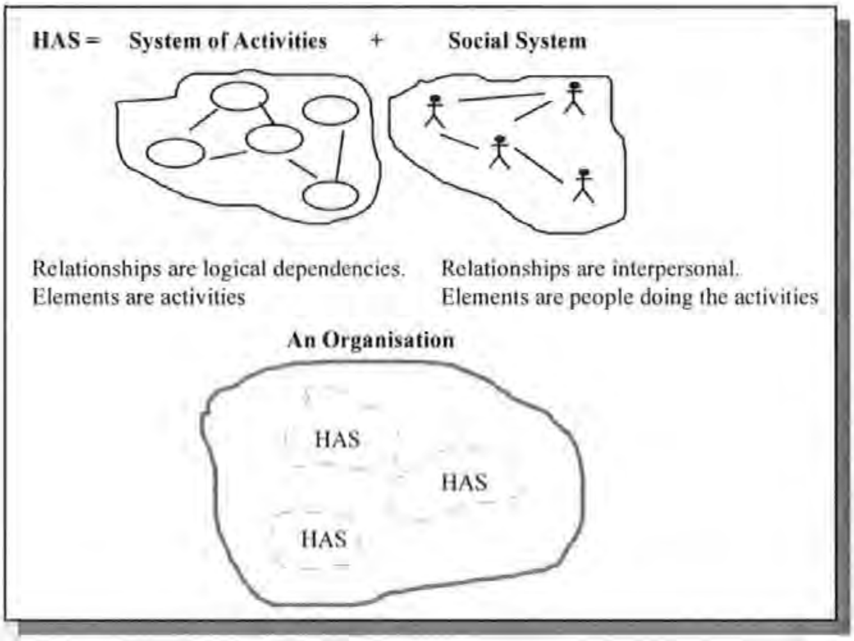


Figure 3.3, the Human Activity System concept (after Wilson, 1984).

This move away from the 'harder' analysis techniques was a response to the problems encountered with structured analysis methods. Namely, that systems failed because these techniques did not address the way in which work was actually carried out. Rather, techniques concentrated on a reductionist view of the environment and its problems to provide a normative solution (Bansler & Bodker, 1993). SSM aims to generate a conceptual model of the system which improves the understanding of the situation under consideration. Ho and Sculli (1994) summaries SSM's theoretical assumptions of the characteristics of managerial problems as :

- There are many equally legitimate perceptions of the reality of the problem;
- Each viewpoint of reality is restrictive or incomplete and can be challenged by alternative viewpoints;
- Debate and discussion among the interested parties will lead to a more comprehensive understanding of the problem situation;
- The discussion and debate will also tend to 'move' the parties towards some agreed feasible solution that should alleviate the problem situation.

(*after Ho & Sculli, 1994*)

Whilst the final point is open to some interpretation, that is whether unfacilitated that debate and discussion will 'move towards an agreed solution', this summary captures the essentials of SSM. The essence of SSM is the idea that there is no one problem to be solved, but that there will be a complex set of influences and issues affecting a problem situation. What is being transformed into what, depends upon the perspective taken of the system. This idea of perspectives of transformation requires the identification of the parties affected, the stakeholders, and then discovering and recognising their interests. For example :

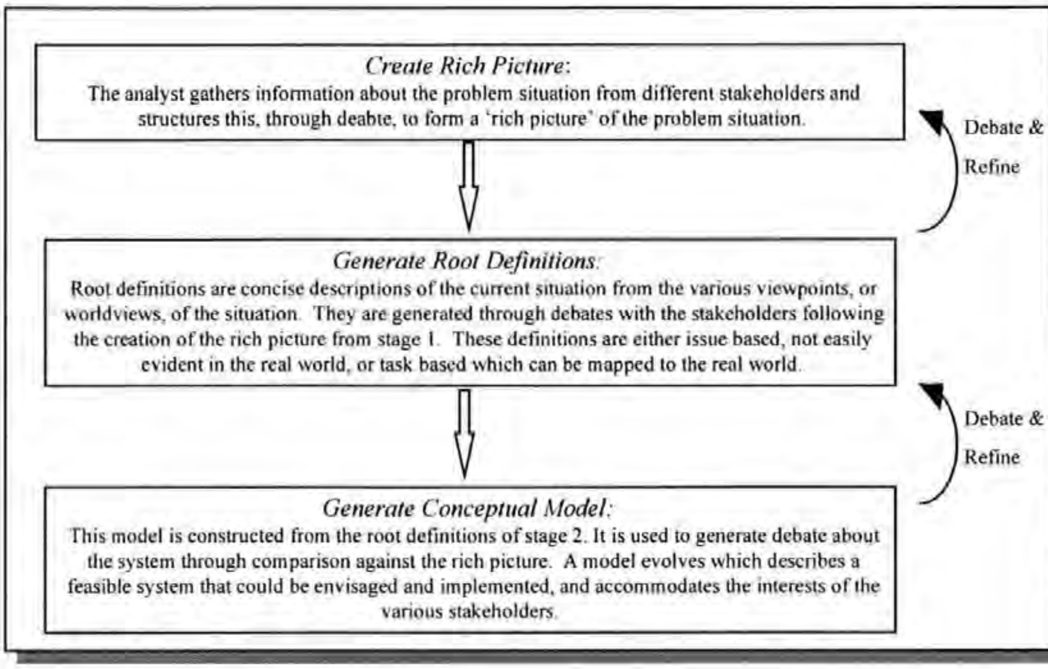
Customer Demand ⟶ Transformation ⟶ Customer demand met through satisfactory products.

or

Business needs ⟶ Transformation ⟶ Business needs met through return on investment.

(after Wilson 1984)

These different perspectives of the system are termed by Checkland and Scholes (1991) as Holons, and any system will typically comprise a number of these holons. Their key application is at the point of developing the various root definitions of the relevant systems as discussed below. SSM's development cycle comprises seven stages, however the following overview of three phases describes its key concepts :



As Stowell and West (1994) discuss SSM is not a discrete series of steps, but an iterative process which may or may not result in a computer based solution. The above cycle concurs with the descriptive model promoted by Bansler and Bodker (1993) to address the deficiencies found in adopting a structured analysis (hard) approach to systems analysis. The deficiencies being, that the organisation is viewed as a machine, and only considered as a series of information flows. One clear benefit from SSM is that generating such a 'rich' representation avoids reductive bias and the separation of the stages de-couples elicitation from implementation, two key issues when working in a domain reliant upon expert knowledge (Wood & Ford, 1993).

The representation of the deliverables from the SSM stages are various. What they share is not a well defined syntax, but an understanding which is shared by the participants in the development process. This soft form of requirements capture is a key tool in SSM application (Lewis, 1992). The foundation to this process is the creation of the rich picture of the current situation. Checkland and Scholes (1991) suggest that this representation should be achieved in a neutral context, without imposing or referring to technological solutions, artificial structures for interpreting the problem etc. The idea being that the rich picture should reflect the stakeholders perception of the reality as it currently stands without polluting this understanding. However, as Ho and Sculli (1994) argue sometimes systems terms can be used beneficially within the rich picture and do not necessarily preclude a technological solution. This work is an example of such a situation where the stakeholders are heavily reliant upon and immersed in an extant socio-technical system. Due to the nature of their expertise they communicate and discuss many aspects of their environment in these terms and thus represented some aspects of the environment thus. As Ho and Sculli (1994) discuss, because SSM can handle the complex and interrelated issues that exist in an organisation, it is better able to cope with a systemic-pluralistic approach to an environment. Consequently, the extant socio-technical system could be accommodated as discussed in chapter 4.

Davies and Saunders (1988) successfully applied SSM in a study of the provision of a company wide project management services team for a medium sized electronics manufacturing company. Their rationale being, as in the present work, that it provided a tool for improving the understanding of a complex and unstructured problem situation. As Checkland and Scholes (1991) argue SSM does not aim to generate a normative solution for an organisation, rather it seeks to generate debate of visions of the environment by the organisation. This is achieved through the social activity of debate, where optimal enhancements to support the environment may be identified and agreed. As such debate may be considered a catalyst for change which can assist the development and implementation of a support system. SSM can be considered to be an interpretative systems methodology which acts as a tool to help participants learn about their situation, and stimulate the identification of methods of improving the current environment (Stowell & West, 1994).

This chapter, up to this point, has led to the following premise for this research. That the socio-technical paradigm was the arena in which the work was to take place, and that SSM offered a framework for a method of analysis which could incorporate emergent issues and a variety of perspectives and data sources. This view was taken to accommodate a poorly understood environment where a normative solution is not thought possible; where the aim to generate intersubjective requirements for improving the current situation.

3.4.3 Object oriented analysis & design

Whilst SSM offered a useful framework, its flexibility and descriptive nature can make it difficult to apply to the design of solutions (Jirotka et al, 1992). Due to the difficulty encountered when discussing an increasingly complex and dynamic conceptual model, a tangible representation of the real world of the electronics design project was required. The object oriented paradigm supports some aspects of such an approach by mapping the real world environment into functional objects. Consequently ideas which could be represented in software were developed using Coad and Yourdon's Object Oriented Analysis (1991). What was not dealt with were the interrelationship between social and technical issues, which we discuss later in the thesis. Thus whilst the aim was not to deliver functional specifications, the prototype designed using this method, help to communicate the understanding of information.

Object Oriented Analysis (Coad & Yourdon, 1991), is a straight forward and widely used object oriented analysis method (OMG 1994). Object Oriented Analysis (OOA) focuses primarily on '*problem space understanding - an understanding of the world and application domain the user lives in*' (Coad & Yourdon, 1991). OOA comprises the following five main steps :

> i) Identify objects. An abstraction of data and exclusive processing of that data, reflecting the capabilities of a system to keep information about or interact with something in the real world;
>
> ii) Identify Structure. Structures represent complexity in a problem space, though two types of structure :-
>
> > a) Classification structure which captures the generic-specialisation's organisation of objects;

b) Assembly structure which captures the whole-part organisation of objects;

iii) Identify Subjects. Subjects provide an overview of the OOA model, and are formulated from the structures created in step ii;

iv) Define Attributes. Attributes are the data elements which describe an instance of an object. The problem space of the system dictates the appropriate attributes for the object;

v) Define Services. A service is the processing performed by an object upon receipt of a relevant message.

Clearly, OOA is technologically oriented and used alone would not be able to comprehend or describe many of the human-centred aspects of a human activity system. Nevertheless, the resultant model of the system provides a resource which is understood by the user because it maps to the mechanistic aspects of their real world environment (in addition object orientation is a technique employed by company A). Software can then be developed directly from this representation, allowing the rapid prototyping of some of the components of the conceptual model.

3.4.4 Evaluation : validation & verification

A crucial element of any project, especially research based, is the way in which the work is validated and verified. Boehm (1981) neatly defines validation as '*are we building the right product* ?', and verification as '*are we building the product right* ?'. Whilst, due to the formative nature of the analysis approach evaluation was continuous throughout the work, more specific evaluation techniques were applied at key stages in the project. In keeping with our research method, the techniques that were employed in the evaluation phases of the system's development were multidisciplinary and user based. The deliverables from each stage of the research were less tangible and richer than those of traditional hard systems analysis, and required appropriate qualitative techniques to evaluate them.

Within software engineering there has been a recent growth of 'Usability Inspection' methods which evaluate systems through the judgement of expert evaluators (Mack & Nielsen, 1994). The term *usability inspection* has been coined to differentiate these methods from the harder code based software engineering inspection methods, for example for debugging software. The intention being that this field represents the combination of human factors experts and software engineers. These methods are pertinent because they allow the early evaluation of system models by small groups of experts[4]. They can be considered as structured thought experiments, which Porter (1988) successfully applied in assessing architectural designs.

Whilst most of the work in the field of usability inspection has focused upon the '*usability*' requirements of an interface, the methods are equally applicable to evaluating functionality requirements and are essentially extensions of those suggested by Checkland and Scholes (1991). Mack and Montaniz (1994) found that combining conventional user testing with usability inspections elicited a higher number of issues for a proposed system design than relying upon one technique, as the benefits of one supplement the weaknesses of another. Our formative evaluations utilised both conventional empirical user testing, and three usability inspection methods.

- The cognitive walkthrough (Polson, Lewis, Rieman, & Wharton, 1992; and Wharton, Rieman, Lewis & Polson, 1994) is the most structured of the three methods applied. The user(s) walk through a sequence of steps to achieve a predetermined goal. The intention being the evaluation of the system's ability to support the user's problem solving process for the given goal.

[4] Nielsen (1993) found that when using Heuristic Evaluations that 3-5 users provided the optimal number of observations.

- In comparison a pluralistic walkthrough (Bias, 1994) is a softer method, where a multidisciplinary group including stakeholders, human factors experts and designers are involved. The method uses debate and discussion amongst the group to evaluate the system, and relies upon "*empathy with the environment*" (Bias, 1994). The discussion is driven through the use of typical scenarios in which the system would be used to reveal problem areas.

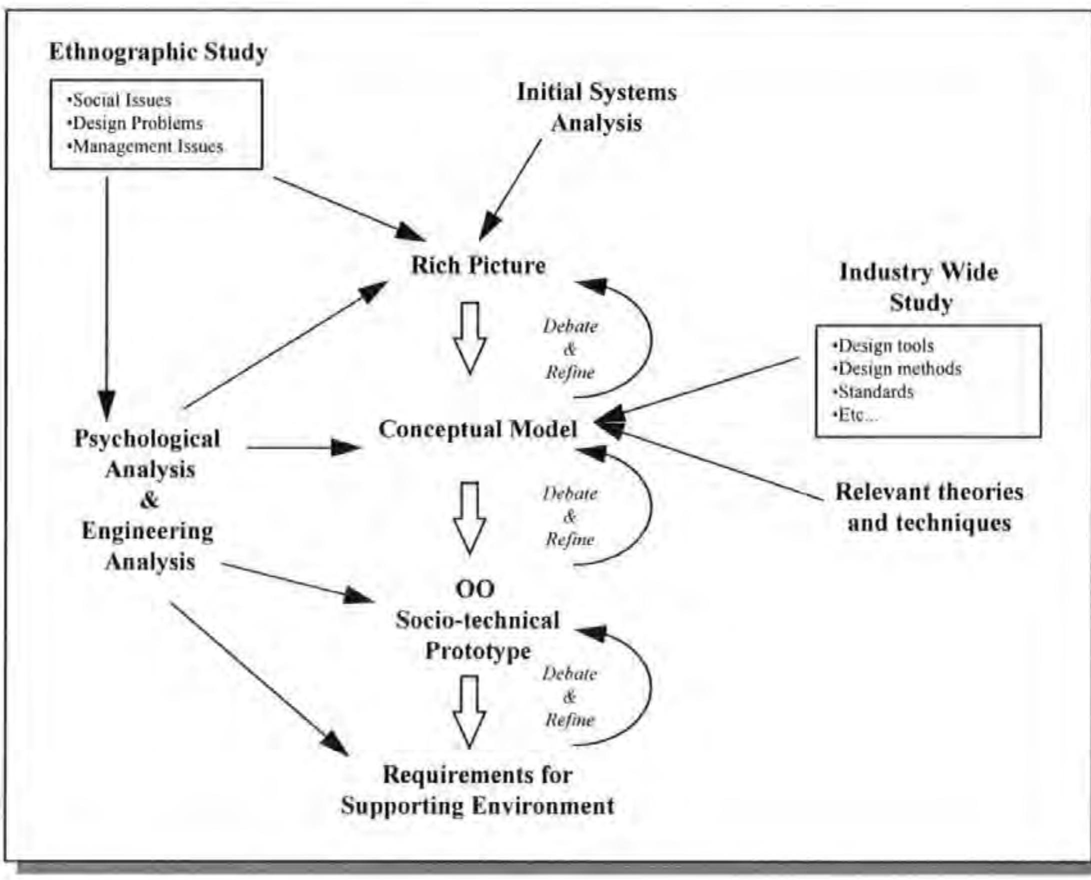
- Heuristic evaluation (Nielsen 1990 & 1993) is the most informal method of the three usability inspections utilised, and is used with a single user at a time. Nielsen has derived a list of usability heuristics for assessing a systems interface usability. He proposes that each topic should have the following three elements; a conformance question, evidence of conformance and motivation. The conformance question determines whether the system or user can satisfy the heuristic being tested. Evidence of conformance obtains examples of the heuristic being satisfied or not. Motivation elicits elements which would contribute to the heuristic being satisfied (in or not in the system). Whilst Nielsen's topics are not currently pertinent to this project, his method provided a useful model for developing and evaluating a set of heuristics for functional requirements.

These alternative methods of evaluating theoretical ideas were adopted at appropriate stages in the development cycle as discussed in the following section. The development of the prototype system may be regarded as a method of buying information about the perceived requirements (Boehm, 1984). It served to capture and validate requirements and possible methods of achieving them, rather than a solution. The prototype provided the users with a usable and recognisable mapping of a case history of one of the design groups studied on to the support system proposed, and thus served as a tangible artefact which enabled the evaluation of clear environment related goals.

3.5 How the work was conducted

This section describes how the work was carried out during the course of the project. Figure 3.4 below provides a simplified flow of the work, and the various points at which major inputs occurred.

Figure 3.4, Method of systems analysis: evolving requirements.



In reality the project oscillated between the various stages as the understanding of the situation developed. For example, the rich picture of the problem situation was further enriched once the ethnographic study was completed and more detailed analysis could be undertaken. This did not happen until after the initial conceptual models were developed, as such this whole process can be regarded as cyclic. However for the purpose of comprehension the following description assumes a normative development (appendix A contains a simplified gantt chart illustrating a notional proportion of time spent on each task).

The first stage of SSM is the generation of a rich picture which describes the current problem situation. The rich picture was constructed from the preliminary findings of the ethnographic and an analysis of the extant system. The analysis was conducted over a six week period via two main methods: analysis of the company's existing documentation; and interviews. The interviews were either unstructured or semi-structured, and involved the system's stakeholders, that is managers, PL's, and engineers, in the following areas :

- *Design Teams* : The areas which perform the design task; this study focused upon the same groups as the psychological study which was conducted in parallel.
- *Design Support Team* : This area provides support to the design groups in terms of procuring, testing and tailoring, or developing software tools.
- *Information Technology Services* : The department which provides the hardware, operating system and network software support to the design area.

The rich picture provided a common medium for communication, enabling debate and refinement of the perceived situation by both the research team and company A's stakeholders; and is presented in chapter 4.

The second stage of the work was the development of root definitions of the various relevant systems that emerged from the rich picture. These relevant systems concern the transformation process of an input to an output dependent upon the worldview of the situation being taken as discussed in section 3.4.2.; and embodied the integration of the ethnographic study, previous studies and existing theories. Checkland and Scholes (1991) suggest that these relevant systems are formulated by considering the following CATWOE mnemonic:

- Customers : the victims or beneficiaries of T
- Actors : those who would do T
- Transformation process : the conversion of input to output
- Weltanschauung : the worldview which makes this T meaningful in context
- Owner(s) : those who could stop T
- Environmental constraints : elements outside the system which it takes as given

Within this work examples of different relevant system being 'a system to resolve conflict between opposing management roles' (an issued based system) and 'a system to manage documentation change control' (a task based system). A number of such relevant systems were defined which formed the basis for the conceptual model for improving the current situation. The rationale for these systems and their synthesis is discussed in chapter 5.

The third stage developed a series of conceptual models of possible mechanisms for improving the situation. The models were constructed from a synthesis of the relevant systems defined in stage 2, and through the evaluations discussed below, optimal enhancements to support the environment were identified and agreed. In this way a complex, highly interrelated support system evolved. To enable the evaluation of this complex model a prototype system was evolved.

The fourth stage utilised an object oriented prototype system which was populated with data from the design projects that had been studied. The prototype system provided the users with a usable and recognisable mapping of a case history of one of the design teams studied on to the support system proposed. This enabled the illustration of tangible scenarios that the stakeholders could readily challenge, which revealed key issues which had previously been missed, and assumptions which had not been communicated. The resultant conceptual model and prototype are discussed in chapter 6.

SSM provided a tool to assist participants learn about the situation, stimulating the identification of opportunities for improving the current environment. Essentially formative evaluation was continuous throughout the model's development through workshops, reviews and internal reports. However, at key stages of the project evaluations were conducted thus :-

- The evaluations of the rich picture were paper based achieved via debate amongst the research team and the stakeholders (see Jagodzinski et al 1995). This was achieved primarily through pluralistic walkthroughs[5] of typical design project scenarios encountered at company A. Refinements of this picture led to an agreed representation of the problem situation at company A;

- The reviews of the conceptual system models were conducted via pluralistic walkthrough;

- Reviews using the prototype system utilised pluralistic and cognitive walkthroughs;

- The users carried out more conventional user testing whilst the system was assessed on site for six weeks. During this time the users were asked to consider the heuristic topics discussed below. Following this period structured evaluation interviews were conducted. The interview format was derived from Nielsen's Heuristic Evaluation model (1990 & 1994). This model exploits the consequence that an aggregate assessment of five evaluators will produce an optimal assessment of the system (Nielsen, 1994). As discussed in the previous section, Nielsen proposes that each topic should have the following three elements; a conformance question, evidence of conformance and motivation. A result of this approach is that in addition to the assessing the system, further empirical information is gathered. The topics for these interviews are discussed below.

- A workshop with senior management and stakeholders to assess the results of the project and determine the best approach for further development.

The final phase of SSM is the comparison of the conceptual model versus the rich picture; this concluding evaluation of the system was conducted in two main phases. Firstly, a series of session using pluralistic walkthroughs, involving multidisciplinary groups assessed the way in which the system would function in a given scenario, were conducted. The scenarios were typically : one taken from the ethnographic study, and one suggested by the users (for example, planning a project with a wish list of

[5] As discussed in chapter 3.

requirements). Some of the issue identified during this phase were incorporated into the prototype prior to the second phase.

The second phase of concluding evaluations was modelled upon Heuristic Evaluation. This entailed the system remaining with company A for six weeks, during which time the system could be assessed in depth in its intended environment[6]. Following this period four key stakeholders were interviewed using a structured interview based upon the Heuristic Evaluation model[7]. The interviews lasted for approximately 2 hours each, the model used can be found in appendix C. The topics for this exercise drew from a variety of literature such as CSCW evaluation findings. The intention being that in addition to unresolved issues or inappropriate support issues that have arisen due to the nature of the system could be captured and assessed. For example, a variety of issues have been identified by Grudin (1989 & 1994) regarding the problems of introducing groupware solutions into organisations which can result in effects such as the workload merely being shifted. The interviews took the following structure. A short preamble assessing the interviewees level of understanding of the system's intention, followed by two main sections of questions. The first section considered each of the system's components individually, the second considered the system as a whole. The topics that were selected for assessment stemmed from the rich picture, and the work of Grudin (1994), Mumford and Weir (1979), Aiello and Shao (1993), and Cockburn and Jones (1995). In summary the topics considered were :

Section 1 : considering each component individually :-

- flexibility;
- benefits gained versus additional effort required;
- whether workloads were shifted to others;
- whether the component would be used;
- any changes to improve the component;

[6] Due to resource constraints the stakeholders had limited time to assign to the project, this approach enabled the users to dedicate time to the system when it suited their workloads.

[7] As discussed in chapter 3, Nielsen (1996) found that the optimal number of users using this technique was between 3 and 5 (inclusive).

Section 2 : considering the system as a whole :-

- implications to the users - status, recognition, efficiency, support, interest, decision making, and personal development;
- impact on the design process - access to knowledge, ability to apply knowledge and skills, workloads, working pressure, and collaborative work;
- the future.

Users were asked to recall up to five difficult problem situations that they had experienced, prior to the interviews, in order to asses the prototype under those conditions. A series of open questions were used as a mechanism for capturing any additional issues which were not discussed. The results of these exercises are discussed throughout the course of the thesis. In particular the findings from the concluding evaluations using the above interview structure are discussed in chapter 7.

3.6 Conclusion

Beck (1993) identifies three key issues which arise when employing a user participative approach, which were evident in this work. Firstly, organising and managing user involvement is difficult because organisational rules for involvement are typically vague or do not exist. In a project of this nature this is further compounded as the research is at the mercy of the industrial needs of the company. This situation led to, at times, sporadic contact with users making the development of working relationships difficult. When utilising soft approaches this often meant that past issues had to be refreshed due to the length of time since their last involvement. A further complication is that the turnover of staff within this domain is fairly high, thus during longitudinal studies it is likely that staff will be moved to different projects or leave the company.

Secondly, seldomly do the users participating in the project discuss the work with their co-workers, thus the system is determined solely by the participating users. Form the debates that took place, and the actions of company A it is evident that this has not been a significant issues as yet for this project. This may in part be due to the SSM approach of generating debates which appear to reverberate outside of the project group.

Thirdly, user motivation can be weak due to the length of time before results from their input are evident and/or because they have been forced into their user role by management. This project did not experience the second of these issues, however frustration with the time span for development was detected. A research project, especially involving longitudinal study, due to limited resources and the innovative nature of the work appear to the users to take an excessive period of time[8]. However, motivation appeared to be revived once a tangible product, the prototype software, was evident. These issues may be further supported by better communication at the outset of the project of the timescales and likely deliverables from collaborative research work.

The fact that the studies are longitudinal combined with the richness of the technique, means that ethnography produces a vast quantity of data. As Sommerville and Rodden (1996) state ethnographers have no interest in classifying data to some pre-defined framework, which is important because the "*notion that there is a fixed procedure for most tasks is an over-simplification*". However this necessitates assistance in the eventual structuring of the data. Clancey (1993) argues that a role for knowledge engineering is to assist ethnographers in organising and modelling workplace observations, as ethnography lacks a language for modelling how people interact. As Clancey states "*.... such models transcend individual points of view. They describe what coordination between people accomplishes as a whole, not individual reasoning*". He suggests the application of qualitative models for issues such as organising data, job functions, interaction patterns, and representing agent roles and interaction strategies. Where these models should focus upon facilitation rather than automation, as the aim is to support *communities of practice, not information processors*. In many ways this combination of techniques concurs with

[8] Although it should be noted that some participants considered the thoroughness of the investigation reassuring.

Sommerville and Rodden's (1996) view that "*ethnography [is] a means of putting flesh on the bones of a model produced using more abstract approaches*".

Integrating these differing data sources required an analysis approach which enabled and reflected the various perspectives involved in this complex socio-technical system. As discussed in this chapter this work used soft systems analysis to embrace the ethnographic investigation. From the analysis representations of supporting systems evolved through user input, debate and validation. The end result is a clarification of intersubjective requirements for human centred support to improve the management of the early phases of team electronic design. A vital element of this work was the technical analysis by the research team's electronics engineer in conjunction with a social analysis by the research team's social psychologist. This interdependency of the social and technical expertise of the team was vital in revealing the key issues of the socio-technical model; clarifying the purposive nature of the social processes within design teams revealing their overall objectives.

As Eisenhardt (1989) discusses, approaching this work without a preconceived theory or hypothesis 'retained theoretical flexibility'. Using multiple data collection methods and investigators enabled triangulation and fostered divergent perspectives; important elements in work which is essentially theory building. Interestingly the emergent nature of the approach and the work itself was mirrored in the findings. Essentially the work began with a blank sheet, what emerged began with a framework for synthesising a number of issues which eventually evolved into a rich paradigm of support. This process would seem to be characteristic when taking an emergent approach to such work.

> *"...without order, nothing exists: without chaos, nothing grows. The instinct for order is... the desire for safety (which permits nurture), for stability (which permits education), for predictability (which permits one thing to be built on another) - for equations of cause and effect simple enough to be relied upon.*
>
> *[Whereas chaos]... focuses upon the resources of individual imagination and cunning, rather than on the potentialities of concerted action... [and] an insistence upon self-determination (freedom from restriction), individual liberty (freedom from requirement), and nonconformity (freedom from cause and effect)... both order and chaos must be aggressive to obtain and sustain the conditions that they seek."*
>
> *(Donaldson, 1991, p. 63)*

4. Problem situation definition

4.1 Introduction

This chapter discusses the development of a rich picture of the current design situation at company A, the initial stage of the present work. The rich picture encompasses potential problem issues in the current design environment at company A as perceived by the company stakeholders, and from psychological and engineering perspectives of the ethnographic data. The principles of our research method meant that the initial phases of this work were conducted with no preconceived model of a solution or reference to other literature, to limit the bias in gaining an understanding and appreciation of the environment of the early, conceptual stages of the design process at company A.

We begin with a characterisation of company A to provide the context for this work. Each of the three sources from which the rich picture was generated are then discussed in turn: the psychological perspective, the engineering perspective and then the stakeholders perspective. Finally a complex rich picture of interdependent issues which detract from the productivity[9] of the design process is presented, based upon these three perspectives.

[9] Design productivity is "*the efficiency of producing a required design which is effective to the overall system; where system depends upon the level of interest.*" (Engineering Design Debate, University of Strathclyde, 1996)

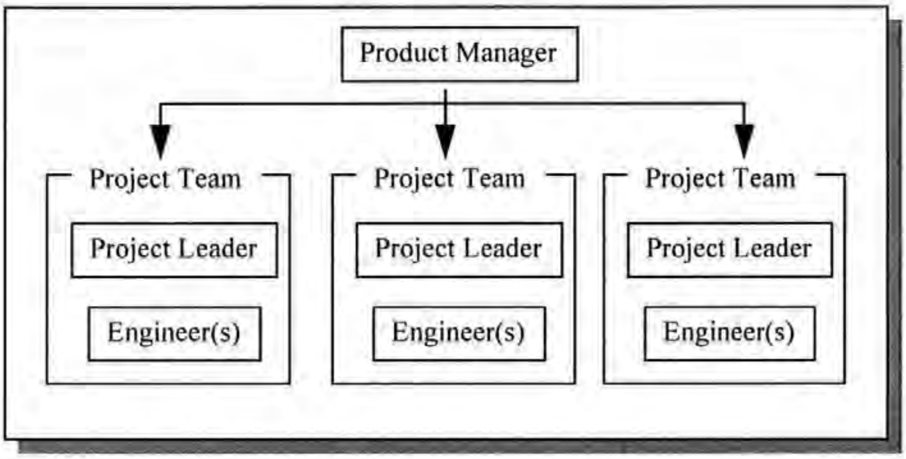
4.2 Characterisation of Company A

Company A consider themselves to be a medium size company in terms of the world market for the design and production of semiconductors. Company A aim to produce high value, high cost products for niches in the electronics market; their driving factor, or 'Hoshin', being 'time to market'. The electronics market is fairly volatile, Adachi, Shih, and Enkawa (1993) describe it as "*one of the most competitive and technologically innovative among all product segments in Japan...the average life cycle is only one year*". As a result company A must constantly evolve their working practices. At the time of the study company A were restructuring their organisational structure and their design process.

The company has a number of UK sites, each of which developed individually and tended to specialise in a particular product type. Consequently, each site had developed its own preferred methods and models of development. Design at company A is project team based. At the time of the study although some senior staff from each site were involved in projects at other sites, the majority of projects were single-site. That is, the project only involved personnel from one site. The consideration of multisite work would have further complicated the understanding of this environment at that time. Consequently, the study was conducted solely at one site and focused upon single site design issues. However, the implications of multisite work can not be ignored and were considered during the later stages of the present work.

Company A's design environment is a high risk climate. Company A estimate that from 56 ongoing projects 10 will be completed to the production stage, and only 1 of the 10 will be a commercial success: "*As a result staff are always working to the limits of their capabilities*". Due to the size of the company the teams tend to specialise in certain areas (for example MPEG) and remain together for a number of projects. This situation means that knowledge and skills are focused, but also dictates the products that can be developed at any given time. For example, if the MPEG team are currently engaged on a project it is likely that the company would typically have to wait for their current project to be completed before it could begin another product which involves MPEG capabilities. Further implications of company A's structure will be discussed later. A product team hierarchical communications structure, would typically be as shown in Figure 4.1 below.

Figure 4.1, Product team communication structure.



Typically a product would comprise a number of components, for example a software component and a hardware component. Generally project teams specialise in a certain domain, for example software or hardware. Using the above diagram as an example, one company A product required a software team, a hardware team, and a 'capabilities' team which integrated the peripherals of the cell into a product. As discussed in chapter 3, it is primarily the product manager and project team leaders (PL) which the present work sought to support.

4.3 A psychological perspective

This section presents the key findings of Reid et al (1997b) who examined the ethnographic data from a psychological perspective. The findings revolve around management dilemmas which confront the PLs, as Reid et al explain :

> *"Management dilemmas present themselves to the PLs as real problems which they have to resolve, but unlike technical difficulties that respond to creative design solutions, these problems are recurrent and sometimes intractable, and have to be addressed repeatedly throughout the product development process. In other words, they are problems that have to be managed rather than solved, and are probably best thought of as system states which have to be maintained within acceptable bounds rather than held to fixed values or alienated altogether. Good design managers are capable of steering the design team on a satisfactory trajectory within these bounds, rather than simply passively fitting management*

> *solutions to eventualities as they arise. This is achieved by being capable of reading the situation, and responding to perturbations that threaten to push the team outside acceptable bounds with corrective measures. The task facing the PL is therefore to maintain a complex and dynamic equilibrium over the course of the project."*

Two main management dilemmas emerged which represent recurrent and contrasting skills: the management of workflow interdependence, and design team integration. Workflow interdependence concerns the coordination requirements involved in complex design problems where the activities of the team need to be coordinated to result in an integrated product design. The PLs recognise that different responses are appropriate to different task situations. For example :

> *"recognition that inadequate and insufficiently formal procedures for project decomposition, planning, and scheduling, lead to an inappropriate reliance on judgement and ad hoc adjustments later in the design process. This concern acknowledges the value of an ad hoc approach to management, but only if combined systematically with a planned and scheduled approach;*
>
> *recognition that inappropriate workflow arrangements are often accepted by default when communication difficulties within the company impede mutual adjustment. Under these circumstances, a sequential workflow arrangement where everybody waits on hold whilst a critical problem is solved may be reluctantly accepted."*
>
> *Reid et al (1997b)*

Secondly, design team integration concerns the difficulties PLs face in maintaining their teams as functioning units, which Reid et al describe as a well-known and much studied problem of :

> *"...establishing and maintaining equilibrium within the team between two opposing motivations, the motivation to pursue and accomplish task objectives (the task motive), and the need to attend to personal concerns and relationships within the team (the socio-emotional or group integration motive). .... this balancing act has been known to be a primary concern of all team managers. The reason for this lies in an obvious paradox: whilst a team that spends too much socialising may fail to address its primary task, a team of people who cannot get on with each other are unlikely to be able to cooperative effectively."*

The result of these dilemmas are for example, that the PLs experience conflict between being a technical expert or as managers of the design process. The PLs respond to this conflict differently. For example, some prefer the technical consultants role, others as managers using their social skills to a larger extent. A consequence of this conflict is that some PLs experienced role overload through having task functions to fulfil as team members, whilst also dealing with management problems. As Reid et al illustrate :

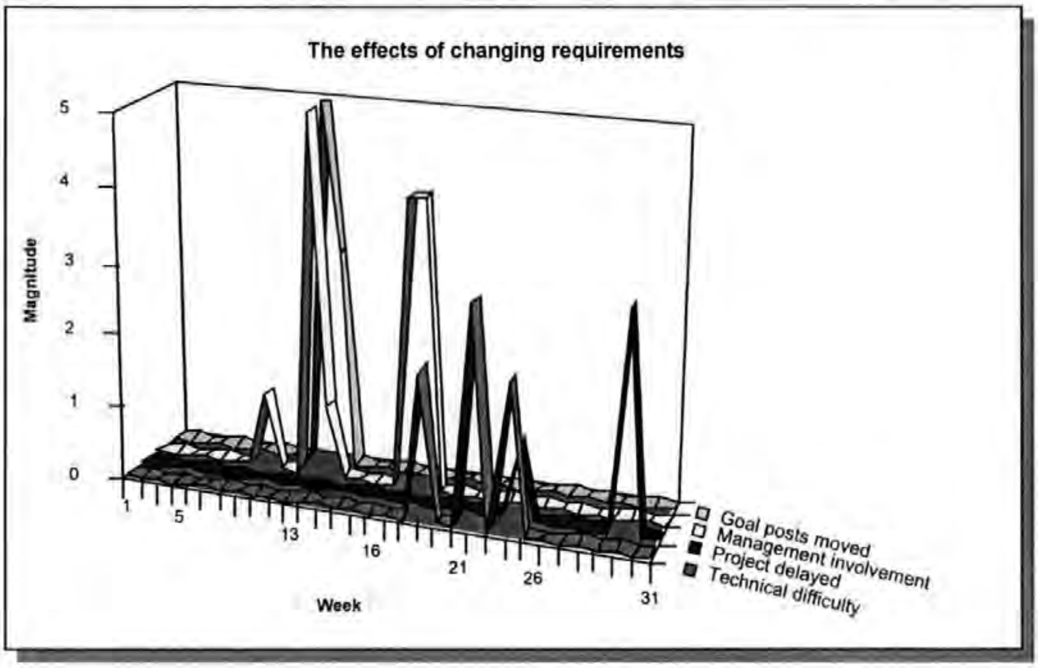
> *"This was expressed not so much as a dislike of having 'managerial' functions but simply not having enough time to do a run-time design role and also manage. This was expressed in,* [...you have a workload yourself which needs to be done and you can't always devote the time necessary to sit down with them and ask them how it is going]. *Also expressed as,* [...ideally you would want, if you were a PL, the main task to be the project and you wouldn't want to have a large technical load. ...in reality you never have enough people with enough experience for some of the tougher problems]"

The study indicated that PLs continuously and dynamically respond to changes in the project's situation. Reid et al propose the identification of relevant occurrences which call for corrective management action and appropriate responses to enable the provision of support to design managers; '*Tactical shifts in management structure are actually this process, the real design management issues facing PLs*'.

4.4 An engineering perspective

This section outlines the work of Culverhouse (1996 a & b) on the analysis of the ethnographic study from an engineering perspective. The work identified six problem tracks which followed significant problems from their inception to resolution. The magnitude of the problem situation was assessed in terms of causing technical difficulty, delay to the project, requiring management involvement, and changes in project requirements. For example, one track examined the effects of a customer driven reduction in the 'time to market', which resulted in the level of functionality for the product being reduced to meet the new time scale. The indications of a major change to the requirements for the project were visible in week 8 however a change to the project's plan was not effected until week 11. For the following 10 weeks the plan was described as *reactionary* and '*no one takes the plan seriously as it is continually changing*'. As a consequence engineers were reluctant to finalise and conclude tasks due to the likelihood that it could be wasted effort. Figure 4.2, below illustrates these effects.

Figure 4.2, An example of the flux of a problem situation (after Culverhouse, 1996b)



With the benefit of hindsight, analysis of this situation indicated that the magnitude of the change in the project's requirements necessitated a major change to the project's conceptualisation. In other words, the most effective course of action would possibly have been to replan as if from scratch. Being able to perceive this change in the project's status proved difficult for those involved due to the complexity of the factors, their closeness to the problem and a lack of guidance for, and/or experience, of dealing with such situations.

Briefly the topics of the other five tracks concerned :

- A major change in the information model of the artefact being produced was required. Potential problems were identified in week 3, but due to problems with intent of designated tasks and the irrelevance of published plans, this was not addressed until week 9. The result being a reduction in the functional capability of the product in weeks 13-16. The underlying message being that potential problems were difficult to prioritise due to project management deficiencies, for example '*crossing bridges when you come to them*'. The consequences of taking a more proactive approach is discussed further in chapter 5.

- A software tool, known as a 'toolkit', which was required for a project was developed in house. The development process for the software was ad hoc, for example there was no formal requirements specification. The resultant software was late, had many bugs, and did not meet the requirements of the project. This issue required management involvement, caused delays to the project, and technical problems as tasks which the tool was supposed to handle had to be dealt with in alternative manners. The key issue here is that there was no explicit recognition for the risk involved in this development strategy at the projects conceptualisation and planning. The project continued to struggle on with the software once it arrived, awaiting revisions to improve its functionality. Finally in week 18 it was decided to use the functions which worked and solve any other tasks in other ways. The problem was laid to blame with the support area whom were developing the kit, however the design project could have better assessed the risks involved at the outset and possibly sketched out contingency plans, as Company A are well aware of the potential problems inherent in software development.

- The software tools chosen for a project were changed in an *ad hoc* fashion because of their apparent superiority over known tools. As discussed in the previous track the impact upon the risks introduced to the project were not explicitly considered or assessed.

- A lack of adequate planning and resource allocation placed an engineer in a situation where they had no experience of developing a required artefact, and was allocated a development time which was a tenth of the *recognised training time* normally associated with such an artefact;

- The problems encountered through a series of support system failures, for example file server failure. This track illustrated recurrent situations which are intuitively recognised by the PL's, but are not accepted by senior management as legitimate for planning purposes.

Culverhouse (1996b) presents a more detailed discussion of this work. A generalisation of the impact of these issues is that a problem spreads horizontally through the technical team before becoming a management issue which then spreads vertically through the company hierarchy. Many of the issues mentioned above can be seen the stakeholders' perspective described in the following section.

4.5 Stakeholders' perspective

The following sections describe the key issues which arose from the initial study of the extant socio-technical system[10]. These issues are discussed in the following five sections: specification; project management; management of risk; organisational knowledge and roles. Whilst the issues have been categorised for ease of discussion, as will become apparent they are interrelated and interdependent.

4.5.1 Specification

As discussed in chapter 1, the first stage of the engineering design process is normally some sort of market needs assessment, resulting in a marketing requirements specification. The marketing specification normally initiates a design project. The content of these specifications can cause problems, in particularly communicating the intent of the specification and the business aims for the project.

The intent of a specification would typically lie somewhere on a continuum ranging from hard to soft :

hard ◄——————►	**soft**
a statement of detailed functional requirements which the product should satisfy, with budget and timescales for design testing, production and marketing.	a vague wish list of areas in which potential customers have expressed an interest and for which new ideas are sought, without specific timescales or budgets.

Both the hard and soft forms of specification may be equally valid, as may an intermediate form, depending on the conditions in a particular market. Ideally the soft form would be expected to develop into the hard form before detailed design took place. However, this is where difficulties occur. It would seem that designers can be unclear as to the intent of the specification with possible consequences as follows:-

- specifications can lack information about the intent of the originators so that it is not made explicit whether they are hard, soft, intermediate or a mixture of all three;

- specifications pass up and down the hierarchy from design manager to PL to design engineer. In this journey soft specifications sometimes become hardened up as each level adds its interpretation to the original request for ideas. Design engineers thus receive the impression that the specification is hard when it still should be regarded as soft. Alternatively, the hardening is intended, but the difference of intent is not evident.

- thus for soft specifications, depth first, detailed design may take place when breadth first, outline consideration of a wide range of possibilities would be more appropriate. Downstream design work can be wasted when an alternative option is adopted;

- when a soft specification is being developed it may not be circulated to the right people, for example for reasons of commercial confidentiality, so that when design starts, changes to the specification are needed to accommodate additional knowledge;

- due to functional divisions within company A, occasions can occur where communication channels do not function adequately to allow either discussions between designers and customers to refine details of technical requirements or to

[10] Further details of which can be found in Jagodzinski et al (1996) and Parsons (1995).

identify key individuals to facilitate the discussion of issues which would elicit a balanced view.

- the uncertainty of the intent of a specification leads to uncertainty about the development strategy to use, makes planning and scheduling difficulty, and has caused projects to suffer false starts.

- The lack of intent of a specification can also be traced to uncertainty of the business aims for a given project. Engineers felt that they did not have access to strategic project information which would have proven beneficial in terms of understanding and appreciating the project[11]. For example, the business aim may be to produce a design for long term reuse therefore an object oriented approach to the design might be adopting. However this could possibly increase the length of time to initially develop a product.

The uncertainty of business aims and intent can sometimes be partly attributed to restricted access to information due to differing hardware platforms, coupled with the problems of assumed communication which are discussed in the project management section 4.2.2. However this situation could be alleviated somewhat if the information was included in the specification and would also provide vital information for possible reuse of the specification and resultant solutions in the future.

Regardless of the problems that these issues raise, as discussed above, the need for 'soft' intent or aims often stems from the need for flexibility; flexibility for the customer, flexibility for the market place, flexibility considering other potential company projects, etc. The decision to concretise such issues is risky and contingent upon many attributes. Consequently, flexibility can be a necessity for survival that must be acknowledged, preferably in an explicit manner.

[11] This need has been recognised and is being addressed to an extent through a company *Voyager*; see section 4.4.2.

4.5.2 Project management

Project management at company A can be considered to comprise the management based activities of project planning and scheduling; risk analysis[12]; resource allocation; communication and tracking; and control and coordination. Company A utilise contemporary project planning tools and techniques such as activity networks, critical path analysis, PERT, Gantt charts, and computer based tools in this area. Nevertheless, project management may be regarded as difficult and not always successful. This section discusses several interrelated reasons underlying this problem.

4.5.2.1 Control and coordination

The control of a project requires a gauge against which progress of work, milestones, etc., can be monitored and refined. This would typically be a plan based upon a process model of the design cycle. It was evident from the study that a common process model of design was shared by most designers at an abstract level. However, at a more detailed level their models differed. Company A recognise this and have attempted to develop a common model through New Product Implementation Procedure (NPIP). However NPIP is a generic framework of the process with various 'stop' gates, which the engineers view as something with which they had to 'comply', rather than a model or guide to help them.

The specifics of activities such as planning, scheduling and resource allocation are left to the managers preference which allows flexibility. However, this approach makes the storage and reuse of plans difficult. Consequently, due to a lack of access to previous experience and estimations, and the looseness of requirements specifications it can be difficult to adequately plan and control projects. If the initial estimations are inappropriate this will often make the refinement of estimations extremely difficult. This has led to phases of the design not developing in a controlled sequence, which can cause problems such as peer group reviews being missed and specification writers also writing their own test benches. Another consequence is that if planning lacks credibility then the possibility arises for a snowballing effect. For example, it is

[12] Risk analysis is discussed in more detail in section 5.3, however its implications are included in this section.

normal at company A for personnel to be involved with a number of projects simultaneously, and carrying out a number of different roles (see section 4.2.5). If a particular engineer is not given a hard deadline for a particular piece of work then it is easier to divert him to some other task, so that more slippage occurs on the first project.

NPIP stresses the importance of the initial stages of the project, that is, ensuring that the requirements specifications and implementation specifications are completed adequately. The message being, that the investment must be made at the outset of the project. In response to this message, one design team decided that module test specifications should be written at the same time as the module requirements specification. Thus ensuring that both specifications are devised by different engineers. However, due to the non-linear nature of a design's development this could often result in repeated changes to the test specification, as the Implementation Specification is amended. Putting this problem aside, it is evident that the key issue here is access to pertinent information, for example past plans, current experience available and workload, etc. As this information is rarely available, generating adequate estimations and controlling resource allocation becomes even more difficult.

Further complications can arise due to the looseness of certain procedures. An example of this being change control. Once a document has passed its relevant design review it is frozen. However, this is a status label only, the document or code is still amendable, that is, the frozen status is not enforced. The frozen document is passed to the design department secretary, a non-engineer, to "Archive'. Thus the whole mechanism relies upon one person. If a document is changed it is the author's responsibility to notify the design department secretary, who updates a changes list. This list is intermittently distributed to all personnel notifying them of all the documents which have changed since the last notification. The receiver has to search through and check if any of the changes are relevant to them. Consequently people often rely on word of mouth for notification of a relevant document change. Engineers have stated that 'word of mouth' of document changes was unreliable. Instances have also occurred where documents have been changed and the changes have not been deemed worthy of formal notification to the system. Furthermore, control and coordination are complicated by the incompatibility of some of the software tools and platforms used. Company A's initial solution was to use 'Abode Acrobat' software and *mosaic* file structures to allow information to be moved across platforms. However, some of the software packages used, for example Microsoft Project, are not convertible. More importantly, this solution does not address the issues of control and coordination of the retrieval and storage of information.

The flexibly approach to control and coordination that has been outlined here enables management to quickly deal with problem situations and adopt their own preferred working style. This appears to be a useful approach when the PL is in sufficient control of the situation. However under pressured situations, typically some way into a project, this approach can fail as the PL and designers are unable to cope with the increasing burdens.

4.5.2.2 Communication

The engineers indicated that the existing communication structure of review meetings and regular project progress meetings did not take place as intended. This was due in part to the difficulties in planning and coordinating meetings and reviews caused by the uncertainty of the design goal. However, engineers also felt that they did not have access to strategic project information which would have proven beneficial in terms of understanding and appreciating the 'big picture'. Additionally the engineers felt that they received little if any feedback. Company A have proposed to address this situation through a project "Voyager", an electronically based data source which accompanies each project allowing access to all the project information.

At present information, especially strategic, tends to be communicated via memos (often email) and through six weekly design group communications meetings. The dissemination of information within a design group can be dependent upon the leadership style of the PL or manager of the group. Predominately information is shared within the group via word of mouth due to the open plan structure of the environment, and via Email outside of the group. There were no known official restriction to information, information was communicated subject to people's assumptions about what their audience or college, needed or wished to know. Furthermore, a common assumption was that due to the open plan office environment information will often be overheard and therefore circulated. However the engineers indicated that, especially when under pressure, this communication mechanism breaks down. This concurred with the ethnographic study which identified the importance of:

> *"..fully open communication and feedback channels between engineers when mutual adjustment and reciprocal interdependence is the priority concern. This is also reflected in comments about the physical proximity and open plan arrangement of the teams' working environment: that such an arrangement is essential to workflow interdependence, but that it is assumed to take place, and that without astute management and regular monitoring this may not actually occur. In other words, the open plan office is also considered to have a potential for facilitating information loss"*
>
> *Reid et al (1997b)*

Communication within the project team was also seen to be affected by technology, in two ways. Firstly, the compilation of data for project progress assessments is usually gathered via word of mouth by the PL. Whilst there are obviously benefits for face to face communication between the PL and the engineers, tasks such as this which could be automated, are seen as fairly time consuming and a burden by the PL. Secondly, due to platform differences and software incompatibility engineers generally receive hard copies of project plans, for example produced using Microsoft Project software. However, most engineers refer to the majority of information electronically via their terminals, that is they work in a virtual environment. It was evident that maintaining easily referenceable current hard copies of plans proved difficult.

The flexible approach to communication discussed in this section enables the PL to filter information so that engineers are not overwhelmed and encouraged social interaction amongst the team. However, as discussed in the previous section this approach can fall down when the team and PL are working under pressure and communication can then suffer at critical points in the project.

4.5.3 Management of risk

To enable flexibility the specifics of the management of risk have generally been left to the discretion of the management team. The main consideration has been the level of risk associated with new design knowledge required and to a lesser extent the production knowledge required. A number of points may be raised considering this approach.

As discussed in the project management section above, whilst this approach may be flexible it is very difficult to capture and reuse past risk assessments. This is particularly difficult if you wish to reuse estimates with which you were not personally involved. A lack of standards also means that there are no measures of the risk being adequately assessed. Not being able to capture and reuse risk assessments also hinders the evolution of risk assessments which are basically forecasting exercises.

The degree of innovation actually required by a particular design typically varies from project to project. This distinction is often not made at the start of a design project. The consequence is that levels of innovation in the design may vary throughout the project in an uncontrolled, ad hoc fashion. For example, a new technology or process may be incorporated into the design part-way through the project, bringing significant delays with it. The net effect of such *ad hoc* changes in the level of innovation may be beneficial if it results in a better product, or harmful if it delays the release of the product in the market, or even both. However, what is important here is that such effects often seem to happen in an uncontrolled way. The decision on levels of innovation usually being made deliberately on the basis of a conscious assessment of the associated risks, but this was rarely made explicit or communicated to others

Risk assessment within the design environment should not be limited to the new knowledge required for a design alone. Risk should also be explicitly considered and assessed for the project's aim and for the process of design. For example, the reliance upon design software tools has, and is likely to, increase dramatically driven by market demands. The following illustrates the effects of software tool problems upon the design process:

> *"Approximately three years prior to this study, company A's design tool suite supplier ran into difficulties and were unable to continue supporting their software. Company A were therefore forced to select alternative design software. Company A selected a group of design engineers to assess a new design tool suite as an alternative. Under the test conditions applied at company A the software appeared to function correctly. In their view it provided the best features currently available; plus some of the engineers had experience of some of the producers point tools. However, company A were the first industrial user of some of the new features. In particular, a version control and integration tool. Little account of this situation appears to be have been taken in the project's planning or risk assessment. Unfortunately, once the tool was applied to a large scale project, for example 1.5 gigabytes of data, it began malfunctioning. For example, data would be lost, or it was not possible to retrieve and/or link related data. As an interim solution to this problem a group of design engineers were selected to provide the missing functionality by using Source Code Control System (SCCS), which is a basic version control tool, shipped free with the Sun-Unix platform. This solution ensured future software support and access to the data. To facilitate this activity a member of the design group is acting as a librarian, to ensure document standards and structure of storage. Individual engineers generally use their own preferred style to hold their data and documents, hence there is no 'standard' approach until the documents have been passed to the librarian. In addition to this problem it was found that the synthesis tool did not integrate with the other software tools used in the design process. Consequently the SCCS records and the VHDL data are held separately."*
>
> *(Parsons, 1995)*

This situation illustrates two key issues. Firstly, the implications of the risk inherent in the project. A review of this project by the design team involved concluded that subsequent projects should draw up a 'tool requirements specification' at outset, which would enable the Design Support Team to profitably evaluative future software tools. However this solution does not address the effect of not adequately assessing the risks that were present and introduced, which were not explicitly acknowledged. This situation, as discussed in section 4.3, also occurred for a different tool as identified in the engineering analysis of the ethnographic data. Secondly considering reuse, this situation obviously causes additional short term problems and work for the design team. Taking a long term perspective the reuse of the design data by other areas becomes extremely difficult.

Once again as discussed in the previous sections, the flexibility of company A's approach to the management of risk enables expediency. However it does not facilitate reuse or improvements in what is essential a forecasting task. Furthermore, this flexible approach can fall down when the team and PL are working under pressure.

4.5.4 Organisational knowledge

The knowledge used in the design environment can be considered to exist in two complementary forms, human memory and externally stored knowledge, which form the core of the organisations design knowledge base. The following section discusses issues which were found to exist when utilising these knowledge sources.

4.5.4.1 Human memory

Whilst the role of peoples memory although obviously implicit in this work was not the focus of this project as a whole, what did emerge was the need for knowledge about what other people know. For example, in the specification process it was important for the initiators of the project to know who should be consulted in order to cover all of the important aspects of the proposed design. Likewise, it was fundamental that members of a design team should know who within, and more pertinently outside of, the team they could or should consult about particular issues. This knowledge was an important component of the PL's role. However the PL relies upon informal communication channels which, as discussed in section 4.2 and above, can be unreliable, particularly within a multisite company. During specification, problems arose from the need to consult more widely and over long distances.

4.5.4.2 Externally stored knowledge

The key issues facing company A concerning externally stored knowledge is the capture, control and recall of project and design information. The overriding opinion was that engineers generally dislike doing documentation because they feel it interferes with design, or alternatively that a minority of engineers over document. Typically a design's documentation would contain the minimum amount of information necessary to specify its form to enable the next step of the design or manufacturing process to proceed. As discussed in section 4.2.2, project management based information is rarely stored with the design data, and is not viewed as a priority for reuse.

A lack of standards for design documentation and project management information makes storage and retrieval for reuse difficult. However, where standards have been adopted they can have a negative effect. For example, company A have generic design review forms which were felt to be ineffective as many of the requirements were irrelevant to the modules reviewed. The engineers concluded that the forms needed updating. However, the key problem appears to be that different projects will require different templates, consequently generic based templates will often require irrelevant information. This situation also applies to design and project management documentation. Due to problems such as these, once a design's documentation has been archived it is often difficult to reuse. This problem is compounded by the method of distributing the project documentation to the rest of the company. At the time of the study distribution was achieved by taking a 'back-up' of the files for the project, which was sent to the other company A sites for 'reuse' purposes. The information in this format is extremely difficult to reuse and consequently word of mouth is generally the only consistent method of communicating 'reuse' issues.[13]

Thus information on previous projects and designs are effectively unavailable even though such information and knowledge might easily be, at least partly, reusable. Clearly, reuse of previous project information and designs could greatly reduce the risks and time scales of new design projects. Similarly, knowledge of previous, unsuccessful design projects could help project teams to avoid exploring fruitless options; or suggest alternatives which failed in the past due to reasons that could be overcome now, for example due to technological advances.

[13] This method of communication could be supported through knowledge about who should be contacted regarding subjects, especially in a multi-site company.

4.5.5 Roles

A conflict appears to exist between the demands of the design task and the designer's perception of their own role. Generally engineers viewed their prime function as designing electronic artefacts through problem solving. They judged themselves, and felt judged by others on their performance on this basis. However other tasks, such as documentation of the design, can also be seen to be very important. Yet typically designers regard the activity of documentation as detracting from their performance in their principal role.

Another area in which there was role conflict was in cases where experienced designers had been promoted to management positions. This could cause several problems. First, their technical expertise was still in demand so that they were diverted from their management task and yet were not being properly recognised in their secondary role. Secondly, when technical experts were also managers it was possible for their objectives to be in conflict. For example, adherence to a management plan might result in a risk-free reuse of an existing design whereas technical creativity may pull towards a riskier, innovative solution. This conflict was identified in the psychological analysis of the ethnographic data as discussed in section 4.2.

Design teams appear to regularly need to create informal sub-roles such as "Technical Author" and "Librarian". For example, a contingency role of Librarian was required due to the software tool failure discussed in section 4.4.3. These sub-roles are vital for the progress of design projects, but are often not made explicit and are not formally recognised. Clearer definition of role would alleviate such tensions by at least enabling the dilemmas to be recognised and arbitrated consciously. Furthermore, without recognition the experience and skills gained in these sub-roles will be made more difficult to capture and access. Especially if these roles are not made explicit and some form of company wide mechanism exists to communicate people's skills and experience.

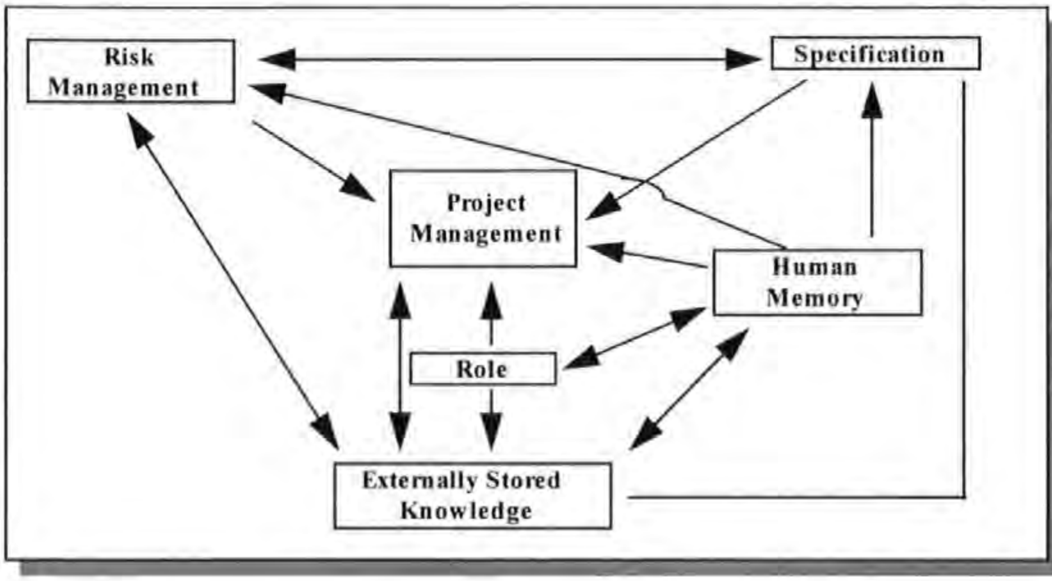
As with the preceding sections, 'roles' are subject to problems when working under increased pressure. Typically a '*fire fighting*' approach is adopted, and the implications and risks involved when ignoring any 'non design' roles is not considered due to the complexity of coping with the design project under these conditions.

4.6 The rich picture : *the current situation*

The aim of this stage of the work was to gain an understanding and agreed picture of the current situation at Company A, not to produce solutions. The principles of our research method, as discussed in chapter 3, meant that the initial systems study was conducted with no preconceived model of a solution, to limit our bias. In other words, the aim was to capture an unpolluted rich picture of company A.

The construction and content of a rich picture of a problem situation has been an area of contention (see Lewis 1992). The representations used within this project follow the conclusions of Lewis (1992), in that they evolved during the work and are meaningful '*to those involved in that particular instance of enquiry*'. Consequently, it is the engineering design issues which are of relevance here, rather than the use of SSM techniques. From the three perspectives described in this chapter a complex, rich picture of a number of key interdependent issues emerged (see Figure 4.3 below).

Figure 4.3, A rich picture the key design environment issues at company A.



The key area of concern which were identified from this exercise can be summarised by the following three points:

I. A number of design activity issues exist, which have been discussed under the issues illustrated above in Figure 4.3. The main problems are :
   - *a lack of tools*: for example not having sufficiently detailed and appropriate design process models;
   - *no suitable mechanism to support the interdependent and interrelated aspects of project and design information*: for example changes in a design should be propagated throughout the environment so that risk assessment can reapplied, test strategies re-examined, etc.;
   - *a lack of information resources*: for example without access to previous risk assessment exercises it is difficult to develop and refine this forecasting activity;

II. A conflict exists between adopting a flexible approach to the design process and using more formality. The PL's, and to a lesser extent the engineers, require flexibility to be able to cope with the flux of an industrial design project. In contrast the introduction of more formal processes may assist in planning and permit more structured communication of information. However, whilst increasing formality and bureaucracy may improve some of the issues that have been discussed, company A require flexibility to deal with the continual fluxes of the design environment. A problem which often occurs is that due to increases in stress placed upon the team the less formal and more flexible approach will fall down. Within company A the PLs and engineers are often involved in a number of challenging tasks at any given point in time. For example, one member of staff was simultaneously involved in 14 different projects due to his expertise. The PL's felt that when one of tasks becomes too complex intellectual overload occurs and the complex task is given complete attention; resulting in the neglect of the other tasks which may be associated with a different project and hence a knock on effect occurs. This was felt to be due to the engineers perceiving their key role as problem solvers and hence pursuing the solving of a problem as a priority. As discussed in section 4.2, at times the PLs find themselves in conflicting roles and under pressures which mean that they simply do not have sufficient time to ensure that the 'low priority' tasks are completed or supported. Thus issues such as the long term development of organisational knowledge are hindered.

III. Perceiving the current situation of the project and deciding upon appropriate courses of action was identified as being difficult. For example section 4.2 discusses the issue of managing recurrent problems, which was thought to be best achieved when the PL could properly assess the current situation and had sufficient experience to proactively steer the project in the best direction. The rich picture illustrates that this is a highly dynamic and interrelated environment, when coupled with the situations discussed in section 4.3 where the design team are often under extreme pressures, it is difficult for them to adequately perceive the current project situation. As there is no resource of knowledge available to guide the actions in these circumstances the project becomes extremely reactionary and as discussed in section 4.3 situations where the team 'waits on hold' are accepted. This effect can be seen in the example illustrated in Figure 4.2 where a project requirements were changed.

In essence the root of these issues is the conflict of flexibility versus formality in the design environment. Formality enables coordination, learning, and improvements in efficiency; flexibility enables change, and the ability to cope with the dynamic environment of design. As discussed in chapter 3, the next stage of development in the SSM framework is the generation of root definitions for relevant systems. The synthesise of the key relevant systems was the crux of the present work.

4.7 Conclusion

The rich picture proved to be beneficial in representing the stakeholders', psychologists' and engineering perspectives of the design environment at company A. Through this exercise a complex interdependent picture of issues which detract from the management of electronic engineering design teams was revealed. The key areas of concern were a lack of support for the various interdependent design issues identified, the conflict between flexibility and formality in the design process, the difficulties in perceiving the current situation of the design project and deciding upon appropriate corrective actions.

It is evident from the work described in this chapter that the research method adopted enabled each perspective to identify issues which would have been difficult to reveal by adopting only one of these perspectives. For example, the psychological perspective illuminated the role conflicts that can be present and possible reasons for role conflict, whilst the stakeholders perspective revealed possible contingency roles. The differing perspectives also enabled the triangulation of issues: for example the engineering examination of the ethnographic data revealed the implications of the software process tool choices, concurring with a separate incident from the stakeholders' perspective. Furthermore, the UoP studies were enhanced by selecting to study a variant and an innovative design project. The problems experienced are not limited to say innovative projects[14], however the weight of an issue appears to vary

[14] Culley et al (1996) report that UK design engineers carry out 20% variant design and 30 % innovative design.

between different project types. In other words, project types should be differentiated, and the appropriate project requirements emphasised.

The crux of this work became an approach which synthesised the issues identified in this chapter. This approach would need to incorporate appropriate indicators of potential problem situations, and guide the application of techniques and management tactics, in a dynamic environment. The rationale for this concept is discussed in the following chapter.

"A reasonable probability is the only certainty"

(E. W. Howe, Country Town Sayings)

5. Rationale for a dynamic contingency approach

5.1 Introduction

This chapter discusses the rationale for adopting a dynamic contingency approach for supporting the management of the complex environment of electronic engineering design. The earlier stages of the UoP project, discussed in chapter 4, developed an unpolluted rich picture of the design environment at company A. This chapter represents the next phase of SSM, that is, the development of relevant systems from the rich picture into a conceptual model of support.

The crux of this work was the synthesise of three key relevant systems. This chapter argues that a dynamic form of contingency theory can synthesise the key relevant systems, and based upon appropriate influencing factors, may be used to guide the tuning of design environments to match changing circumstances. In other words this approach could provide a guide to appropriate states, help to maintain states, and alert stakeholders when a project appears to be in an inappropriate state.

5.2 Key relevant systems from the rich picture : *the aim*

The contribution from this work, a dynamic contingency approach, stems from three key relevant systems which were identified from the rich picture discussed in chapter 4 (the CATWOE definitions for these systems are contained in appendix B). These systems encapsulate the issues which were determined to be of highest concern for company A. Whilst the rich picture was intentionally 'unpolluted' by reference to other literature, at this phase of the work pertinent literature was drawn upon. The crux of the work, and hence this thesis, was the development of a conceptual model which synthesised the requirements of these systems. This section discusses the essence of each of these systems.

5.2.1 Relevant system 1

Relevant system 1 concerned the provision and coordination of design project information, resources and tools. The term coordination is used here rather than control because as Litterer (1973) argues, the emphasis upon control can suggest a confining or coercive objective. He proposes that control and coordination may be viewed as being the same in principle, where the essence is "*on directivity and integration of effort, [and the] required accomplishment of an end*". This approach is supported by Aiello and Shao (1993), and O'Brien, Feldman and Mount (1993), who conclude that, particularly in 'professional roles', the use of automatic monitoring for anything other than simple tasks increased levels of anxiety and stress resulting in a decrease in task performance.

The need for this relevant system concurs with Cockburn and Jones (1993) who argue that systems which support team environments must meet two integration aims, curative and augmentative. *Curative* to reduce the number and magnitude of transitions between tools, and *augmentative* to integrate access to resources that serve communication and collaboration. The resources and tools identified in this work concur with those identified by Andreasen, Duffy, MacCallum, Bowen and Storm (1997).

5.2.2 Relevant system 2

Relevant system 2 concerned a system which alerted the team and PL(s) when a project's situation changed significantly. Both Morris (1989) and Palmer (1987) argue that many projects fail due to changes in situational factors external to a project. The effect of changes in such factors was evident in the studies described in chapter 4, for example the propagation effect that was seen in the engineering analysis of the ethnographic data by Culverhouse (1996b).

The environment in which design takes place is a complex work domain as described by Carstensen and Schmidt (1993). That is, that the complexity has three sources: the work itself is often interrelated and interdependent, something that the industry is already aware of (see for example Andreasen et al 1997); the environment is typically dynamic and event driven; and cooperative work arrangements rely upon social interactions such as negotiation. Consequently such domains "*have an inescapable aspect of contingency*" (Carstensen & Schmidt, 1993). As chapter 4 discussed, Company A adopts a flexible approach to the design process and methods to enable the design teams to deal with such an environment. However the studies described in chapter 4 indicated that under certain conditions this approach did not function as intended.

These situations, when the design teams function ineffectively, have been described by Hosking and Morley (1991) and Pugh (1996), as vigilant and non-vigilant states[15] as discussed in chapter 2. To reiterate, the characteristics of a vigilant state are the serious consideration of more than one course of action and being sensitive to new information even if it is unpalatable. In contrast a non-vigilant state is characterised by satisificing and limited evaluation of any consequences. As Hosking and Morley discuss under certain conditions, for example when decisions need to be made quickly, can be reversed, and are of limited consequence, the speed of non-vigilant processing can be an asset. However according to Hosking and Morley, non-vigilant processing can be inappropriately applied due to aspects such as personal bias and social processes. They define three such instances of this occurring:

i) a strongly cohesive group[16] can evolve such that the group reacts in concert to issues and can "*engage collectively in defensive forms of information processing which mean they are no longer capable of confronting difficulties head on, in an active, open minded way*";

ii) when there are structural faults, that is the way in which the environment of design is configured, for example having an inappropriate team structure.

[15] This notion is founded upon the well documented social psychology concept of 'Groupthink' (Janis et al , 1970).

[16] Hosking et al (1991) describe group cohesiveness as the force attracting members to, and causing them to remain in, a group.

iii) when the decision makers are in "*provocative situational contexts*". These situations were clearly evident in the studies described in chapter 4, for example role conflict.

Hosking and Morley place the responsibility for structuring the design process, to encourage more or less vigilance as required by the task, upon design management. Clearly, the management of such an environment requires the ability to determine the current project situation as a whole, in conjunction with the social skills of the manager. Company A consider their current approach to be a '*sinking boat mentality*'. In other words, they are reactionary, if all appears well at present '*things are left alone*'. This '*management by problem solving*' approach to design was also noted by Anderson et al (1993c). The intention of this system is to be able to automatically detect that a project may be in such a situation and alert appropriate personnel.

5.2.3 Relevant system 3

Relevant system 3 concerned the provision of guidance upon appropriate management action to take in certain situations. This system deals less with the dynamic issues of the environment, although it could be invoked by them. Its concern is in providing project scenarios and recommended responses to the scenario. As discussed in chapter 4 due to the flexibility permitted in most activities, coupled with the non-homogeneous environment, it is difficult to capture and retrieve the experience of previous actions. Consequently, this information is not available as a resource to assist in guiding actions in potential problem situations. Relevant system 3 would provide a context driven guide to past actions and possible suitable actions. The need for such support concurs with the work of Cantamessa (1997), Hosking and Morley (1991), and Frakenberger and Pabke-Schaub (1997).

What is being provided by this mechanism are ways of enhancing and using the extant structure to meet the needs of the current situation, what Scott-Poole and DeSanctis (1990) would describe as 'Adaptive Structuration'. Their theory is based upon Structuration Theory (Giddens, 1989), which postulates that any organisation has a structure which is composed of rules and resources, which are fairly stable. A group can adopt and use the structure in anyway they deem necessary. In this sense the use of the structure becomes the system. Scott Poole and DeSanctis (1990) adopt this theory and apply it to groupware technology. They postulate an Adaptive Structuration Theory where the system emerges from the groups' use and adaptation of the structure available, and its affordance. In other words, the system emerges from the groups' use and adaptation of the structure available. The use is driven by the affordances of the structures and the context of the situation of use. Relevant system 3 should provide assistance upon such structuration.

5.3 Existing organisational paradigms : *a possible foundation ?*

The previous section identified three key relevant systems which encompassed the pivotal issues in the current design environment at company A. To summaries the requirements at this stage of the work an approach was required which enabled the synthesise of these three relevant systems. The approach needed to be dynamically responsive to changes in the situation of a project; facilitate the coordination and interrelationships of various information and situational factors (that is, both social and technological factors); and provide a way of viewing the current design project situation which enabled proactive action and consideration of the context of the project. The crux of this work was the synthesis of these requirements into a conceptual model of support.

There are a large number of paradigms for conceptualising and guiding structure at an organizational level, for example Scientific Management (Taylor, 1911), Contingency theory (Mintzberg, 1983), Organisational Learning (Nicolini & Meznar, 1995). Jirotka et al (1992) argue that the various paradigms available are not always alternatives from which systems designers can select to their liking, as many of the paradigms are often reconceptualisations of others. They argue that the appropriate paradigm for conceptualising the organisation should be revealed by utilising social science approaches. In other words, the paradigm should in part be stakeholder driven and will be dependent upon the level and context of enquiry. This section outlines various organisational macro level paradigms, which were considered for providing a basis at the micro level of the design team. The following draws heavily upon the work of Nicolini and Meznar (1995), Donaldson (1995) and Jirotka et al (1993).

Proponents of Institutional Theory (for example Powell & DiMaggio, 1991) believe that the norms of equivalent institutions cause organizational structures to become similar, in other words a process of imitation occurs. The key principle being that organisational ideas are legitimised by the state and professional bodies; thus the ideas become '*embodied in language and symbol*' (Powell & DiMaggio, 1991). However, Donaldson (1995) argues this rarely occurs except where the organizational structures may sometimes be *state* driven. In addition it does not consider social issues and as Murray (1993) argues, whilst many companies in a given arena will have similar patterns of working their social processes will be the key difference between organisations and must be considered. Consequently, institutional theory was considered to be inappropriate in the present work.

The Organisational Economics paradigm (for example Williamson, 1985) comprises two theories which view control of management as the focus for structure. These being Agency theory and Transaction Cost Theory. Agency Theory views managers as having interests which diverge from the 'owners' of the organisation. Whilst Transaction Cost Theory views economic and market control breaking down due to management being removed from these pressures. For example, middle management can pursue their own goals because of the cushion that is provided by senior management and the workforce which shields them from direct contact with economic forces. This paradigm emphasises the need to control, it does not recognise the need for 'organic' structures where mutual adjustment of work is necessary. As discussed in chapter 4, and later in this chapter, mutual adjustment is sometimes required to reach consensus and progress a project. Further, the rationale is less valid when applied at the project level of an organisation where middle management (for example, Project Leaders) become the buffer between senior management and the design engineers.

Resource Dependency Theory (for example Pfeffer & Salancik, 1978) has been described as being extra and intra organisational. It proposes that organisations rely upon their resources to survive. Therefore they should focus upon controlling their environment to ensure their resources are delivered. This is a more politically driven theory than the preceding two, '*giving primacy to maintenance of autonomy by the organisation*' (Donaldson, 1995). Whilst this idea of considering the resources is obviously important, it presumes that the organisation is able to exert control over its environment. However, a high degree of control over the environment is unlikely, even at a project level where resources are rarely stable or certain as illustrated in chapter 4. Therefore it would seem appropriate to find a balance between adapting to the environment and attempting to influence resources, rather than expect to control them.

Population-Ecology Theory (for example Hannan & Freeman, 1989) can be considered to be a metatheory. It is biologically based on a cycle of variation, selection and retention of groups of organisations. The belief is that focus should be placed upon new organisational structures in a given arena, which survive. The rationale behind this belief is that managers have no control over ecological factors, for example the number of competitors. Therefore through examining 'births' of new organisations which survive, and copying their structure, the organisation will be adapting to its environment. Essentially, the belief is that things that do not 'fit' the environment do not survive. This paradigm does not assist in proactive action to help a project adjust to the highly dynamic environment of design. Moreover this idea of learning from success and failure is incorporated in other paradigms such as Organisational Learning discussed below.

Contingency theory (CT) is a classical organisational viewpoint (see Burns & Stalker 1961, Galbraith 1977 & Mintzberg 1983), which has been characterised as stressing that "*it is management's responsibility to obtain a good fit between the tasks, the environment in which the tasks will be performed and the style of management*" (Jirotka et al, 1992). CT may be considered to be management positive and task oriented (Jirotka et al, 1992). As Donaldson (1995) discusses adopting CT assumes the following two points: that managers have the ability, given appropriate mechanisms and resources, to be able to coordinate the organisation; and that the needs of the organisation can be based around the tasks that are required to successfully produce their products. This concept moves the project manager from a driver to a facilitator, becoming an *environment builder* (Tampoe & Thurloway, 1993), that is a coordinator rather than a controller. CT proposes that based on a number of 'contingent factors' appropriate organisational structures should be adopted. Contingency management has been criticised for not considering concepts from the preceding paradigms, for example considering the management of resources and for being too management positive.

The contemporary offering is the Organisational learning (OL) paradigm. However, this paradigm is currently still establishing its focus (see Dodgson, 1993 & Tsang, 1997). Nicolini and Meznar (1995) describe OL as currently having three focuses : environmental alignment; distinguishing between individual and organisational learning; and the need to incorporate the four contextual factors of culture, strategy, structure and environment in the learning process. Tsang (1997) would add that a dichotomy between descriptive and prescriptive research also exists. Dodgson (1993), and Tsang (1997), describe a common underlying theme as the acknowledgement for the need to improve efficiency and adaptability, particularly at times of change when great uncertainty exists; that is, the ability of an organisation to understand its competitive advantage. This paradigm appears to capture the essence of the requirements identified at the beginning of this chapter. However, it lacks a clear and accepted definition of application (Tsang, 1997), which as Osigweh (1989) states is vital when building on a theory.

Of the existing organisational paradigms outlined above, only organisational learning and contingency theory consider the flux of an interrelated environment in terms of social and technical factors. Contingency theory (CT) is an example of an concept which has been subsumed by another paradigm, namely by the organisational learning (OL) paradigm. That is, the first of the three focuses described by Nicolini and Meznar (1995) above, refers to a form contingency theory where an organisation aligns itself to its environment to remain competitive and innovative. However, in OL the theory is extended to encourage a learning cycle to develop adaptation to situational changes. At this stage of the work, adopting a management positive perspective, CT offered a basis for developing the support required as outlined in section 5.2[17]. As Donaldson (1995) argues, the deficiencies of contingency theory could be alleviated by incorporating aspects of the alternative paradigms outlined above. For example, Resource Dependence theory could be utilised through the use of multidisciplinary teams. Population-Ecology Theory could be applied at a company level to review projects and evolve best practice. Above all it is important that the approach acknowledges that is must not be applied in a deterministic and reificating manner.

In terms of labelling this work, it could be construed as a form of Organisation Learning. However at the present time it would seem more informative to describe the work as adopting a dynamic contingency approach. As the work progresses further and OL matures it is likely that the concepts described in this thesis could be considered as adopting aspects of the OL paradigm.

This approach of considering the implications of situational factors is supported by the recently propounded cognitive science paradigm. Within the field of cognitive science a debate has emerged concerning the virtues of 'situated action' versus 'symbolic human cognition'. Whilst it is not the purpose of this thesis to resolve this debate, indeed as Norman (1993) states "*They emphasise different behaviours and different methods of study. They do not conflict*", the reasoning of each approach is described to illustrate how the situated action paradigm supports the concept of the rationale proposed in this work.

The symbolic human cognition model is the more traditional information study approach applied in cognitive science. Norman (1993) characterises it as "*studies of symbolic processing ...[that] focus entirely upon the processing structures of the brain*

[17] As the project progresses it is envisaged that the other themes from the OL paradigm would become important. As such this work could be viewed as OL based but starting from one theme of OL, namely

and the symbolic representations of mind". More recently a new paradigm has emerged, that of 'situated action', two of its key proponents being Suchman (1987 & 1993) and Lave (1988). In contrast with the symbolic approach this paradigm may be described as focusing upon the way in which an environment is structured and how this environment may constrain or guide human behaviour within it. The emphasis of these two approaches therefore differs. The symbolic paradigm focuses upon the importance of internal cognition, whereas situated action highlights the importance of more environmental factors such as history, social interaction, and culture. Norman (1993) and Agre (1993) succinctly differentiate these two approaches as being cognition in the head (*symbolic*) and cognition in the world (*situated action*). Clancey (1993) characterises one of the intentions of SA as seeking "*the value of planning and representations in everyday life, rather [than] seeking to explain how they are created and used in already coordinated action.*" Such an aim fits the design environment, particularly during the conceptual phase, where flexibility and 'articulation work' (Schmidt & Bannon, 1992), are necessary to complete projects. As such Suchman (1987), an anthropologist , argues for the use of techniques such as ethnography to reveal such information :

> "*insofar as actions are always situated in particular social and physical circumstances, the situation is crucial to the action's interpretation. ...the contingence of action on a complex world of objects, artifacts, and other actors.. is seen as the essential resource that makes knowledge possible and gives action its sense.*" (p. 178).

Suchman argues that the virtue in this view is that vague plans are not a problem, that they are merely contingent upon the elements of the situation. As discussed in chapter 4, plans are heavily embedded and dependent upon the situation.

This section has suggested that contingency theory, if its limitations are acknowledged and considered, may provide a basis for developing a framework for the complex process of fitting responses to patterns of indicators; an idea supported by the situated action paradigm. To explore this idea further we need to examine contingency theory in more depth.

5.4 Contingency theory : *a basis*

Contingency theory (CT) has generally been used macroscopically to describe whole organisations and long term structured shifts, say over several years. For example, Mintzberg (1983) proposes that an organisation can decide upon the appropriate structure for their business based upon the following four 'contingency factors' :

- The age and size of the organisation;
- The organisation's technical system (that is, whether it is regulating, sophisticated, automatic etc.);
- The organisational environment (that is, stability, complexity, diversity, hostility etc.);
- Organisational power relationships (that is, control which is external to the organisation, personal needs of staff, fashions etc.);

Mintzberg offers a framework which emphasises coordination based upon these factors and utilising the following five mechanisms :

- Mutual adjustment: the coordination of work through formal & informal communication;
- Direct supervision: individual(s) take responsibility for the work of others;
- Standardisation of work processes: contents of the work are specified or programmed;
- Standardisation of outputs: results of work can be clearly specified;
- Standardisation of skills: knowledge and training required for process is known.

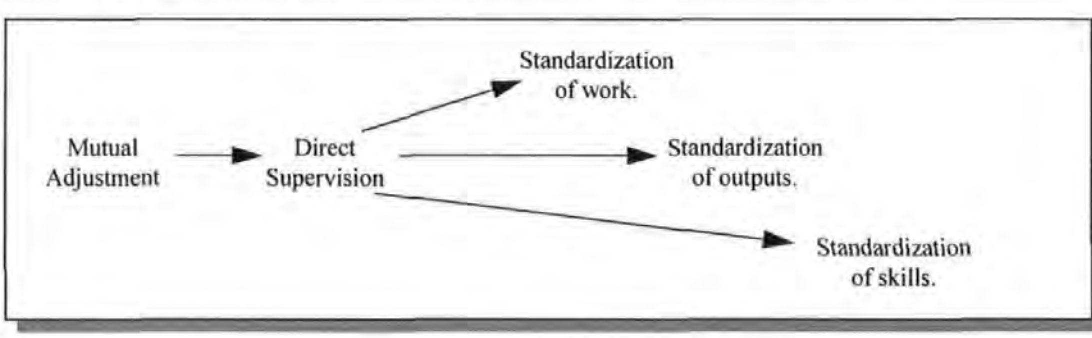
These mechanisms are fairly self explanatory, with the exception of mutual adjustment. Mutual adjustment refers to the formal and informal social processes which exist in any organisation. Mintzberg suggests that the methods are interdependent, in that the formal processes will normally evolve from informal methods. He classifies the methods of achieving MA as being either liaison devices or positions. The following table illustrates examples of some of these methods.

Methods of mutual adjustment

Liaison Devices		***Liaison Positions***	
Project Teams	Formal	**Technical Gatekeeper**	Formal
Task Force	Formal	**Integrating Manager/Product Champion**	Formal
Meetings	Formal	**Gatekeeper**	Informal
Grapevine/Storytelling	Informal		
Shared Work Area	Informal		
Friends/Cliques	Informal		

Mintzberg describes how the reliance upon each particular coordinating mechanism may change as an organisation grows. For example, in a small company of one or two employees, the use of mutual adjustment is the most convenient and satisfactory mechanism for coordination. However, if the company were to expand it would find it increasingly difficult to maintain coordination of a larger number of staff if relying purely upon mutual adjustment. Consequently the emphasis for coordination would shift to other mechanisms, for example direct supervision. Mintzberg represents this change in the following diagram, Figure 5.1.

Figure 5.1, The progression of coordinating mechanisms (after Mintzberg, 1983).



Mintzberg characterises different types of organizational structure, which align with their means of achieving coordination. The following lists the key characteristics of three of these structures :

- Adhocracy: Dynamic environment, dependent upon mutual adjustment.

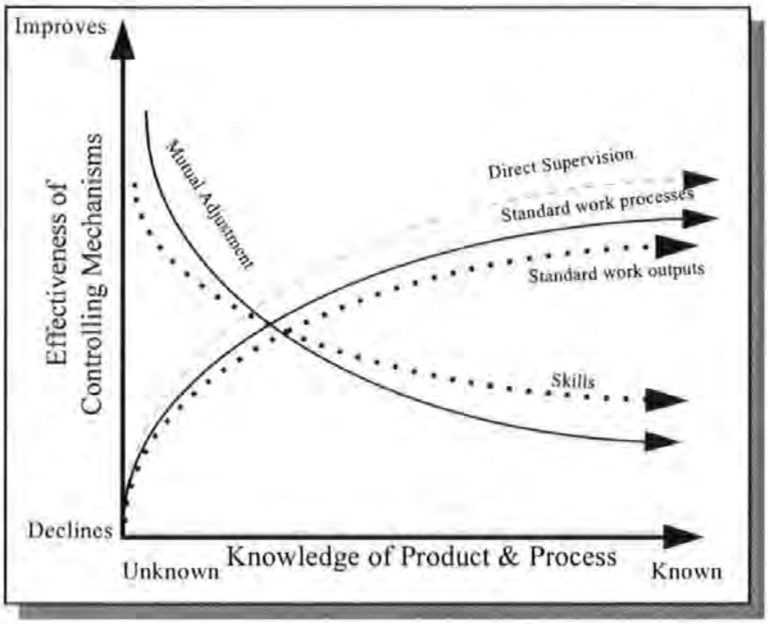
- Professional Bureaucracy: Relatively stable environment, relies upon standardisation of skills.
- Machine Bureaucracy: Well formalised, reliant upon standardised work processes and output.

The idea of an organisation's structure being suited to its ambient circumstances has been discussed by many authors (see Burns & Stalker 1961, Jirotka et al 1992, Galbraith 1977). Whilst the terminology may vary, for example a machine bureaucracy may be described as a 'mechanistic' structure, the essence remains the same. That is, that dynamic circumstances can best to dealt with within an adhocracy or 'organic' structure, whilst static environments are better suited to a mechanistic structure[18].

From the studies described in chapter 4, it was apparent that the change of emphasis (illustrated in Figure 5.1) upon increasingly formal coordination mechanisms, may also be seen to take place at a micro level. That is, at a project level within an organisation. Given that an organisation's product and process experience normally evolve, for a given product, through a sequence of projects, it seems likely that the emphasis on each coordination mechanism may change as the knowledge of a product and its related design process increases, as illustrated below in Figure 5.2. In other words, in the case of a design project, its position on the continuum of possibilities for its management and coordination is likely to be governed by factors such as the degree of new knowledge involved.

[18] For the remainder of this work we shall adopt the term mechanistic rather than machine bureaucracy, as we feel this better describes the characteristics of the environment.

Figure 5.2. An approximation of the change in coordinating mechanism emphasis



The nature of these micro-organizational structures corresponds to the shift in emphasis of the coordinating mechanisms of design projects, as an organisation's knowledge of a product and processes grows through a sequence of projects. For example, when a product is new to an organisation the project which initially develops the product could be categorised as an 'innovative project', where due to the high level of unknown information mutual adjustment would prevail as the dominant mechanism. In later projects, to modify existing functionality of the product for instance, a project might be described as 'variant', in which the level of knowledge has increased and the mechanisms for achieving coordination have shifted as illustrated in Figure 5.1 above. As discussed in chapter 4, within a design project changes in circumstances such as the adoption of a new tool or technology may lead to the need for changes in coordination mechanisms over short time scales such as weeks or days. If we were able to characterise projects, as their circumstances change it would be possible to target and support the most appropriate coordinating environment.

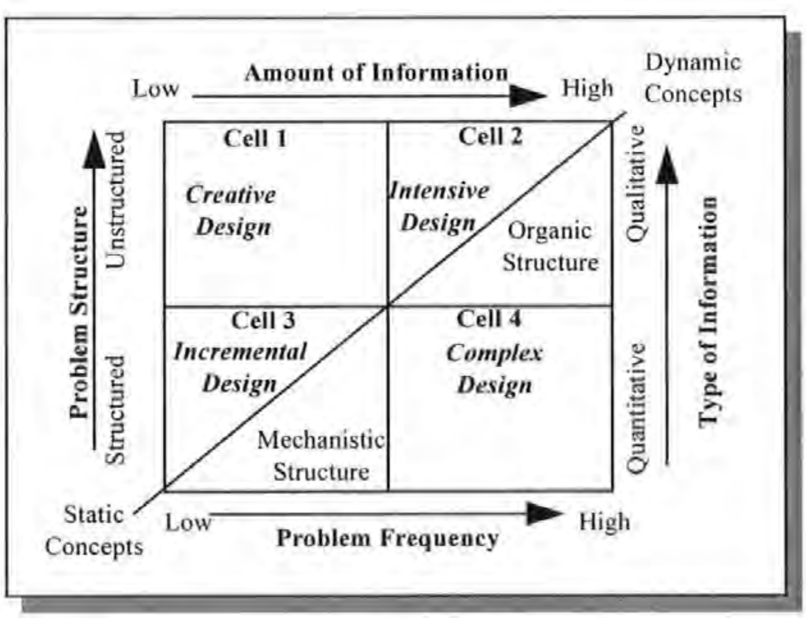
Whilst the majority of studies have focused upon applying CT at the organisational level, research has also been conducted at a work group level. Fry and Slocum (1984) tested a contingency model of work group effectiveness within police organisations based upon technology and structure. Their findings indicate that effectiveness is multidimensional and measurement cannot be based upon simple criterion. In addition they suggest that the technology-structure configuration adopted by organisations may vary dependent upon their type. Similarly inconclusive findings arose from Bays' (1994) work. Bays conducted a study focusing upon applying contingency theory to 'align information systems development activities to line business unit needs'. The work was based upon three components of contingency theory : structure, effectiveness and uncertainty. The study suggests that traditional structural contingency theory is inadequate in 'organising the IS function to optimise IS product and service quality'. However, the effectiveness variable was based upon the measurement of the 'perception of quality', which is highly subjective and perspective based. Bay's acknowledges this weakness in the work when she states that 'judgements of effectiveness involve questions of values'. Bays concludes that the basic premises of traditional contingency theory being applied at a work group level remain uncontested.

Whilst Bays' and Fry and Slocum's work proved to be inconclusive, both regard contingency theory as a potential model to adopt at the micro level of work groups. In addition, studies by Van de Ven, Delbecq and Koenig (1976) and Argote (1982) concluded that the most effective means of communication and coordination were affected by the level of task uncertainty and workflow interdependence, in accordance with the model of coordinating mechanisms presented above and discussed in section 4.2.

A common conclusion of research at the micro level has been that contingency factors are difficult to make generic for use in other domains (Fry & Slocum, 1984). All of the studies discussed above have taken place in different domains, from systems development to police forces, and whilst their findings are of relevance to our level of interest they did not focus upon an environment similar to design. More pertinent work has been conducted by Slusher, Ebert and Ragsdell (1989) in the mechanical engineering domain and Adachi et al (1993) in electronic manufacturing.

Adachi et al (1993) present a matrix for organising concurrent product development teams based upon a number of organisation factors, for example competition intensity. Their focus, whilst on the product initiation stage, confirms the value of considering this concept during the design stage. Slusher et al (1989) present a contingency model for engineering design management. They state that designs fall within one of four cells. These being creative, intensive, incremental and complex design. They suggest that management structures should range on a continuum from organic (an Adhocracy), to mechanistic (a Machine Bureaucracy). For example, the most appropriate structure for an intensive design being organic, whereas an incremental design would require a mechanistic structure. They identify four contingency factors for assessing the position of the design within their cell structure: problem structure, amount of information, type of information and problem frequency. Figure 5.3, below shows the relationship of these ideas.

Figure 5.3, Contingency model of engineering design management (after Slusher et al 1989)



There are two main criticisms of Slusher et al's model. Firstly, as Hosking and Morley (1991) rightly suggest, design projects typically contain both static and dynamic concepts[19], but to varying levels at times throughout the project. Slusher et

[19] Pugh (1996) defines Dynamic and Static as boundaries of a design continuum dependent upon the level of innovation involved in a design, for example Static new designs are based entirely upon existing design solutions.

al's classification of designs, involving either static or dynamic concepts, is too simplistic. Hosking and Morley (1991) state that "*it is clear that some kind of contingency theory is required, since different kinds of creativity are required when concepts are static and when they are dynamic*". However as Jagodzinski et al (1997) discuss, the model is a classificatory scheme, designed as a typology to allow one to slot design problems into boxes, rather than attend closely to the design process and moment-to-moment shifts in task demands and appropriate management responses. This criticism also applies to Tampoe and McDonough's (1992) work, who believe that different management styles should be adopted based upon the product strategy. They characterise the following three types of strategy : breakthrough, me-better, me-too. Where 'breakthrough' would be an innovative product, and 'me-too' would be a copy of a competitor's product sold at a lower price. However, the concept of adopting an organic or mechanistic structure, dependent upon appropriate contingency factors, is accepted as being a useful concept (see Hosking and Morley 1991, Galbraith 1977).

Secondly, due to their information processing based perspective, Slusher et al describe the design process as 'Managing design is a process of managing information flows'. However, as the studies discussed in chapter 4 and others work (see Cross & Cross 1995; and Frakenberger & Pabke-Schaub 1997) show, design management must also involve the management of people and their interactions. As Jagodzinski et al (1997) discuss, if the Slusher et al model is expanded (for example, adding a design team integration dimension of low integration-high task orientation to high integration-low task orientation), a more complex response envelope becomes possible. Thus appropriate management structures can be associated with the various combinations of these settings.

Past contingency theory, at both the micro and macro level, stops at a rather static view of the world. The exception is the extension of the concept as part of the Organisational learning paradigm as discussed above in section 5.3. The rich picture and relevant systems which evolved form this work suggest that a more dynamic and responsive approach is required, as discussed in the following section.

5.5 A dynamic contingency approach : *a way forward*

In contrast to Slusher et al's relatively static interpretations of contingency theory section 5.2 Key relevant systems from the rich picture : *the aim*, indicated that a dynamic contingent approach to design management is necessary in order to support the design process. As discussed in chapter 4 and by Jagodzinski et al (1997), managers have problems which unlike technical difficulties that respond to creative solutions, are recurrent and sometimes intractable, and have to be addressed repeatedly throughout the product development process : problems that have to be managed rather than solved. The management of these problems is complex as the design environment requires coordination of both social and technical issues :

> *"different tasks exert different kinds of demands, for example the different kinds of social processes that need to take place for a team to be effective. Additive tasks require each team member independently to make their best effort and to combine the results of this work with other team members to produce a team product. This would correspond to different team members being assigned responsibility for different subassemblies, working independently on these, and simply combing the results with only limited mutual adjustment. Other tasks exert more complex interactive demands. In particular, a disjunctive task requires team members to decide between alternative design solutions, and this places a premium on social interaction and mutual adjustment. If communication between engineers is impeded, this cannot be achieved. The task facing design management is therefore to maintain a complex and dynamic equilibrium over the course of the project and steer the design team on a satisfactory trajectory by choosing and implementing tactics which suit the moment."*
>
> (after Jagodzinski et al, 1997)

This continual state of flux of design projects is confirmed by Anderson et al (1993c). They describe how organisational exigencies affect design activities and design train of thought, as considerations for design are often subordinate to organisational priorities. As a consequence designers and design projects are always in a state of flux, what Anderson et al describe as the '*organisational facts of life*'. Their recommendations call for tools to support this dynamic environment which is affected by a 'multitude of exogenous forces'. This concurs with the rationale for the approach that has been discussed here, and with Hales (1993) who calls for a "*match of design team composition to project requirements in each phase of the work*". By providing a guide to suitable team and social structures, and the appropriate coordinating mechanisms for a given project situation we can support the issues discussed in section 5.2. To achieve this, support must be based upon appropriate indicators, as discussed in the following section.

5.5.1 Influencing factors : *the drivers*

Hales (1993) discusses a key problem from a design manager's perspective being "*that so few of the many variables [from a design team] can be quantitatively measured, and in fact the only simple measure is work effort in hours*". He discusses the factors that effect a design project at two levels, those internal to the project and those external to the project. For example, social, legal, random, and technological influences internal to the project; and market, resources and customer influences external to the project. Hales creates this '*big picture*' of the project through the completion of a series of checklists. His approach requires user intervention and monitoring, which makes the maintenance of such a resource an unfeasible task for engineers and managers working in such a highly pressurised environment, particularly when considering the shifts between vigilant and non-vigilant states. For example, the studies discussed in chapter 4 indicated that project plans are unlikely to be updated in real time.

Whilst the mechanism proposed by Hales may not provide viable support to the design environment, the factors that he identifies are consistent with those determined as being of key interest by the studies discussed in chapter 4 and other pertinent work. Changes in a number of factors identified in the UoP project (see Culverhouse 1996b and Reid 1997a), and that of others for example Slusher et al (1989), Frakenberger and Pabke-Schaub (1997), and Hales (1993), can provide indication of significant changes in a project's situation. The following lists some key factors which have emerged as being potentially significant from these studies :

- Design Knowledge : the existing knowledge of the whole design and its component parts may be measured using Culverhouse's Four Path Model (1993) which can classify designs as repeat, variant, innovative or strategic;

- Process Model, Method(s), and Tool(s) Knowledge : the amount of experience of the adopted process model, process method(s), and process tools;

- Project Intent : for example, whether the project is exploratory or a fixed goal as discussed in chapter 4. In many ways this factor is intertwined with what French (1985) describes as a design's philosophy. Which he states is the basis from which a few key decision are made, arising from a few important considerations, out of which many consequences flow. He argues that frequently this philosophy only emerges when the scheme is complete;

- Size of Team and length of time together as a team;

- Team structure: i.e. multidisciplinary, peers, hierarchical, etc. a factor which Frakenberger and Pabke-Schaub's (1997) work also identified as important;

- Management style: i.e. adhocracy, authoritarian, etc. as discussed in this chapter;

- Access to information: by information we mean data held in a document or on-line etc. This factor was determined as important by both Slusher et al (1989) and Frakenberger and Pabke-Schaub (1997);

- Access to knowledge: by knowledge we mean interpreted information held by people;

- Urgency: the pressures due to time constraints. It was evident from the studies discussed in chapter 4 that the duration of project is prone to change. Cathomen (1995) identifies this factor as typically being missed when applying contingency theory;

- Coherency of mental models: this is the extent to which the project personnel have a common understanding of the current project situation. As Rouse (1992) discusses mental models help to form expectations and explanations of a situation and are of particular importance in team performance in complex systems. This factor is significant if say the group's opinion changes or a minority of the group have drastically different opinions to the majority. Rouse's (1992) studies of mental models in team performance in complex systems have shown clear correlation's between degrees of team co-ordination, communication, and performance. For example, they predict that team members who share mental models will generate similar explanations for observed phenomena, and will be more resilient to stress effects since they require less explicit coordination;

- Morale: from the time series analysis of the ethnographic data (see Reid et al 1997b) this factor appears to be important when events occur within a project, something which the engineers termed the 'feelgood factor'. This view is supported by the work of Frakenberger and Pabke-Schaub (1997) from studies in the mechanical engineering domain. Frakenberger and Pabke-Schaub found morale to be one of the most important influences on an individual's performance. Consideration of morale's influence upon design is echoed by the arguments of Hales (1993), who views factors such as motivation as key indicators of a project's situation. It is the capture of such information that has proven difficult;

- Business aims : a key factor which influences strategic or philosophical choices in design is the company's business aims (EDD'96 & Lawson, 1990). As discussed in chapter 4, company A currently use a number of Hoshins, the most important currently being Time-to-Market. However other high profile business aims exist which can also guide the choices made regarding approaches such as Design For Manufacture or Design For Engineering. For example, ensuring that future projects can reuse design components may increase the time to market for the current product, but it is known that the component(s) will be used in a future project.

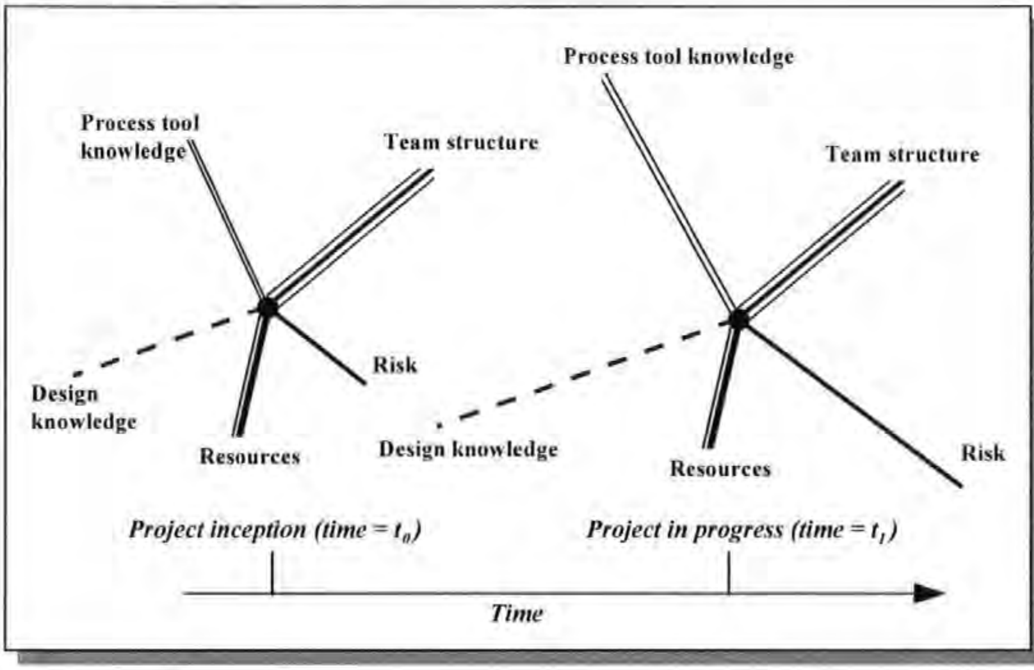
5.5.2 What could be gained from such an approach ?

The beginning of this chapter introduced three key relevant systems which were determined to improve the current situation. The crux of this work was stated as the development of an approach which synthesised these three systems. This section illustrates the way in which the approach outlined in the previous sections could support this synthesis.

It is envisaged that the dynamic contingency approach could serve three purposes. First, at a static point, for example at the planning stage it could be used *strategically* to plan the project. Secondly, whilst the project is in progress it could function dynamically indicating the need for *tactical* shifts and impromptu structures. Thirdly, the system could provide a mechanism for identifying issues which were the "*result of recurrent interaction*" (Clancey, 1993). Company A estimated that 14% of their project time was lost to due to 'technical hitches' on one project. Without storing a contextual record of these occurrences it is difficult to determine their cause. Clancey cites the example of a computer system at Stanford University which crashed every October when the first rains of the season began. This was traced to the fact that the initial increase in moisture effected the phone lines to Santa Cruz, which in turn resulted in the system being swamped with "*control-C's*" causing the system to crash. This type of problem is likely to be particular to the environment and unlikely to be resolved until a number of such incidents happen; and only then once the data regarding the events is available.

Due to the multidimensional nature of this approach star charts proved to be an easily understood representation of this complex picture of the design environment. Figure 5.4 illustrates the way in which influencing factors might flux during the course of a project.

Figure 5.4, the flux of influencing factors.

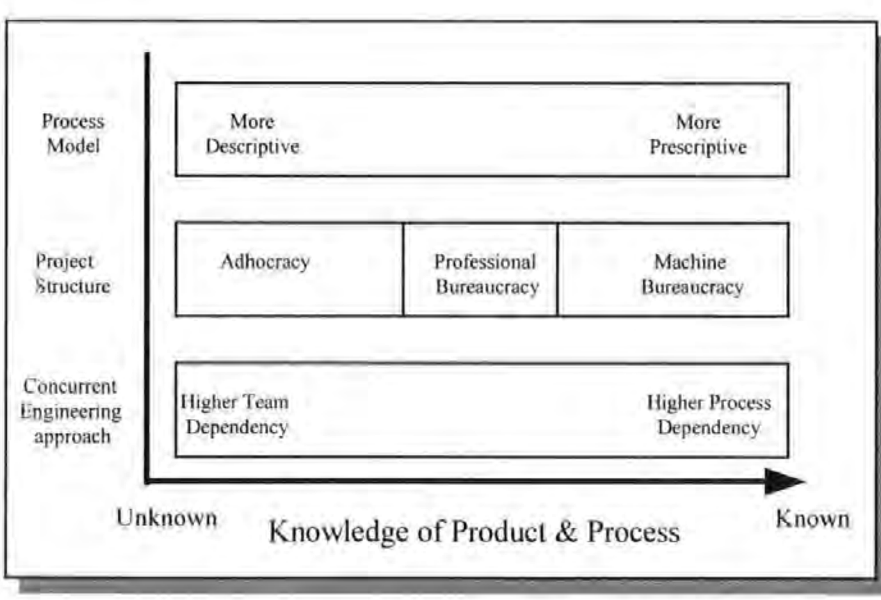


In this example at t_0 using the Four Path Model (Culverhouse, 1993) the design is assessed to be a repeat design. Applying Mintzberg's (1983) organisational structures discussed above, it may be considered that a mechanistic project structure is the most appropriate. During the interval between t_0 and t_1 it emerged that a large amount of additional design knowledge, and additional process tools were required. The combined effect of these changes is the increase in the amount of risk being accepted for continuing with the project in its current state. The design risk has increased and the design is now considered to be innovative, management action is therefore required (for example changing to an adhocracal structure). This different team structure may require new roles, for example to facilitate communication (Hales, 1993).

This example illustrates a dynamic alert and the potential to use the approach as a resource for guiding replanning. This situation occurred in the studies discussed in chapter 4, when there were long periods of instability and delay to projects because the team were working in a non-vigilant state. That is, the project required reconceptualising but instead it was 'defended' until it became unavoidable that the project was replanned.

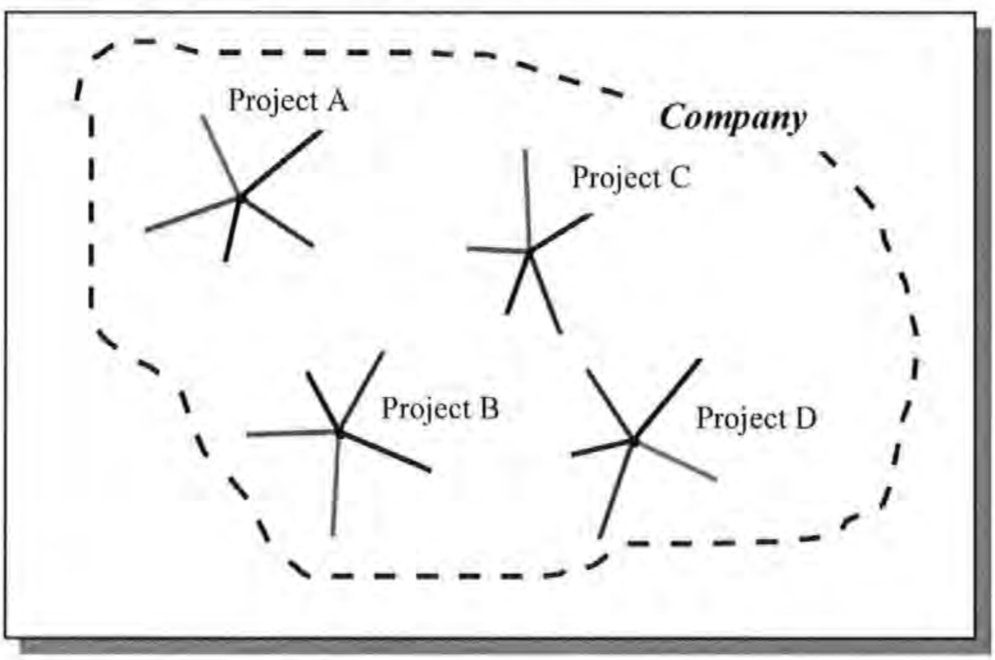
This categorisation of project situations may also assist other approaches such as the utilisation of CE techniques. At company A the application of CE is likely to increase as products become more sophisticated, rather than the increase in the designs functionality per se. In other words, chips are evolving from the requirements for one user, to becoming a generic chip, to a programmable chip. This necessitates the integration of hardware experts, software experts, design kit developers, etc. Hence the management of such projects is likely to become increasingly interdependent and complex. Hybs and Gero (1992) cite the previous lack of attention to the environment of the design, by which they refer to the artefact of which the design is a component for example a mobile phone or a washing machine, as a key problem in previous design process models. As discussed in chapter 2, the idea of applying the CE approach which is most suitable for a given situation is supported by Race et al (1994). Race et al's three year study of CE implementation focused upon the multidisciplinary team approach. One of their findings was that the team development based approach proved to be inappropriate for what may be termed 'repeat' projects. Figure 5.5 below, compares CT with design process models, as discussed in chapter 2.

Figure 5.5. A rough comparison of management approaches & structures.



Anderson et al (1993b) discuss how organisations can afford knowledge which enables employees to function effectively within the organisation. One aspect of which is the ability of members of the organisation to understand what is going on around them. This, as Anderson et al discuss, is often achieved through social constructs. However it may be further supported through this approach, particularly for multisite projects, where the current status and changes in the various situational factors can help to shape the sense of the project's environment. As well as providing support at a project level, this approach may be able to assist in generating a company view of the status of its current projects. As shown below in Figure 5.6.

Figure 5.6, a company view of the status of its current projects.



The concept of a dynamic contingency approach proposed in this chapter utilises situational factors to provide managers with metaknowledge on resolving mismatches, something which is currently unavailable. However, the implications of such a potentially flexible environment are far reaching. For example, changing a project team structure will effect the costing of projects. Obviously the skills required from the manager shift; Cullin (1996) reports that a manager's time is split 20% technical issues, 80% human issues in a CE structure. Perhaps more important are less immediate issues, as Flemming and Koppelman (1996) discuss projects often span years, but funds are typically authorised per fiscal year. Multidisciplinary team approaches tend to accelerate functional efforts to earlier stages of a project. Thus whilst the overall cost of a multidisciplinary project may be less than a sequential approach, the early indications may be that the multidisciplinary project will be increasing costs. The implications of introducing such a concept will require further study considering such issues.

This reconceptualisation of contingency theory can be viewed from an organisational learning perspective. The levels of 'learning' discussed here can be mapped against the three-fold typology of learning first presented by Argyris et al (1978). Argyris et al state that organisational learning "*involves the detection and correction of error*", and describe three levels of this occurring:

Single-Loop learning	an error detected and corrected permits the organisation to carry on its present policies or achieves its present objectives
Double-Loop learning	an error is detected and corrected in ways which involve the modification of the organisation's underlying norms, policies and objectives
Deutero learning	the organisations members learn about previous contexts for learning. They reflect on and inquire into previous episodes of organisational learning, or failure to learn. They discover what they did that facilitated or inhibited learning, they invent new strategies for learning, they produce these strategies, and they evaluate and generalize what they have produced

(*adapted from Argyris et al 1978, page 3*)

This concept illustrates the point made in section 5.3 Existing organisational paradigms : *a possible foundation*, that this work could be construed as falling within the organisation learning paradigm, but as argued previously the support's basis stems from contingency theory. As any future work evolves, the support becomes further developed, and the OL paradigm matures, this demarcation may be more easily resolved. However, for the present the ideas discussed here will be offered as a dynamic contingency approach.

5.6 Conclusion

This chapter has discussed the rationale for supporting the management of design projects through the use of a dynamic contingency approach. Where for example, the most appropriate coordinating mechanisms are utilised dependent upon the current situation of the design project. Past interpretation of contingency theory has taken too static a view of its implementation. This work has suggested that through extending the theory and considering the benefits of other organisational paradigms the key relevant systems derived from the rich picture may be supported and synthesised into a conceptual model of support.

Essentially the approach aims to guide the development of an environment which better supports the activities of managing a design project at the early conceptual stage. Many of the ideas and approaches discussed are well known within the industry and are to a certain extent carried out, either consciously or unconsciously. The intention is to enhance the current design environment by supporting and communicating required actions appropriate to the type and context of the project. The basis for guidance are the situational factors in conjunction with the socio-technical system discussed in the next chapter. The nature of the research method and type of environment influenced the resultant conceptual model, but as Jirotka et al (1992) state " *[cscw] designers will find it increasingly hard to avoid becoming involved in debates about how organisations should most properly be conceptualised*". The following chapter discusses the exploratory prototype that was used to develop these requirements and assess the potential value and viability of this approach.

I hear I forget,
I see I remember,
I do I understand.
(anon, Chinese proverb)

6. EDAPT : an exploratory prototype

6.1 Introduction

This chapter discusses the *Engineering Design Ally for Project Teams* system (EDAPT). Whilst this chapter is weighted towards the technical elements of EDAPT, it should be noted that EDAPT is a socio-technical system, as described in chapter 3. The social aspects of the system are typically emergent. Examples of some social issues such as working practices and the context in which the system may be employed were discussed in chapter 5. The further development and definition of the social aspects of the dynamic contingency approach will be delivered in the final conclusions of the longitudinal psychological study. Within the present work examples of these social issues are used to illustrate the need, and provide the context for, elements of EDAPT.

The evolution of EDAPT can be seen to comprise three clear phases: two conceptual models of support and an exploratory prototype. Conceptual model v1.0 addressed the initial issues revealed in the early stages of the work. Conceptual model v2.0 constituted a refined version of v1.0 combined with software agents. At this stage of the research, discussing a system of this complexity via intangible media such as specifications and diagrams with a development group proved difficult, especially via group debate. In particular, as Jacobson (1992) discusses it is difficult to represent the flows, interactions, and interfaces using purely paper based media. This problem is compounded if the model is to be evaluated autonomously 'on site', as the system builders are often needed to provide the linkages between concepts. Consequently the exploratory prototype was developed. The prototype was capable of illustrating the possible functionality of key components of the system in a tangible, or to use the users terminology *'touchy-feely'*, format which could be used autonomously by the stakeholders for evaluating requirements.

The development of a prototype system, which Clancey (1993) neatly describes as "*more like architectural sketching than laying bricks in concrete*", may be regarded as a method of buying information about the perceived requirements (Boehm, 1984). It serves to capture and validate the requirements, and as a by-product[20], potential methods of achieving them. The prototype was populated using a case history of one of the design groups studied. Thus the users were provided with a tangible and recognisable mapping of the system which related directly to the target environment.

The following section describes the development of the two versions of the conceptual model of support. The remainder of the chapter discusses the framework and development tools employed in the prototype's development, and then finally the components of the system are described. This chapter does not critique the system or discuss the concluding evaluations, as these topics are dealt with in the following chapter.

6.2 The early conceptual models

Conceptual model v1.0 focused directly upon addressing the initial issues depicted in the rich picture discussed in chapter 4. That is, it involved the development of components which supported the requirements first identified in the rich picture and the interdependencies between them. The model was not envisaged as a rigid, prescriptive straight jacket into which all design projects must fit. Rather, it was seen as a flexible collection of components surrounding a database of organisational knowledge. The intention was that the system would be used selectively and adapted to meet the needs of particular projects.

At this stage of the work pertinent theories were incorporated into the model to assist in developing appropriate support. The model comprised the following types of component which align with the design management needs described by Dym (1991), Katz (1985), and Hosking and Morley (1991) :

[20] Whilst the aim of this work was not the detailed definition of a system, an inevitable by-product of the evaluation of the prototype has been the outline of a potential systems architecture.

- Software tools to provide support for activities such as risk management and project control;

- Databases and access mechanisms to support the provision of organisational knowledge;

- Working practices which reflect first those social mechanisms which have offered improvements in facilitating the design process, and secondly the availability of software support in the areas identified. For example, anonymous peer reviews of work and working groups to develop and refine roles.

This conceptual model was paper based and evaluated utilising pluralistic walkthroughs, as discussed in chapter 3. Whilst the model of support concurs with that proposed by Andreasen et al (1997), from the evaluations and further ethnographic findings it became evident that the components addressed the users' immediate concerns, but that due to the complexity of the situation it did not adequately address the problems which occurred when the PL and engineers were placed under increased pressure, for example they were unable to monitor the many interdependencies of their work.

As discussed in Jagodzinski et al (1996a) a key issue which emerged from the evaluation of the v1.0 conceptual model was the need to drive and coordinate large and small grain communications between tools, information repositories and users in order to accommodate the dynamic nature of design team activity as described in chapters 4 and 5. To meet this need, the concept of software agents presented a possible mechanism for performing such functions. This approach has also been adopted by Tan et al (1996) for supporting the planning of concurrent engineering design projects, and in the Lockheed SHADE project (see Gruber et al, 1994 and Olsen et al, 1994). This the was key development from v1.0 to v2.0 of the conceptual model.

Within the v2.0 conceptual model a software agent can be considered to be a surrogate for a person or process that fulfils an identified need or performs a particular activity. This surrogate entity provides operational capabilities that are similar to the described requirements of a user. Agents can broadly be classified as either *organisational* which execute on behalf of a business process or software application, or *personal* which carry out tasks on behalf of a user.

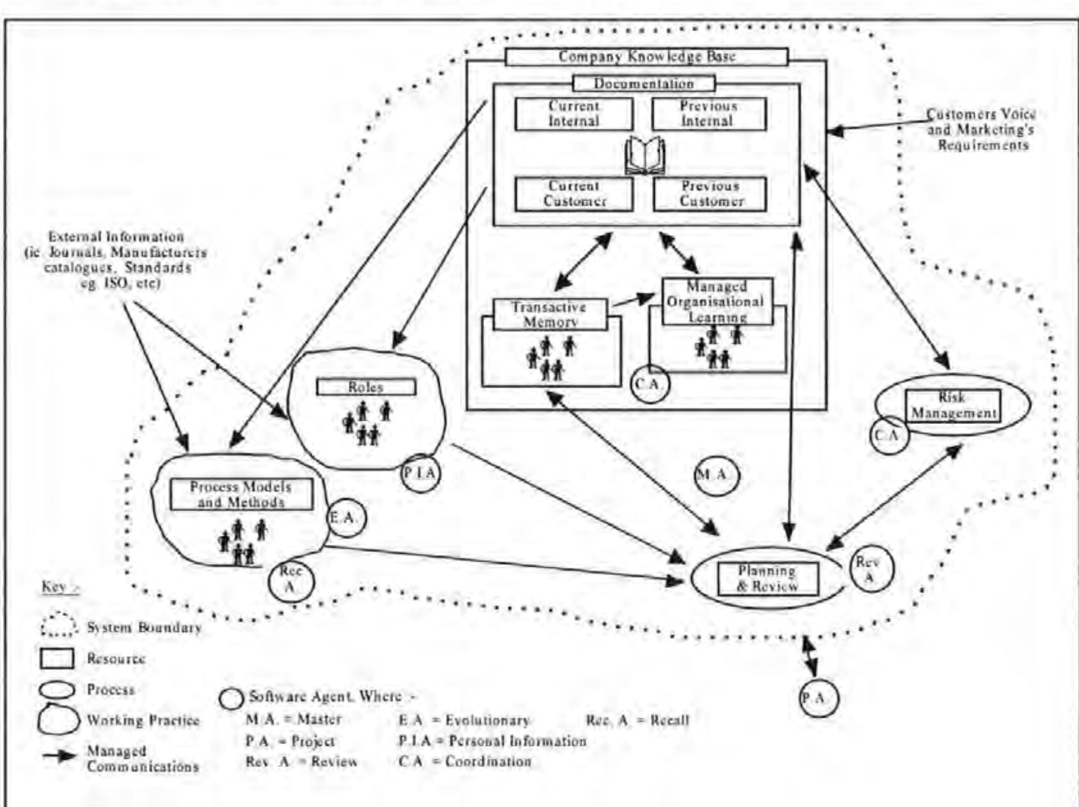
The application of software agents and multi-agent frameworks has been shown to be successful in monitoring, interacting, intervening and learning in complex, dynamic environments (for example Zhang, Wang, & McGreavy 1996, and Silva 1996). The agents envisaged in the present work would not be strictly autonomous in that aims and motives would be provided in the system design. However, aims and motives may be able to evolve to some extent. The role of agents would be to monitor the continuous and fine-grained contingency factors, discussed in chapter 5, to an extent which is beyond the practical scope of human PLs. Software agents would also be responsible for many of the small-grain communications between other software facilities and users. By using software agents the system would address the difficulties in the dynamic monitoring, coordination and communication necessitated by the complex interactivity of project management problems which have been described in the preceding chapters. Section 6.4.6 outlines the function of the proposed agents that evolved through formative evaluation.

The evaluation of the v2.0 conceptual model also utilised pluralistic walkthroughs to determine its viability in meeting the needs of the environment. It was concluded that this model provided an acceptable system for supporting the initial needs determined in the earlier stages of the project. However, further analysis of the expanded ethnographic data and these evaluations revealed that the environment lacked a coherent framework for integrating social and technical contingencies to guide the application of techniques, and which incorporated indicators of potential problem situations in such a dynamic environment; a need echoed by Frankenberger and Pabke-Schaub (1997). Such a framework was seen potentially to have the greatest impact upon improving the current environment. To meet this need the dynamic contingency approach discussed in chapter 5 was evolved.

6.3 The exploratory socio-technical prototype

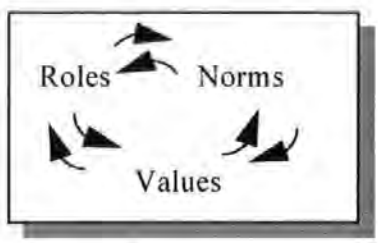
The preceding section described the evolution of the early conceptual models which began to establish requirements for supporting the key relevant systems identified in chapter 5, and their synthesis into the dynamic contingency approach. To recap, adopting Scott Poole and DeSanctis' (1990) Adaptive Structuration Theory (AST), the components presented in the following sections represent the structures and their affordances. That is, the rules and resources that the users adopt and utilise as they deem appropriate. As such, this section outlines the approach and technical development of the exploratory prototype system. As discussed in section 6.1, due to the complexity of the proposed model of support the later evaluations of the requirements were achieved through the use of an exploratory prototype. The components of the system are illustrated below in Figure 6.1, and are described in the following sections of this chapter.

Figure 6.1, conceptual model of support (v2.0)



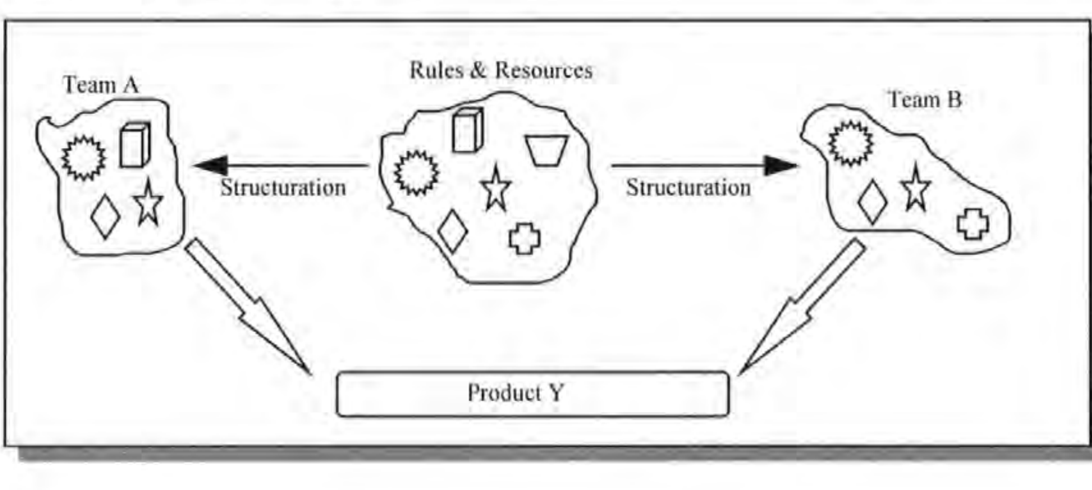
Within this representation a social system behaves as described by Checkland and Scholes (1991) and shown in Figure 6.2, "where each element defines and is defined by the others". In this way the social system provides a fluid medium in which the rules and resources interact.

Figure 6.2, The behaviour of the social system (after Checkland & Scholes, 1991)



Adopting the AST (Scott Poole & DeSanctis, 1990) perspective these rules and resources are *structured* into systems which meet the needs of the users in a particular context. As illustrated in Figure 6.3 below, due to different contexts two teams may structurate different rules and resources to accomplish the same task.

Figure 6.3, The structuration of systems



6.3.1 Software system framework

From the preceding stages of the project a number of vital technical requirements for the software elements of the support system were identified. Many of these requirements are consistent with those identified by others, for example Cockburn and Jones (1993) and Andreasen et al (1997), for systems which support team work in a design environment. The following outlines these needs:

- Reuse : of both project and design information, as well as other people's knowledge[21].

- Flexibility : the system must allow the use of whatever tools are deemed necessary and capture the resultant data, regardless of hardware or software platform. In addition, the system itself must be flexible enough to cope with the constant changes in the design environment.

- Information capture : heterogeneous environment that can capture project and design information and which enables control, reuse and flexibility, as discussed above. In other words, a framework which harnesses information for the entire design project.

- Dynamic and event driven : the environment requires flexibility because of its dynamic, interrelated nature. The system must respond to events which occur in a project's lifetime and encourage proactivity.

- Monitoring : due to the complexity of the environment the system should be able to monitor changes which effect other components in the system, both social and technical.

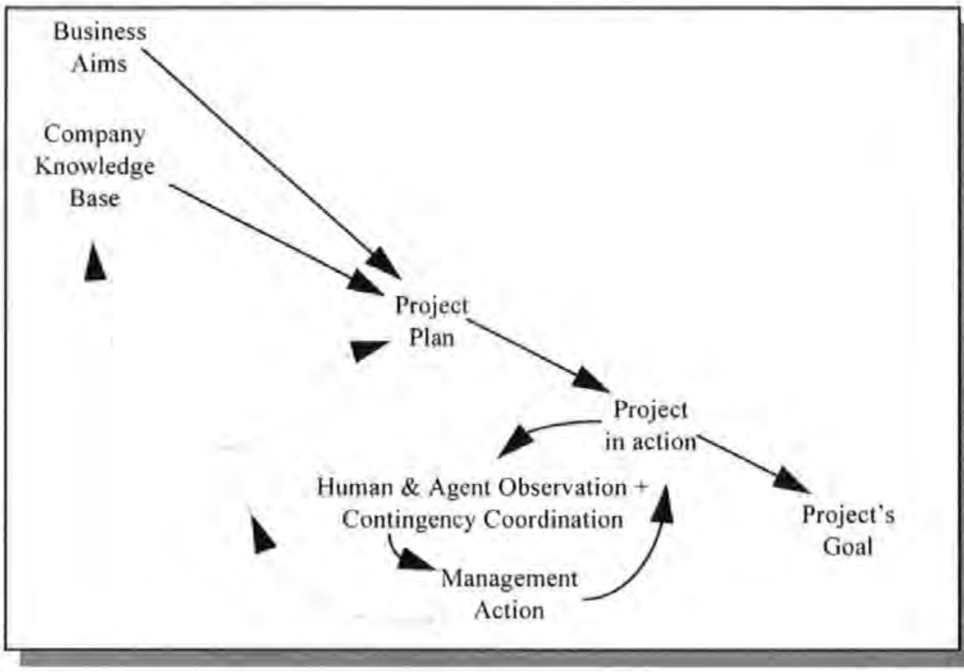
- Veracity : the system should map real world needs, encompass a socio-technical framework and provide flexibility of operation.

- Framework : the system must provide an integrating framework for guiding and coordinating the interrelated, social and technical aspects of the environment.

[21] Company A have extended the concept of reuse to an external perspective, that is increasing the use of 'third part tools' rather than create in house versions.

A simplified overview of the way in which the system would behave is shown in Figure 6.4 below.

Figure 6.4. An overview of the behaviour of the proposed support system.



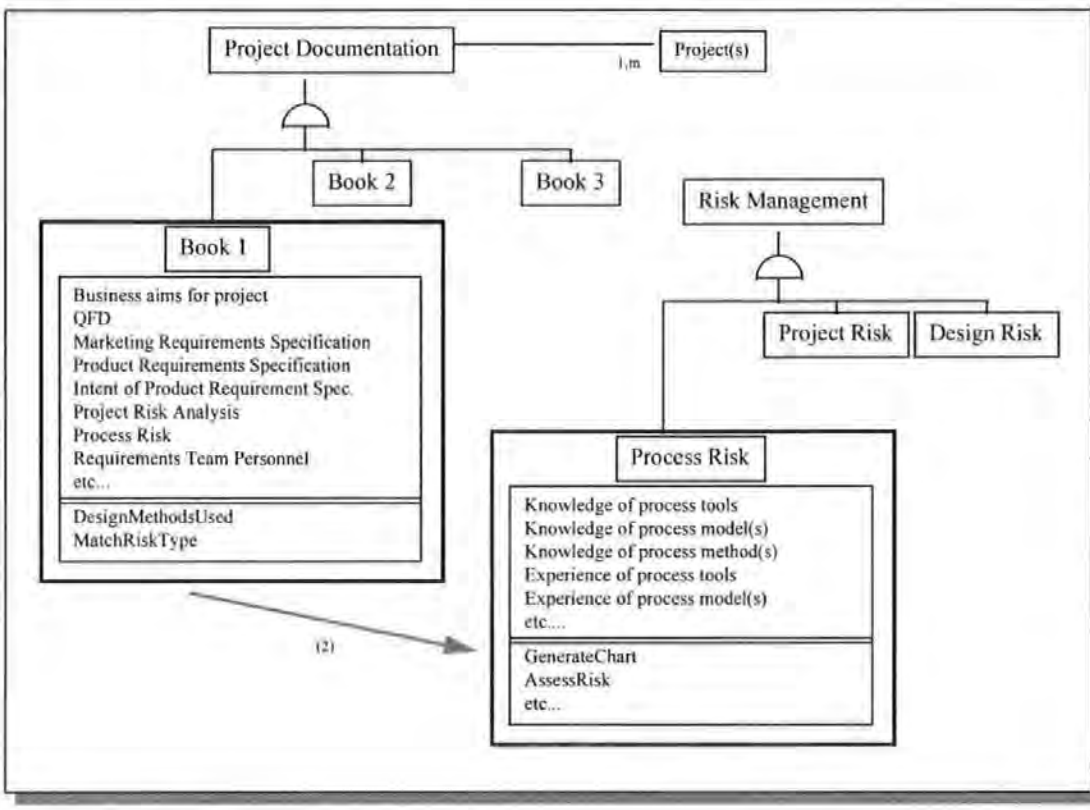
6.3.2 Development tools

The development of the software prototype, in terms of the techniques applied, followed well established software engineering practice and will not be discussed in depth in this thesis other than to outline the methods and tools used.

Prior to the development of any software an outline system design, which met the needs as discussed in the previous section, was required. To achieve this, a system design method was needed which provided an interrelated, dynamic, event driven and flexible system which maps the real world environment. The object oriented paradigm offers such an approach by mapping the real world environment into objects which can be implemented in software. The prototype system's design was developed using Coad & Yourdon's Object Oriented Analysis (1990). As discussed in chapter 3, Object Oriented Analysis (OOA) is a straight forward and widely used method (OMG

1994), and suited the level of detail that was required for this stage of the system development. Figure 6.5 below, illustrates an example of the OOA expression of two objects within the system and the messaging between them. The definition for each of the components in the system is discussed in section 6.4.

Figure 6.5, Extract of an OOA representation of the prototype system : showing messaging between Product Book 1 & Process Risk objects.



To allow the rapid development of a prototype which illustrated the possibilities of supporting a flexible and dynamic system the Microsoft Windows environment was selected. As well as a large range of established software tools, this environment provided proven standards for automatically linking and monitoring various software tools, and data items within applications, into a unified interface[22]. This is achieved through the Dynamic Data Exchange (DDE), and Object Linking and Embedding (OLE) standards. To develop the prototype Borland's Delphi Rapid Application Development software was used. This software development environment is based upon a visual programming tool, is founded on object oriented Pascal, and supports client-server application development. Delphi was selected over similar tools such as Visual Basic or Visual C++ because of its level of functionality, reliability, client-server capability and ease of use. A large number of freeware or shareware Delphi components are also available, reuse of which enabled a shorter development cycle. Delphi proved to be a suitable and effective tool for achieving the aim of this work. However, if the system is to be developed further then the tool would have to be reviewed with new criteria such as efficiency of generated code, the database support required.

To supplement and drive the O.O. system the concept of software agents was utilised. The agents, as described in chapter 4, exist as entities within the system. They can monitor data, objects and messaging and react to given situations or conditions. In addition agents can be triggered by a request from a system component or the user. This section has outlined the rationale for the methods and tools utilised in the prototype's development, the following describes each of the systems components.

6.4 System components

From the earlier work, described in section 6.2, it was evident that some of the components in the system were pivotal for the system as a whole. Based upon the formative evaluations a number of these key components were included in the prototyped software.

The following sections describes the system's components. As Jirotka et al (1992) discuss it is often difficult to neatly separate the social and technical aspects of an environment. As such the system is discussed in terms of its components, and where appropriate distinctions between social and technical aspects are made.

[22] In addition, 86% of practising UK design engineers have access to a PC (Culley et al, 1996).

6.4.1 Process models and methods

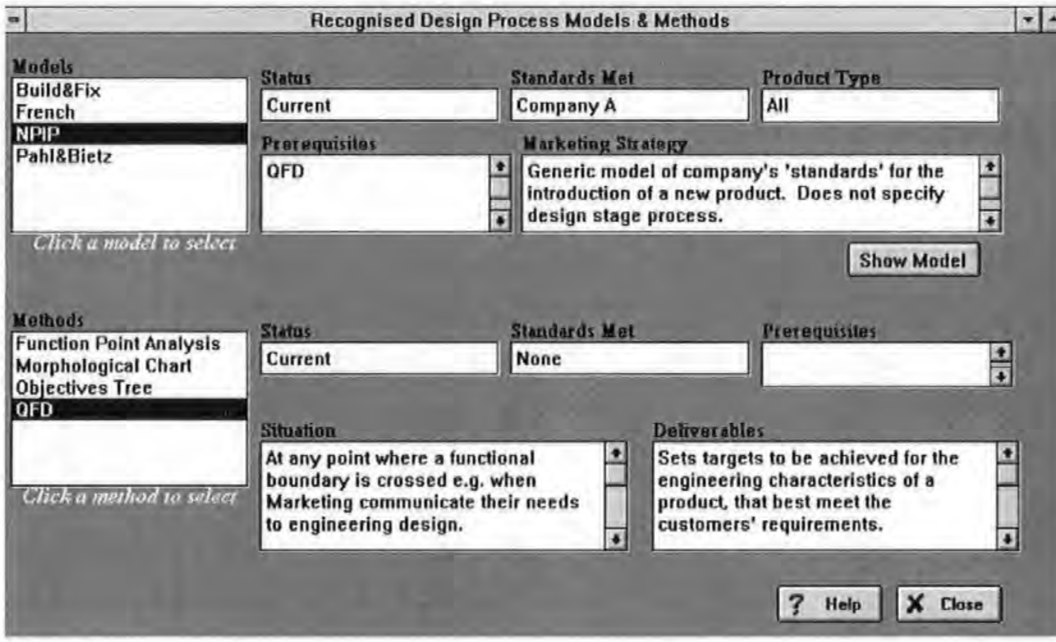
6.4.1.1 Process models

As discussed in chapters 2 and 4, design projects can be described by generic process models which show the sequence of activities and events which comprise a project. Within this work process models, in conjunction with the Product Books discussed below, represent a common understanding of the project's intent, status and direction. In other words providing a 'synoptic perspective of the project' (Anderson et al, 1993), which as Norman (1993b) discusses, we usually require to expand our cognitive ability and to be better able to share information and communicate more effectively.

Typically, as in company A, an idealised model will be prescribed by which design projects will be guided. The problem with such an approach to design is that it does not reflect many of the realities of the situation so that the model is too inflexible to cope with departures from a standard mode of operation, too generic, or incorporates too many irrelevancies. Consequently, access to a battery of process models and methods should be provided which would be appropriate for a particular project. The appropriate model being selected upon criteria such as the level of innovation, marketing strategy. The model would specify the requirements of components of the project such as the level of documentation and roles required, which would in turn, be reflected in the type of documentation template used and personnel assigned to the team. It must be noted however, that under highly innovative conditions that a detailed process model may not be feasible, but it is important that this situation is recognised, respected and communicated.

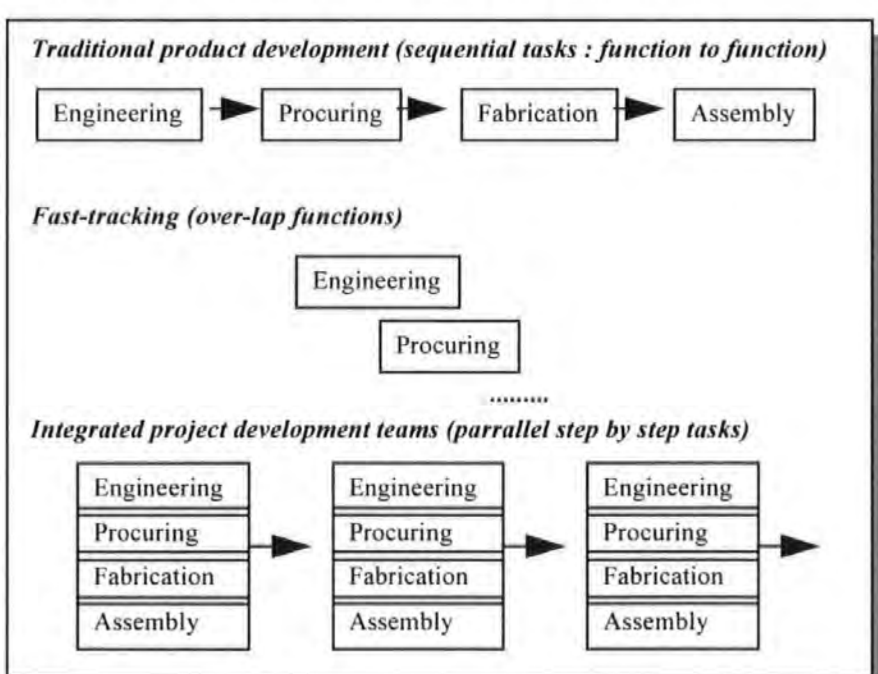
The models would be evolved, refined and authorised through a working group with expertise in this area. This approach complies with the ideas of Hybs and Gero (1992) who debate the benefits of adopting a '*survival of the fittest*' paradigm to design process model evolution. Figure 6.6 illustrates the component's interface.

Figure 6.6, the process models and methods component.



In addition to the models included in the prototype, the initial stock of Design Process Models (DPM) should be design strategy based. For example Figure 6.7, illustrates three common approaches to product development.

Figure 6.7, design process models (after Flemming and Koppelman, 1996).



Assuming a normative design cycle for ease of discussion, these models typically have the following attributes. The sequential approach takes longer, but typically a highly skilled technical workforce emerges. Fast tracking tends to have a shorter time to market, but increases the risk of the project and associated costs due to the potential for rework. The multidisciplinary team approach would reduce the time to market further and can improve quality. However this approach is typically more difficult to manage due the *collaborative conflict* situation (see chapter 3) and not having a *drum beat* for the project's progress, and can also reduce specialist technical knowledge over time.

A further driving factor could be the design philosophy. For example, Maher (1990) differentiates between the following possible design models: decomposition, for example for a new design; transformation, for example when increasing functionality; or case-based reasoning, for example cannibalising a similar problem. DPM based around these approaches would be adopted dependent upon criteria as discussed in chapter 5, such as business aims, levels of acceptable risk. Upon changes in these conditions it may be advisable to change the process model and hence replan the project. The implications of this are far reaching and are discussed in chapter 7.

6.4.1.2 Methods

A large number of design methods exist (Hales, 1993), many of which company A are aware of and utilise. In many ways the use of methods in electronic engineering matches that of software engineering where as Bansler and Bodker (1993) report designers are necessarily pragmatic towards the methods available and that rather than rigidly follow prescribe procedures they take a 'theory building view' and use the methods as they see fit. Methods for French (1981) involve a removal of the problem to a higher level of abstraction, and he describes their usefulness thus:

> *"Design problems like other tough creative problems, are solved by sheer hard mental work. Methods help the designer to keep himself working, to tide over usefully those periods when inspiration will not come, or to break out of circular arguments. They help him to grasp the eel-like tail of a solution as it flashes through the corner of the imagination and pin it out on the drawing board, when, alas, it often turns out to be unworkable"*
>
> *(French, 1981, page 4)*

French views methods as a means of looking for a general element which will extend the solution space, and which attempt to substitute quantitative values for merely qualitative words like advantage and disadvantage.

A key drawback to methods noted by Pugh (1991), is that the use of methods must be appropriate to the situation, for example if the requirements specification is incomplete it may be fruitless to perform complex analysis of the permutations of the functions required. Worse still as Pugh describes, methods may encourage designers to '*go wrong with confidence*'. Hence the use of methods should be guided by a framework. A resource of methods guided by the DPMs discussed above, would assist in this manner as well as in planning projects and provide a resource for engineers to consult when in need of assistance. Cross' (1994) framework of appropriate methods for a given objective or situation would provide a basis for the development of a methods resource by an expert group.

In addition to these more technically oriented methods a number of methods would also be included to assist in more socially oriented issues. For example different forms of peer review are available and are used by company A. These often require that certain roles are undertaken by the review team, and this resource is envisaged to provide information for such activities.

This resource would be maintained by a group with expertise in this area, evolving through use, reviews, and refinement. This is the intended practice of company A although at present they lack mechanisms for capturing and retrieving such information company wide.

6.4.2 Management of Risk

Adopting Mikkelsen's (1990) taxonomy of risk cultures, as shown in table 6.1 below, Company A may be considered to be a *native* culture. That is they have experience of, and practise risk management, but it is generally not a conscious or explicitly communicated activity. Risk management activity is typically in response to signals received and interpreted. The task is respected, the team has no lack of endurance for the project, and any possibilities are exploited, but it is very much a *do it* culture.

Table 6.1, Taxonomy of risk cultures (after Mikkelsen, 1990).

	Conscious	Unconscious
Experienced & practised	*Professionals*	*Natives*
Inexperienced & unpractised	*Amateurs*	*Tourists*

Whilst this approach 'gets the job done' it has drawbacks, as discussed in chapters 4 and 5, which concur with Mikkelsen (1990) who states that risk management needs to be conscious and active. He suggests that there are three serious barriers to this being achieved. Firstly speaking about and understanding the risk phenomenon, secondly accepting that risk can be managed, and thirdly accepting that this will demand methods.

Three main approaches to supporting risk management were included in the software prototype. Firstly, the use of checklists which constitute *screening methods* (Mikkelsen, 1990). Checklists provide useful discussion tools which can uncover areas of uncertainty and gaps in knowledge in the project or design. However, their value is limited and does not provide an easily comprehensible gauge of risk.

Secondly, what was considered to be more valuable than checklists is the evolution of formulae that indicate the highlights and lowlights of risk attributes. Managers must be able to manipulate such formulae, and the assessments must be transparent. A tree depicting the formula applicable to each part of the project was considered to potentially be the best way to represent such information. This approach has been described as *uncertainty analysis* (Mikkelsen, 1990), and has been applied in the prototype to design risk.

Thirdly, metrics and checklists would be utilised to perform *vulnerability analysis* (Mikkelsen, 1990). This would relate to our project risk category, that is, the risk to the business of the project and the effect of business events on the project. Croll (1995) argues that analysis in this area could be improved through techniques such as

Monte Carlo methods based upon probabilistic phenomena, which he states have been applied at engineering level, but only recently adopted in the management and planning phases. These metrics would be developed in conjunction with the checklists.

These three approaches have been utilised in the risk component of the prototype, which comprises project, process and design risk assessments. The project and process risk assessment are at present subjective, qualitative measures, whilst the design risk utilises Culverhouse's Four Path Model (1993) to provide a quantitative assessment. Figure 6.8 and Figure 6.9 below, illustrate the project and process risk elements of this component.

Figure 6.8, Project risk assessment.

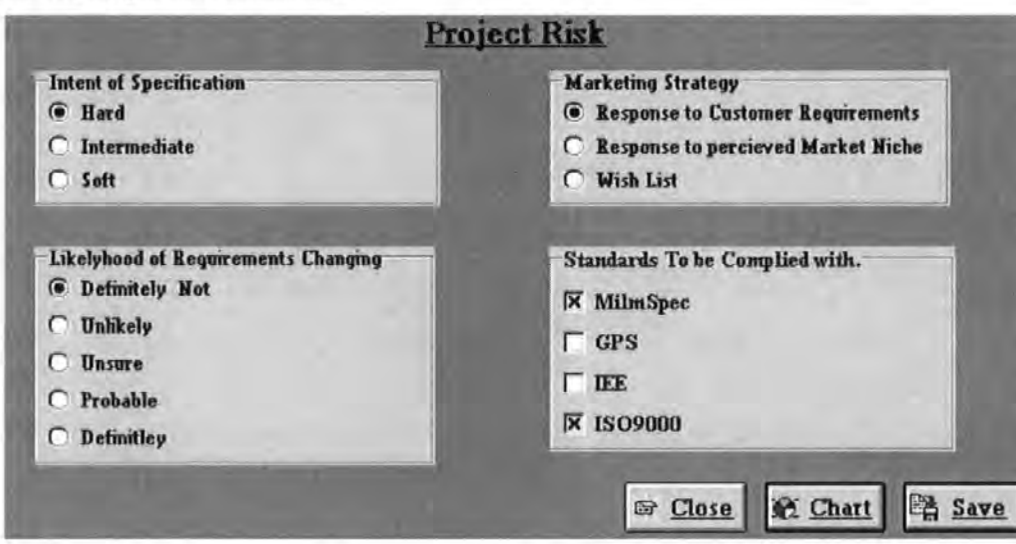
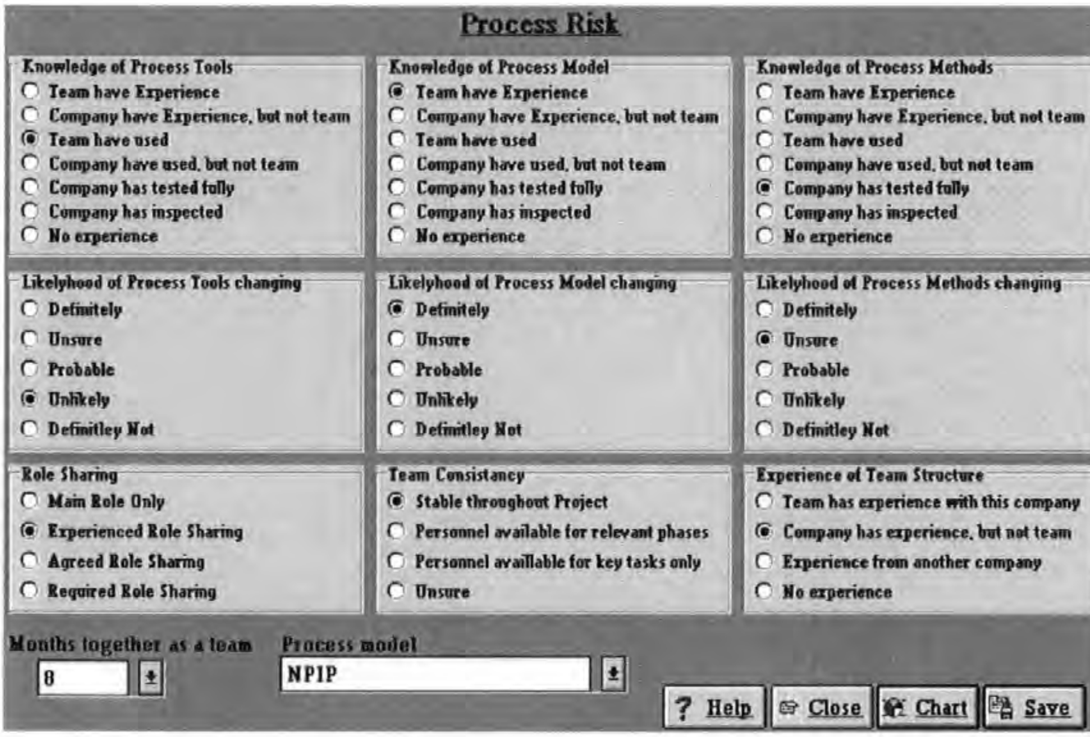


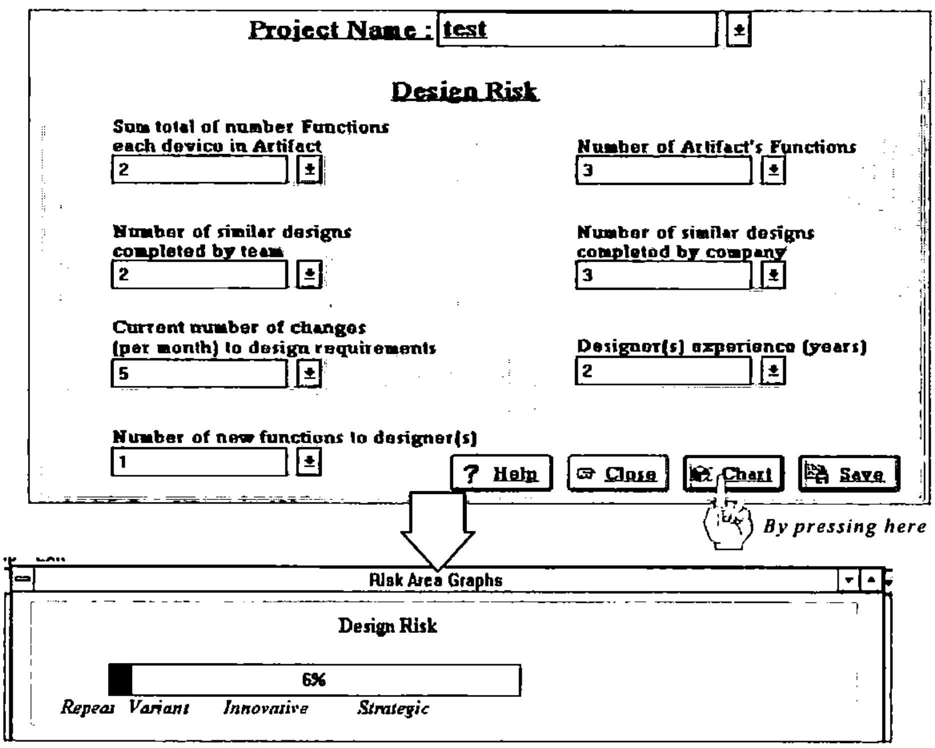
Figure 6.9, Process risk assessment.



Once the risk attributes have been entered an assessment of the design may be generated as shown. The Process Risks component would provide a metric for obtaining an estimated risk of adopting a certain process based upon criteria such as the companies experience of using that process, the relevant experience of the project staff. Previous assessments, if any, and reviews of those assessments would allow the parameters to be refined. Tolerance levels for the process could be calculated allowing unacceptable changes to be detected automatically. As parameters change in associated projects the component will re-evaluate the risk assessment dynamically where possible, and advise appropriate parties as required. A history of the risk assessments will develop in the project's documentation, allowing reviews of the method.

Figure 6.10 illustrates the design risk component. This component is based upon Culverhouse's Four Path Model (1995). The four path model categorises a design based upon the complexity, magnitude and novelty of the design. Design magnitude is a measure of the size of the task related to the personnel charged with its completion. Design novelty is a function of the rate of change of the design specification added to the number of specific design functions that are unfamiliar or new to the engineering team. A simple metric is used to categories a design as being either repeat order, variant, innovative or strategic. The attributes of the metric are part of the documentation of the company knowledge base, as discussed in the following section, and as such can be monitored by the system. Changes in the metric, and hence the type of design can therefore be automatically assessed.

Figure 6.10, Design risk assessment.



Risk estimations would typically be built up from a number of assessments. For example, one project assessment, one process assessment and a design assessment for each function of the design. If the project involves a number of sub-projects, then this scenario would be extended for each sub-project. It is anticipated that the particular attributes to be considered for risk will be driven by the project type being undertaken. This may be guided by conditions such as the process model adopted or the product being produced.

These approaches could be enhanced through the application of *robustness-increasing methods* (Mikkelsen, 1990). Once the metrics, process models, and dynamic contingency approach are sufficiently evolved simulations of various approaches could be carried out. This may enable contingency plans to be determined and associated with anticipated events occurring.

Techniques and tools for the positive management of risk as described by Gero (1990), Boehm (1988), and in particular Culverhouse (1993) can reduce the potential for the addition of unanticipated innovation together with its associated harmful effects on project time scales; what Hosking and Morley (1991) describe as achieving '*disciplined creativity*'. Complementary methods have also been proposed by Symons (1988) and French et al (1993) for generating early functional complexity estimates, whilst Hales (1993) offers a variety of 'worksheets' which constitute checklists for projects, designs and processes. These approaches in conjunction with those evolved in the prototype, form the basis for this resource. However the useful application of any of these approaches is dependent upon evolving sets of parameters which depend upon the capture of, and access to, previous project risk management information. Within this system the assessment history from these activities are stored within the product book structure as discussed in the next section.

6.4.3 Company knowledge base

Within the prototype, the company knowledge base comprises the documentation (product book structure) and transactive memory system components. The organisational learning component has obvious benefits, but its value was judged to be dependent upon the viability of the documentation and TMS components. Consequently the organisational learning component was not developed further in the present work.

6.4.3.1 Documentation : Product books

Within the design environment documentation typically contains the minimum information about a design which is sufficient to allow its further development by the next function in the process (Culverhouse, 1995a). Culverhouse (1995a), and Minneman and Harrison (1997) argue that the capture and retrieval of much richer information is necessary. For example Hosking and Morley (1991) argue that the more criteria that the designers know about a task the better the solution. This idea appears intuitive and obvious, yet as discussed in chapter 4, engineers at company A often felt they received restricted information. The PL's openly admitted to filtering information on occasions to avoid information overload on the engineer, and at other times to make the PL's tasks easier. Clearly, access to too much information can cause information overload to the receiver (for example see Culley et al, 1992). However as Hosking and Morley discuss a key criterion to a problem is its context, that is, issues such as the history and strategy for a project. In addition as Minneman and Harrison (1997), and Cross and Cross (1996) discuss, at times conserving ambiguity, negotiation, and non-committal agreements are important strategies which enable designs to evolve. Consequently to assist in this objective and to improve project management estimates and coordination, engineering documentation should include both design and project information.

The design elements, including rationale, should comprise: generic and specific design solutions, problems encountered and failed or suspended designs. The project elements should include: planning (for example, business aim, objectives, schedules, etc.); risk assessment, resources allocated, processes used, strategies applied and the rationale behind any of the decisions made. Many of these elements Tampoe and Thurloway (1993) cite as issues which need consideration for any project.

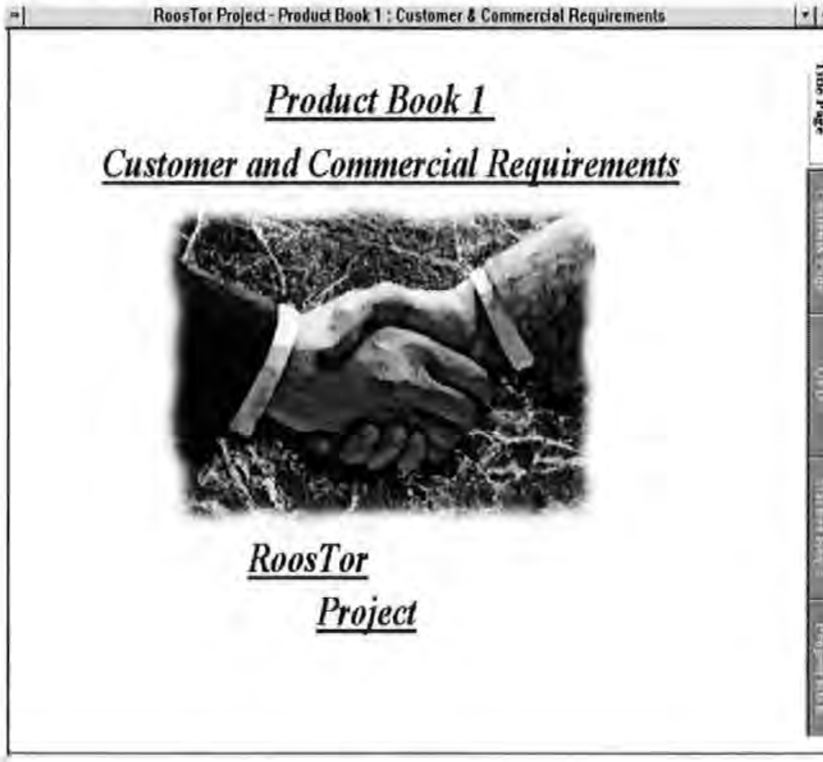
A key issue from the work discussed in chapter 4 was the specification of customers' requirements, which must for certain strategies remain flexible in order to meet the needs of the market. As Hales (1993) discusses, this is a situation common to engineering design, where requirements may be a demand or a wish, but the intent is often not explicitly stated. As discussed in chapter 4, the intent of the specification of requirements could be clarified. Clear understanding of intent is a vital prerequisite for effective risk management and drives the design (Hybs & Gero, 1993). This issue is equally true where a multidisciplinary team is utilised, for example in concurrent engineering. In a multidisciplinary team the intent may be well understood by the team members, but due to shortages of expertise the teams are typically impromptu.

Thus intent of documents must be made just as clear, especially if reuse is to be encouraged.

Mili (1991) argues that the three key issues in reuse of documentation are completeness, consistency and accessibility. He argues that by adopting an object centred approach rather than a document centred one that these goals can be meet. For Mili this involves the use of document templates; the completeness for these templates is assisted by using the object's requirements to drive the documentation needs. These ideas concur with Culverhouse's (1995a) product books structure upon which the documentation component has been based. This concept is founded upon a series of object oriented database of template-based books which corresponds to the product development stages. For example, Book 1 describes the potential product from the customer's and the company's commercial viewpoint; Book 2 describes conceptual design and alternatives; and Book 3 describes the actual product. Due to the focus of this project being the early conceptual stages, only the first two product books were developed as shown in Figure 6.11 and Figure 6.12 below[23].

[23] Within the conceptual model, separate customer based documentation was also deemed to be required, but was judged to be an unnecessary inclusion at this stage of the work.

Figure 6.11, Product book 1.



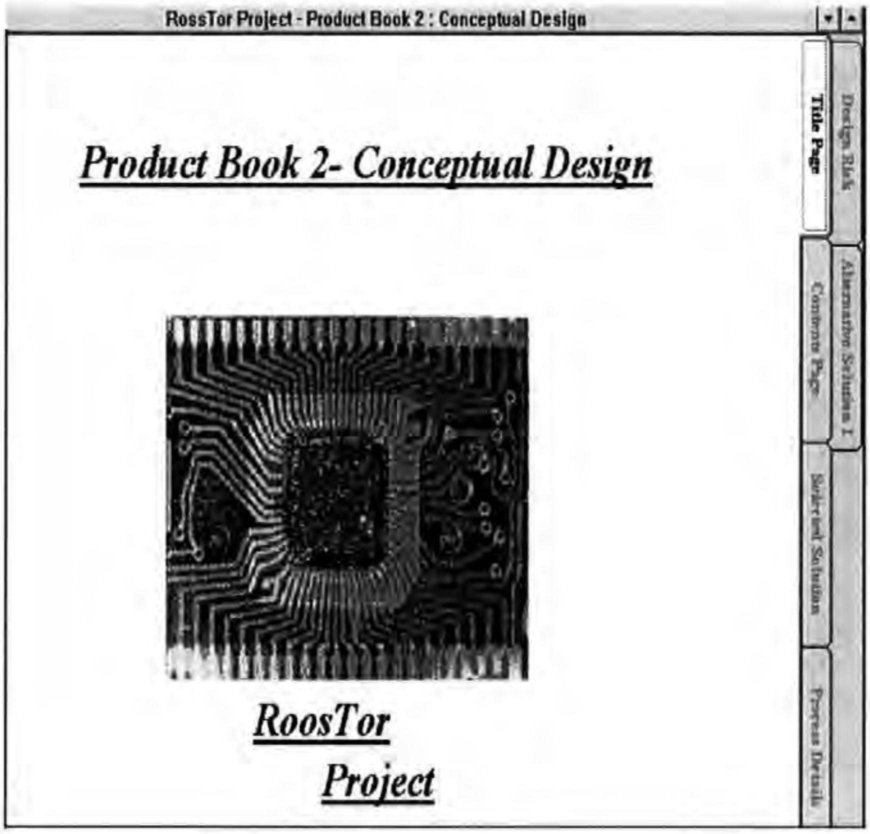
The concept of using a book metaphor provides a recognisable and consistent mechanism for data storage and retrieval, which can be exploited by the O.O. paradigm (Culverhouse 1995a). The use of a book metaphor meets the needs of an interface which reflects the actual usage of current documentation and the requirements for the future. The retrieval and reuse of information relies upon a known and easy to use interface. This concept should facilitate better communication through a recognised, anticipated mechanism for storage and retrieval.

Rada, Wang, Michailidis and Chen (1992) argue that facilitating reuse means that information storage should be a by-product of the task or via a librarian role. The Product Book structure, in conjunction with the software agents, dynamically and automatically captures data from the tools in which it is generated thus facilitating storage as a by-product of the task.

As discussed in chapter 4, use and re-use of templates, would be improved if they did not require irrelevant information. Consequently each template's requirements should be dictated by the type of product and/or project which is being undertaken. In other words, the data requirements will be process model driven. Culverhouse (1995a&b), Hales (1993), and Oakley (1990) offer a variety of design specification checklists which could provide the basis for developing company A's specific template needs.

This dynamic structure will allow the accuracy of information, together with automatic reaction to certain circumstances. For example, a prompt to inform another party that an amendment that is relevant to their work has just been made. The books utilise OLE and DDE standards which allow a diverse range of tools to be used and the output captured and controlled within the books to allow reuse and control of the design and project information. Product book 2, Figure 6.1 below, contains attributes such as the selected conceptual design solution and any alternatives, risk assessments of the selected design and the design process chosen (see the risk assessment component above). The product books are a good example of the use of the OLE standard in supporting dynamic activities. For example, the conceptual specification held within this book was written in Microsoft Word. It is stored within the book, and any changes or access to the document are immediately accessible to the system. Agents, as discussed below, can monitor information stored in these structures and react to changes in appropriate manners.

Figure 6.12, Product book 2.



To facilitate the use and adoption of such a structure company wide this component will function in the same manner as an IPSE (as discussed in chapter 2), providing a cross-platform heterogeneous environment. For example, the mechanism should dynamically capture all necessary information, track the changes to such information and other related information, and evolve a historical log of changes including the events which initiated the changes. The exact construction of the various books will be guided by the process model adopted. A default template will be associated with a particular process model to ensure that an appropriate level of information is captured.

Taking an external view of reuse, the mechanism adopted for capturing information must also accommodate the use and capture of information from third part tools (for example word processing, planning tools, etc.). Within the windows environment this was prototyped using the OLE and DDE standards. It is highly likely that platform independent standards and tools would provide the best approach for further development. These needs may be best met by software such as Java, and standards such as STEP, which Pallot (1996) describes as the "*foreseen solution to the standards problem*".

6.4.3.2 Transactive memory system

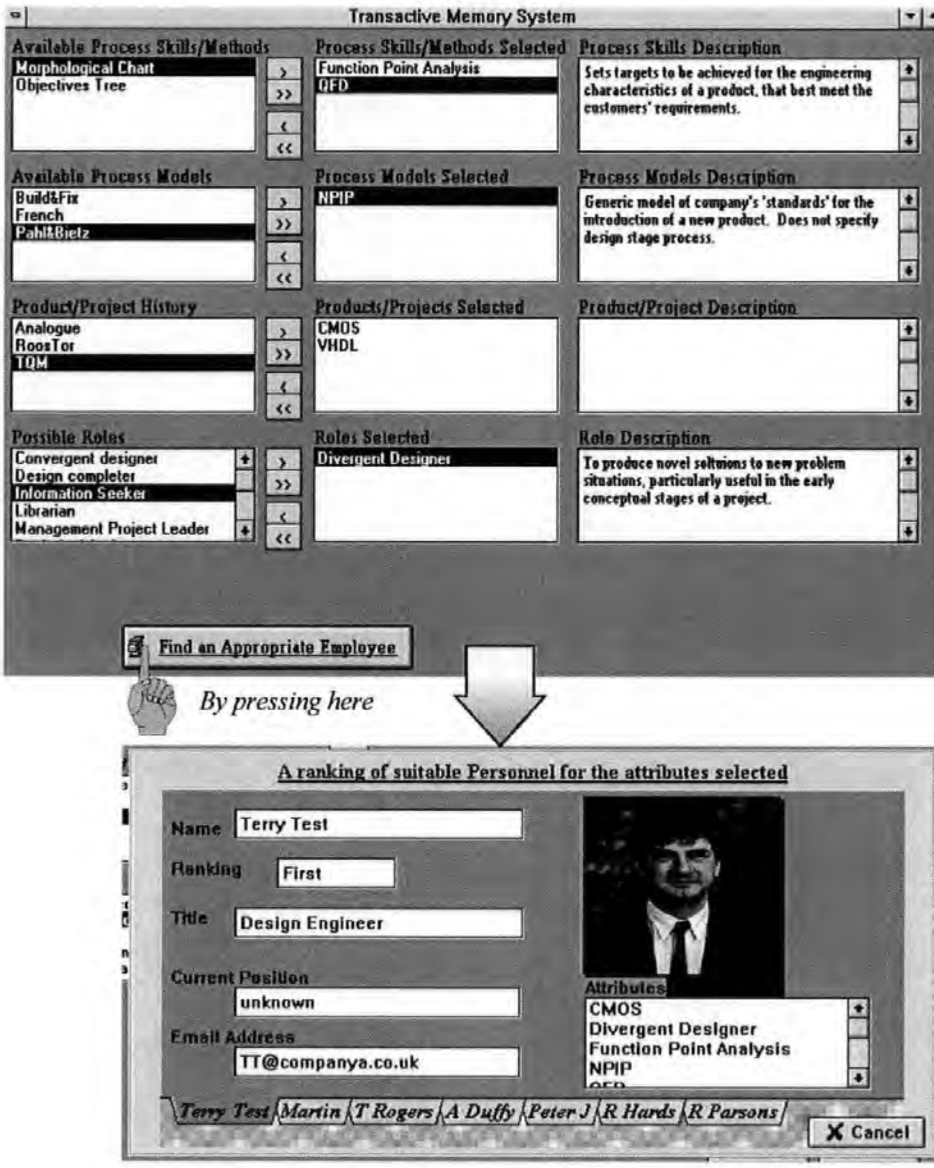
Typically studies which aim to support the *memory* of a company, commonly referred to as organisational memory, have focused upon the capture of people's experiences and/or knowledge in various forms. As Chen, McHenry, Lynch and Goodman (1994) discuss, the intention is typically to provide a resource to enable this information to be reused. They describe the key problems with this concept as building an effective mechanism for capturing and retrieving the information. That is, what and how is such contextually based knowledge captured; and how is it usefully retrieved. Clancey (1993) deliberates capturing such information when discussing the work of Newell (1982) who states that expert knowledge " *can be represented, but it is never actually in the hand*". Which Clancey elaborates as the expert capturing what they need to say at any point in time in that context, and that often such statements may later be interpreted in a number of different ways. This state concurs with Visser's (1996) work where the expert designer's solution is situation dependent. With regard to retrieving such information, data from the ethnographic study indicated that engineers at company A generally prefer to solve problems from first principals or adopt a social strategy such as discussing a problem rather than try and retrieve some partial solution. The engineers felt that the activity of framing and explaining the problem to another person often clarified their own understanding, a view which concurs with Kidd's study (1985). This appears to be particularly true if retrieving such information was in any way a difficult or complex task.

Due to these concerns whilst the incorporation of approaches such as organisational memory was seen to be potentially useful, the present work focused upon a mechanism which maps *who knows about what*. For example, in the specification process where it was important for the initiators of the project to know who should be consulted in order to cover all of the important aspects of the proposed design. As a second example, it was fundamental that members of a design team should know who in the team, and outside it, they should consult about particular issues, such as the characteristics of different technologies. An important component of the role of Project Leader was knowledge of the specialisms within the team, and outside it in the organisation at large. In other words, rather than capture experience we capture topics and enable the social interactions of problem solving to be carried out. This type of knowledge about who knows what, has been termed by Wegner (1986) as *transactive memory* which he defines as :

> *"A transactive memory system is a set of individual memory systems in combination with the communication that takes place". (p186)*
>
> *"... one person has access to information in another's memory by virtue of knowing that the other person is a location for an item with a certain label. This allows both people to depend on communication with each other for the enhancement of their personal memory stores. At the same time, however, this interdependence produces a knowledge-holding system that is larger and more complex than either of the individuals' own memory systems." (p189)*
>
> (*after Wegner, 1986*)

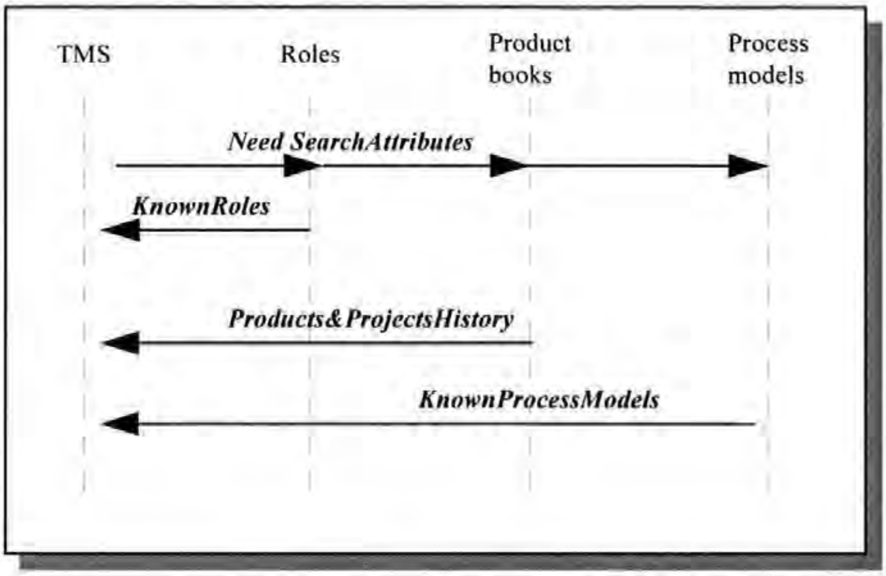
The transactive memory system (TMS) component may be considered to be a database identifying the sources of particular knowledge in a company's transactive memory (Brown, Jagodzinski, & Reid, 1995). This should improve designers ability to find whom they should be talking to in order to solve a particular problem. Additionally, it would help in the formation of project teams and resource allocation, identify knowledge gaps in the company, and assist in determining training needs. In this way the system would support not just access to organisational knowledge but also the management of that knowledge. This component would be dependent upon the definition and maintenance of appropriate model roles, as discussed in the roles component below. Figure 6.13 shows the TMS in action.

Figure 6.13, The transactive memory system component.



In the above example the four categories on the left provide lists of the current attributes on which to base the search criteria. Once the user has selected the appropriate attributes of the person they wish to find the system retrieves any suitable personnel. The TMS provides a good example of the interrelationship of the system's components. The attributes listed on the left hand side of the interface are the attributes held by other components in the system. For example, the available process models are sent to the TMS upon request by the process models component discussed above. Figure 6.14 below illustrates this behaviour.

Figure 6.14, A simplified event trace for the TMS request 'NeedSearchAttributes'.



The TMS would evolve through each employee maintaining their own record. Thus, a high proportion of the workload of maintaining the system is distributed to those who stand to gain most from its completeness, as the TMS could provide a means of acknowledgement for work that is undertaken. As new employees join, especially experienced staff, they can construct their own record, thus removing the need for a third party to extract and catalogue their knowledge. The attributes available for selection are supplied by the other objects in the system. For example, the roles object supplies the possible roles that a person could have performed. Such an approach would rely upon the accuracy of the criteria for adding an attribute, and the professional ethics of the individual for its accuracy.

6.4.3.3 Managed organisational learning

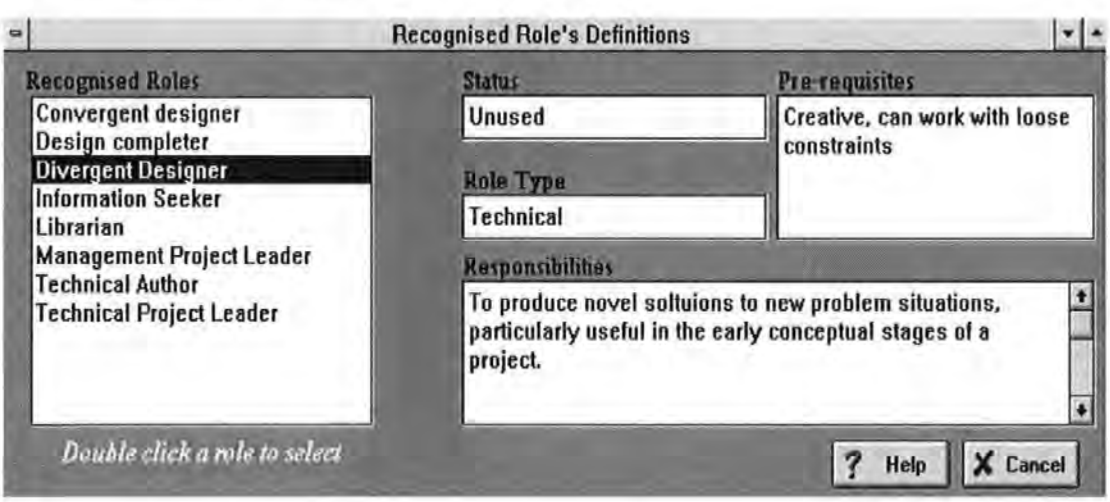
Through the application of the transactive memory component, knowledge gaps in the company could be identified to assist in determining training or recruitment needs. As discussed above the system could then support not just access to organisational knowledge but also the management of that knowledge. Company A judged its further development unnecessary in the present work, but considered that it should be progressed in any future work.

6.4.4 Roles

The term role can refer to a variety of activities and behaviours. For the purposes of this discussion, the term role refers to the activity a person would engage in were they "*to act solely in terms of normative demands upon some one in their position*" (Sonnenwald, 1996)[24]. If we take role performance to mean the actual conduct of a person whilst assuming a role, then as Sonnenwald (1996) argues role performance will be affected by interaction with others : "*others have expectations with respect to an individual's role performance and these expectations help to shape an individuals behaviour*". A key benefit therefore, from adopting the concept of a roles resource is in helping to communicate and integrate responsibilities to others within the team.

The roles included in the resource in the prototype are examples of what Hales (1993) defines as either a functional or a team role in a design project. The functional roles are related to aspects such as technical expertise, whilst team roles relate to particular team contributions. Figure 6.15 below shows the roles component.

Figure 6.15, the roles component.



The categories of roles have included psychometric evaluations, contingency (for example a librarian), and technical (for example an analogue designer). Flemming and Koppelman (1996), Hales (1993), and Cross & Cross (1995) concur with this

[24] The norm at Company A is that a person would concurrently carry out a number of roles, often on a number of projects.

concept citing roles such as designers who work best on their own, good technical managers who are poor social managers, and information gatherers; where each role has value dependent upon the situation of the project. Sonnenwald (1996) provides a descriptive model of a range of *communication roles* that a design project may require. These roles were derived from four studies of design projects in different domains; including engineering design. As Sonnenwald states "*there is a need to extend our design methodologies to explicitly include communication roles and strategies*", he cites failures in certain aspects of projects if particular roles were not carried out. For example, without what he terms an *agent* role - who is in essence a facilitator, a project team was disbanded. This was not due entirely to the lack of this role being carried, but this was seen to be a contributing factor. Whilst the proposals from all of these authors are typically extensions of Belbin's (1993) classifications, they are placed within a design context. These models were considered to provide an adequate basis for developing the resource.

As discussed in chapters 4 and 5 it was apparent that contingency and supporting roles are *de facto* carried out without explicit being defined or acknowledged. By defining and making explicit job descriptions of these roles, which are sometimes neglected in design teams, motivation for undertaking such roles may be improved due to the recognition of their value. In addition, the development of project teams and contingency plans should be improved as experience in these roles can be accessed and contingencies roles anticipated. This resource would also support the transactive memory system described above, enabling reuse of people's experience, and thus planning tasks.

This component is in essence a resource which can support the social roles required within design teams for particular circumstances, as discussed in chapter 5. The roles would be administered and controlled by a group with expertise in this area. At the time of writing Company A are initiating an in-house project to begin evolving a similar type of resource.

6.4.5 Project planning and reviews

The work discussed in chapters 4 and 5 concurred with Sommerville and Rodden (1996) who argue that it is often not fully understood at inception how a project is going to carry through its objectives; how the work is to be actually realised will often be worked out over the course of the project itself. As discussed previously this necessitates flexibility and communication through access to contemporary information such as appropriate process models, clear specification of intent, active risk management, and definition of roles. In addition, to access to such information the development of a resource of past plans is required to enable refinement, a lack of which is a problem common to engineering design (Hales, 1993).

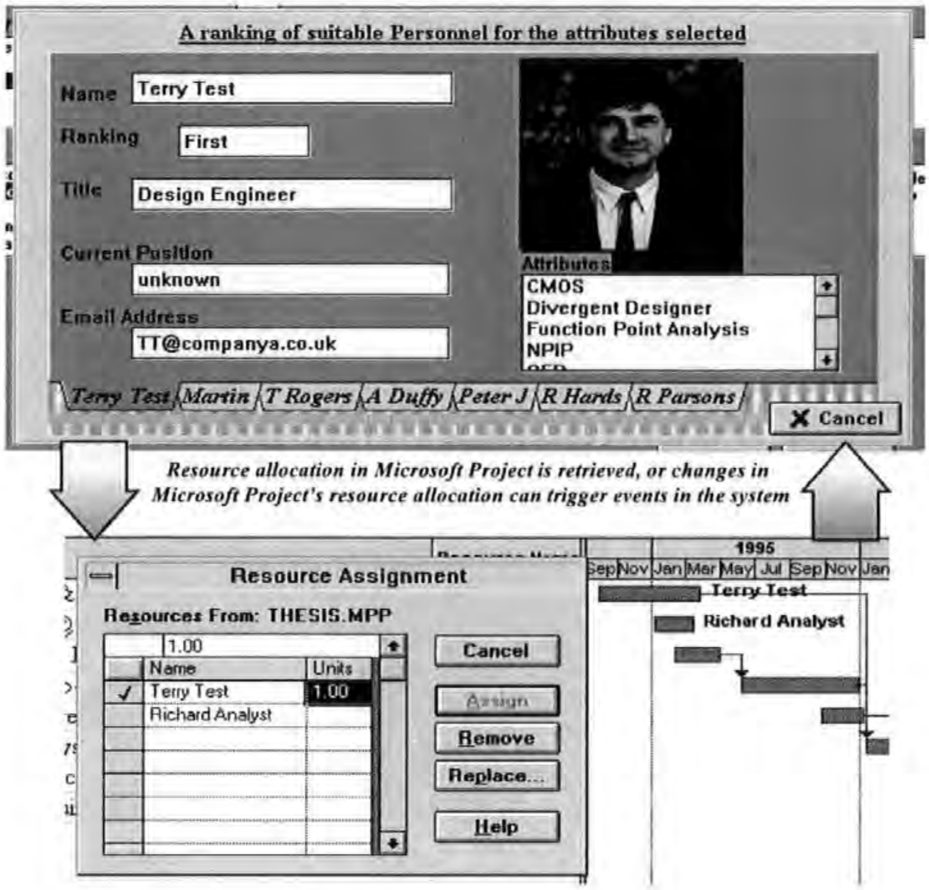
Existing planning software tools, such as Microsoft Project, provide good facilities for generating pert and gantt charts, critical path analysis and basic resource allocation. However as Drabble (1995) discusses these tools are typically platform and operating environment based. Consequently they are restricted to local area network application. Projects on the other hand are frequently becoming wide area network based. Further, as has been discussed in this project, these tools require access to data from a variety of sources which could be automatically accessible given an appropriate operating environment.

Currently planning tools do not allow the development of contingency plans which could be introduced upon a constraint changing or an exception arising (Drabble, 1995); occurrences which are the norm in this environment (Cross & Cross, 1995). This makes responses to situational changes difficult for such tools to deal with. In addition, without automatic access to required data, user intervention and monitoring is required rather than the software carrying out such tasks.

Facilities such as transactive memory mapping, and improvements in the capture and accessibility of past and current project planning information should improve the accuracy of estimates. The plans for a project can be stored for reuse within the Product book 1 structure as discussed above, which can then be interlinked with the dynamic contingency approach discussed in chapter 5 to enable the flexibility required and handle the monitoring of the many fine grain parameters on which the plans are based.

As a resource the planning and review component would be maintained and refined by a group with expertise in this area. Within the prototype, rather than develop a new software component, Microsoft Project (MSP) was harnessed to illustrate the possibilities for enhancement and flexibility. For example, MSP was linked via DDE to the TMS to retrieve personnel's current resource allocation as shown in Figure 6.16 below. Zellouf, Prevot and Aubry (1996) have taken a similar approach in harnessing MSP to facilitate their CSCW application to support cooperative working in software development.

Figure 6.16, Microsoft Project interacting with the TMS component



As discussed in chapter 4 the issues surrounding process models and planning made resource allocation difficult, which in turn had a negative effect upon the review process. As discussed above the development of the other components should alleviate some of the problems associated with planning. It should be noted that under certain circumstances reviews are informalised to enable the perceived speeding up of development time, a practice also identified by Anderson, Heath, Luff and Moran (1993c). However this decision should be explicit and formal allowing any implications to be assessed.

The review resource was not developed in the prototype system. It is intended that it would provide a mechanism to support the working practices and social processes of reviews. For example, by accessing the Methods component to use Fagan inspections (1986) and anonymous reviews in appropriate situations. Both of these methods require certain roles to be allocated and carried out, and a sequence of activities to be scheduled and coordinated, the review mechanism could support such activities.

6.4.6 Software agents

In section 6.2 the conceptual model (v2.0), a requirement to support proactivity was identified. One way in which this was thought to be improved was through the monitoring of system states and interactions. Following Heath and Luff's (1992) emphasis, this concept is not simply to support the administration of complex changes, but also to support the informal exchange of information between staff. This concept was illustrated through a number of software agents. In order that the concepts of agents and the dynamic contingency approach could be evaluated, the following two software agents, a project and a contingency agent, were developed in the prototype.

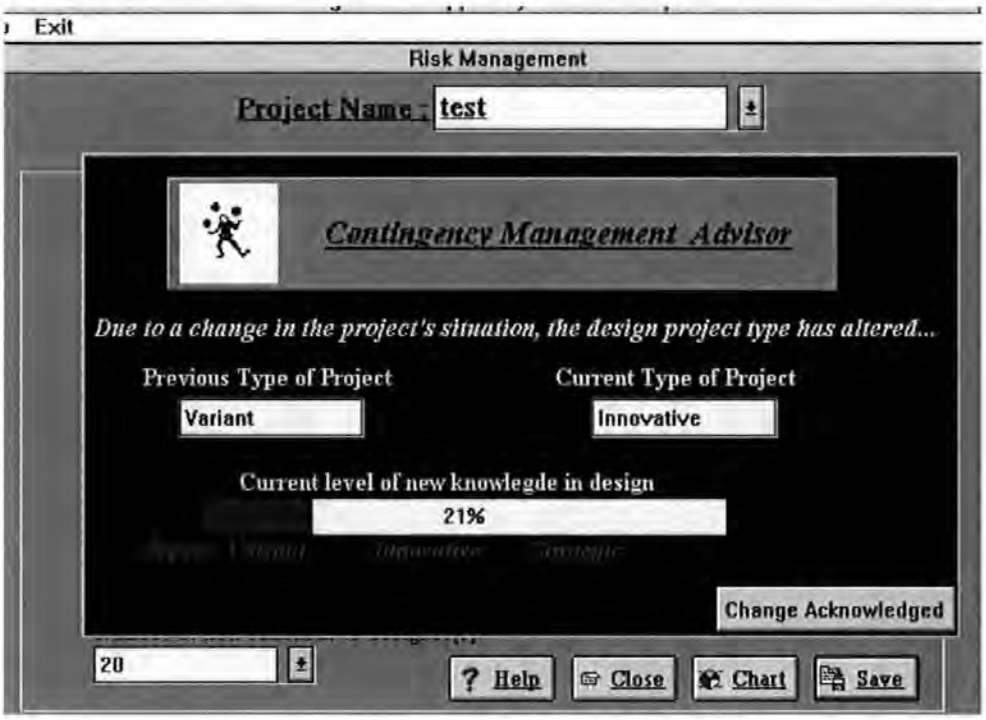
6.4.6.1 Project agent

The project agent is initiated at the outset of a project. It gathers and represents the system components and information as dictated by the process model selected for a project. Within the prototype the agent creates the product book templates, and triggers tasks such as risk assessment. It is intended that the agent could also measure and communicate progress of the project against the process model, and liaise with other project agents, for example to monitor resource overlaps.

6.4.6.2 Contingency agent

Once a project has been initiated through the project agent, a contingency agent (CTA) could be created which sits within the system monitoring messages and other components. Under certain conditions, as discussed in chapter 5, the CTA will alert or advise appropriate personnel of a potential problem situation. Figure 6.17 below illustrates such a situation.

Figure 6.17, the contingency agent in action.



In this instance the number of changes to the initial design requirements, see Figure 6.10, has exceeded the acceptable level for a variant project and the project has consequently been reclassified as an innovative project. The agent in this instance will advise the appropriate personnel, typically the project leader, who then decides upon necessary action. As discussed in chapter 5, many frameworks exist for guiding the adoption of appropriate project structures (for example Mintzberg 1983), which could be utilised.

6.4.6.3 Other agents

A number of agents were considered to be necessary to support proactivity and flexibility in the system, but were not deemed to require further development at this stage of the work. As such the agents outlined below were not developed further in the software prototype system.

- *Personal Information Agent:* gathers and presents information requirements of a user. Default templates can be established to cater for the user's ability, experience or role. For example, for novice users an agent could be created which provides a guide to information retrieval which could assist reuse and stem the problem of drifting and browsing (see Visser 1992 & Fischer 1987). As the user's experience increases and/or role changes they may refine their agent to meet their personal requirements.

- *Review Agent*: administers and controls design or project reviews. For example, if using the Fagan Inspection approach (Fagan, 1986), the agent could suggest suitable personnel via the Transactive Memory System, and appoint roles within the review process. By monitoring the selected review process, the agent could encourage that reviews were conducted and responsibilities discharged.

- *Coordination Agent:* advises target system components of a source component's requirements. For example if a different process model is adopted for a project, additional information may be required for the Risk Management component. The Coordination agent for the Process Model component could trigger the process for obtaining the required information.

- *Evolutionary Agent:* monitors a component's usage and function, with the intention of advising when the module may need to be reconfigured or modified. For example, an agent could be developed for the Roles component of the system which monitors the use of role types. As new design techniques evolve, these roles are likely to shift, thus requiring refinement.

- *Recall Agent*: logs a short term history of the user's actions at a given level of application, for example system operations, and provide an intelligent interface to act as a memory cue which would be capable of retracing a user's actions and correcting mistakes if necessary. For example, if a user is interrupted by a telephone call, they may activate the Recall agent to prompt recall of their previous actions before continuing.

- *Master Agent*: administers and polices the system's agents. The creation of agents and the security of their actions must be monitored and controlled by an agent which is above modification by the agents within the system, and has the power to interrupt an unauthorised action or function being performed. For example, when an agent is created its authority and scope within the system could be set and the agents actions therefore controlled by the master agent which would interrupt actions if necessary.

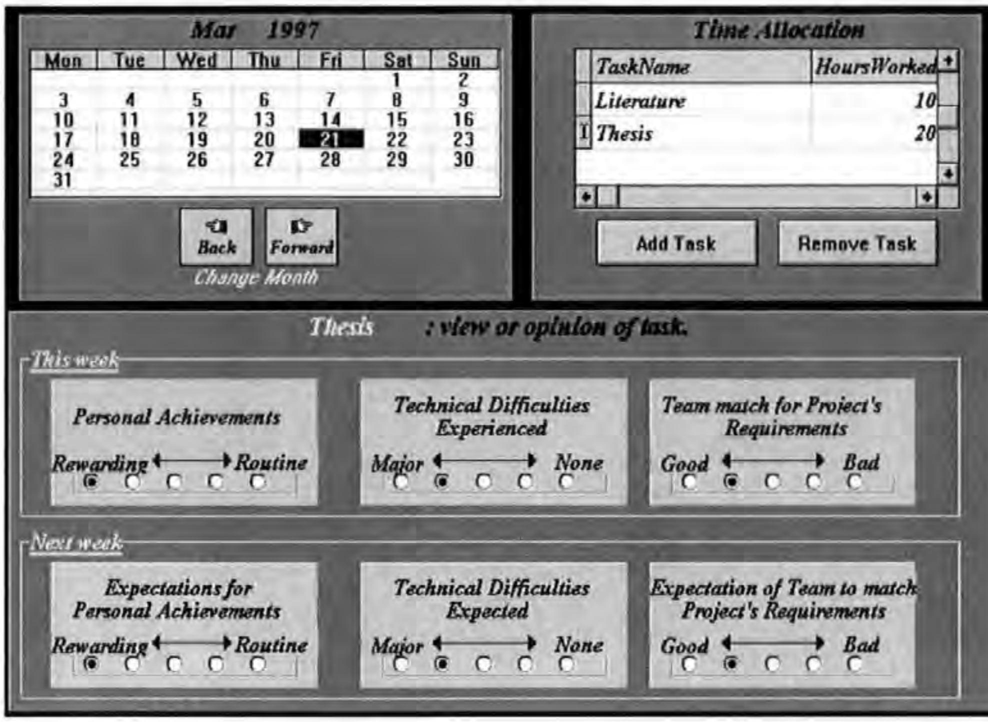
It was envisaged that typically an agent could, as the dynamic contingency approach develops, evolve through the following three stages. First, initially the agent could response to a condition by alerting appropriate personnel. Second in response to a condition, alert appropriate personnel and if the situation has occurred before report the previous scenario. Third, its functionality could be increased to automatically initiate action, for example arrange a meeting between appropriate personnel. The control over the agent's action will lie completely with the personnel whom it serves.

Many of the agents outlined in this section concur with those established by the various Lockheed Knowledge Centred Design Projects (see Gruber, Olsen, Kuokka, McGuire, Weber, & Tenebaum, 1994; and Olsen, Cutkosky, Tenenbaum & Gruber, 1994), and the further development of this project should be able to utilise their infrastructures and tools.

6.4.7 Capturing soft influencing factors

The components described so far would enable the dynamic contingency approach, discussed in chapter 5, to function by providing access to some of the harder influencing factors identified. However a number of key factors are more socially based and are not directly accessible to the software system. Through formative evaluation one means of providing such data was determined to be a timesheet component in which personnel could enter their times spent on tasks and projects. Periodically some of the soft influencing factors discussed in chapter 5, for example morale, could also be gathered. Figure 6.18 below shows one version of this component.

Figure 6.18, the timesheet component.

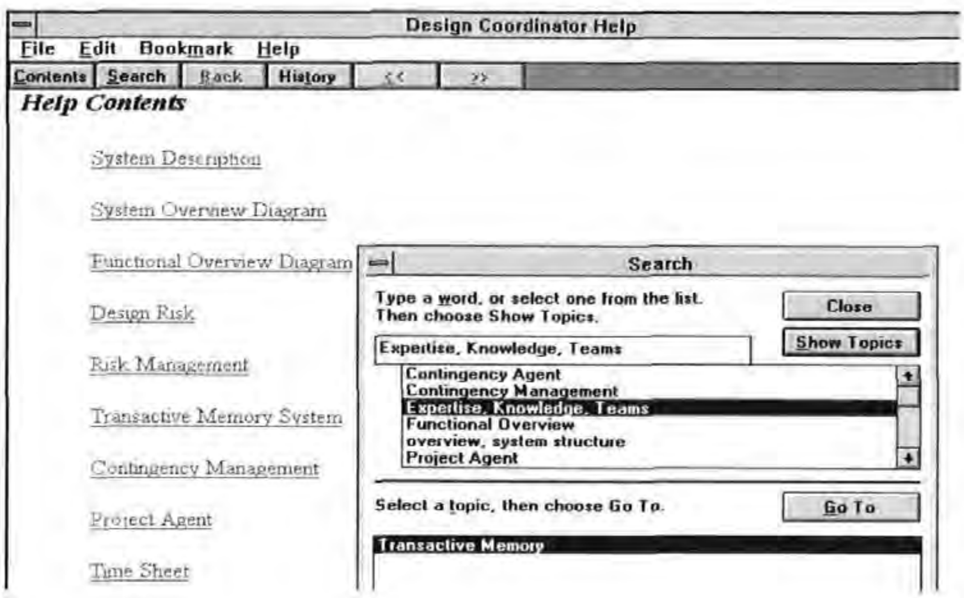


In chapter 5 a number of potentially significant influencing factors were outlined, for example the 'feelgood factor' and coherency of mental models both of which are reflected in the above example. The intent of this component was to determine whether it was viable to attempt to capture such information in this way, the results of which are discussed in the following chapter. The component was therefore developed purely to provide an example of the behaviour of the dynamic contingency approach in a real context and gauge the potential benefits of any further development.

6.4.8 Help ?

As part of the evaluation exercises the system was left with company A for a month to assess, the results of which are discussed in the following chapter. The requirements to be evaluated, as discussed in chapter 2, concerned a socio-technical system. The software elements developed mainly concern the technical aspects which form one part of the whole system. It was therefore vital that the system was considered holistically. To assist this objective a stand alone Windows help system was developed which interacted with the software prototype. The help system supported autonomous use of EDAPT by the stakeholders, and provided explanations and context to the components. For example the social elements and background activities such as the agents were not evident from the software elements of the system. This component also provided assistance to users who had not been involved in the development of the system. Figure 6.19 below shows the help overview window.

Figure 6.19, the help component.



6.5 Conclusion

This chapter has discussed the evolution of EDAPT and the tools and techniques that were employed in its development. The exploratory prototype provided an interrelated, dynamic, event driven and flexible system which maps the real world environment. This tangible representation of the conceptual model of support provided a mechanism which could be readily challenged by all those involved in its development. The results of the concluding evaluations and a critique of the system are discussed in the next chapter.

"From a certain point of view the universe seems to be composed of paradoxes. But everything resolves. That is the function of contradiction. ... When you can see everything from every imaginable point of view you might begin to understand."
(Ben Okri, The Famished Road, 1991, p. 327)

7. Evaluation of EDAPT

7.1 Introduction

In such a formative method of requirements engineering evaluation occurred throughout the project. However as discussed in chapter 3, key evaluation exercises were conducted. In particular, the concluding phase of SSM is the comparison of the conceptual model of support with the rich picture of the problem situation. There are two main aims to this activity : to judge whether the resultant model of support meets the needs identified; and secondly decide upon an appropriate method for progressing the system. In terms of this thesis essentially this meant comparing the approach presented in chapters 5 and 6 with the issues identified in chapter 4. Company A's key observations from this exercise form the basis of this chapter; a broader report of Company A's observations is contained in Parsons (1997b).

The chapter proceeds as follows. First, the application of the methods of evaluation, as described in chapter 3, are outlined. Secondly, the stakeholder's key observations on each of the components in the system, and considering the system as a whole, are reported. The issues raised must be considered in any further development of the present work. Lastly, a route for progressing the system is discussed[25].

7.2 The concluding evaluations

Sommerville and Rodden (1996), Cockburn and Jones (1993), and Grudin (1994) describe the evaluation of groupware applications as being difficult due to the complexity of issues, such as the social and political dynamics of an environment, which can affect the acceptance of groupware. Furthermore, Grudin (1994) reports that unlike tools for individual use, typically groupware tools require 100%

[25] Company A wish to proceed with the present work as illustrated in their letter of support in appendix D.

satisfaction by all the potential users to be acceptable. The concluding evaluations of the system considered such issues and were conducted in two main phases : a series of session using pluralistic walkthroughs; and an Heuristic Evaluation :

- The pluralistic walkthrough, discussed in chapter 3, involved multidisciplinary groups assessing the way in which the system would function in a given scenario. The scenarios were typically : one taken from the ethnographic study, and one suggested by the users (for example, managing a small project). Some of the issues identified during this phase were incorporated into the prototype prior to the second phase;

- The second phase utilised the Heuristic Evaluation Model, discussed in chapter 3. It focused on the comparison stage of SSM, but also explicitly considered the following topics drawn from literature such as CSCW evaluation guidelines (for example, Grudin 1994, & Cockburn & Jones 1993) : the disparity of work and benefit; critical mass : will enough people find it useful; disruption of social processes; exception handling; unobtrusive accessibility; non-intuitive requirements : quality of interface design; effect upon individual users; effect upon the design process; and the effect upon the design environment. Whilst the evaluation considered such issues, it is notoriously difficult to qualify or predict the success of the groupware systems as "*all problems scale up and out; any success may not*" (Twidale et al, 1994).

The second phase of the concluding evaluation entailed the system remaining with Company A for a month, during which time the system could be assessed in depth in its intended environment[26]. Following this period four key stakeholders (a Product Manager, two Project Leaders, and a Senior Design Engineer), were interviewed using a structured interview based upon the Heuristic Evaluation model[27] (as shown in

[26] Due to resource constraints the stakeholders had limited time to assign to the project, this approach enabled the stakeholders to dedicate time to the system when it suited their workloads.
[27] As discussed in chapter 3, Nielsen (1996) found that the optimal number of users using this technique was between 3 and 5 (inclusive).

appendix C). Each interview lasted for approximately 2 hours. The interviews were taped and transcripts from these interviews produced. These transcripts form the body of an internal report (see Parsons, 1997b), which was validated by the Stakeholders interviewed and the UoP research group. Furthermore the findings from this exercise were formally presented to key stakeholders and senior management at Company A for validation and verification.

Company A's key observations from the second phase of the concluding evaluation form the basis of this chapter. Quotations from the interviewees are included where applicable to illustrate a point. Where a quotation is included, a page of the internal report (see Parsons, 1997b) and a coded acronym for the interviewee is cited (for example, "*Parsons 1997b: P10, Eng1*").

7.3 The components of the system

This section discusses the evaluation of the components which comprise the conceptual model of support, that is : process models and methods; roles; company knowledge base; risk management; planning; and the dynamic contingency approach.

7.3.1 Process models and methods

Considering methods first, Company A are confident that a methods resource would be beneficial and viable, and that Cross' (1994) framework of appropriate methods for an objective or situation was considered to provide a basis for development. However, in terms of impact upon the design environment a methods resource was seen as an improvement, but not a priority compared to process models.

In comparison, process models are pivotal for driving the design process and the present work, and potentially one of the most beneficial components. Due to the increasing complexity of projects such a resource is required in order to manage future projects, for example by emphasising considerations at the 'front end' of a project. Whilst benefits are long term, initially requiring a heavy investment in developing the models, they were deemed to be worth the investment. However the following five issues must be considered:

- The Design Process Models (DPM) should be constructed from component stages. A library of approaches for each stage of a design would be evolved through use, an idea which concurs with Hybs and Gero (1992);

- In addition to DPM's, electronic engineering also requires Process flow models (PFM)[28] which would model the flow of data between the process tools, typically software based, used in the production of an artefact. This requirement stems from the increasing dependency upon the software tools used at different stages of a design, which sometimes require extra work to enable data to be passed between them. The PFM, like DPM, would be component based and provide a means of determining which tools can be integrated and how much work is required to achieve integration between them;

- PFM's should be utilised for monitoring process tool usage as on occasion tools chosen for a particular task are not used. For example, engineers may surreptitiously use tools with which they are familiar, rather than new tools selected for a particular task. It would be beneficial, in terms of risk management and assessing the value of retaining the unused tool, if PL's were aware of these occurrences;

- Reuse of both DPM and PFM needs to meet two objectives : enable 'novices' to use and learn from past models; and contain enough detail and history of a model's use to enable refinements. Thus different views of the models will be also be required;

- To encourage reuse it is imperative that the models are validated and verified stringently to ensure control over their application and instil confidence. For example, a product developed using an innovative DPM would not be released

[28] This issue only became apparent in the concluding evaluations, an example of assumptions being maintained until strongly challenged.

until the model used in its development had been sanctioned by senior management.

The present work has concurred with Minneman and Harrison (1997) who describe the value of methods and models as providing a framework for participation and negotiation, *'not blueprints for a specified result'*. However their application requires guidance, which necessitates an understanding of the current situation of the project, which could be achieved through the dynamic contingency approach.

7.3.2 Company knowledge base

Within the prototype system the company knowledge base comprised the documentation (Product Books) and TMS components. The organisational learning component was deemed by Company A to be of secondary importance and reliant to an extent upon the success of these other components. As a consequence it was not developed further in the present work.

7.3.2.1 Documentation : Product books

The Product Book concept (Culverhouse 1995a) was seen as an improvement to documentation. However to succeed this mechanism must be adopted company wide. Whilst Company A would adopt the structure as their standard, a key issue is the constraint of completing documentation tasks which are not currently carried out. For example, "*there is a risk that engineers will see this as an overhead and revert to their own methods when under pressure. Engineers are good at getting around such constraints, especially software*" (Parsons 1997b: P7, PL1). Company A consider this hurdle to be a 'mind set' which is best overcome through education and experience of reuse in conjunction with the support of the system.

Culverhouse (1995a) proposes that documentation can and should be more reactive and dynamic rather than being viewed as a passive repository of information. The present work has confirmed this direction of development for this type of environment, for example by utilising the software agents and contingency factors to link interdependent constraints. It is imperative however, that an acceptable balance between enforcement and flexibility be maintained, otherwise this mechanism will be circumvented. This was thought to rely upon the process of negotiating to allow such *articulation work* (Schmidt & Bannon, 1992) to be carried out, together with the refinement of DPM and PFM which drive the product book templates.

7.3.2.2 Transactive memory system

The implications of introducing a Transactive Memory System (TMS) were found to be complex and difficult to assess without a more intrusive investigation. Two main functions were assumed for the component, as a staffing tool and as a means of locating a knowledge source. It was felt that the TMS would be very useful as a knowledge source, but at present, less so as a staffing tool. This reservation was due to the fact that Company A currently do not have fluid resource pools of staff, as discussed in section 7.3.3 Roles. However, it was thought that benefits would be gained as a staffing tool when applied to multi-site work involving a number of teams; which is likely to be the long term trend for Company A[29]. The following five issues were identified as areas of concern with this component :

- The level of granularity of the attributes available from the TMS needs to be considered in more depth. The level should be task dependent, that is, a different view of the information should be presented dependent upon the user's need. For example, typically when staffing a project a manager requires a guide to suitable candidates based upon some high level information. Whereas for an engineer searching for a knowledge source to help with a very specific problem, the search criteria may be much more detailed;

- The possibility exists that people could be *pigeon holed*, with two possible effects. First, from an engineers' perspective it could detrimentally affect their job satisfaction if they do not enjoy their specialisation. For example "`...pigeon`

[29] For example, the latest Company A project is multisite involving 17 teams. At the outset of this project a 'common resource pool' was set up detailing the staff available. It was noted that the data held for each person in the pool was insufficient for the task, and that additional requirements to those shown in chapter 6 should be incorporated (i.e. the physical base of the employee; their tool skills ; and their preferences regarding working conditions for example, preferences for working away from their base, and attitudes to travelling).

holing a new engineer is dangerous, especially trainees who will take time to find their feet, they won't want to be stuck in the first job that they tackle for their time with [Company A]." (Parsons 1997b: P8, PL2). Secondly, from a company perspective pigeon holing may positively increase the specialisation of roles where needed[30];

- Work may be redistributed across the workforce in an uncontrolled manner. For example by enabling anyone to locate someone better suited to complete a task, or who is able to assist in resolving a problem. The potential redistribution of work in this way may be difficult to manage;

- The potential social implications are likely to be complex, for example it could undermine the status of *gurus*;

- Keeping the overheads of creating and maintaining such a mechanism low was deemed a priority as the value of the component is greatly reduced if not adopted and maintained company wide. This is a contentious issue and the criteria for allocating attributes will require careful consideration.

Despite these issues the TMS was considered to provide a valuable contribution, and the implementation of a pilot system was thought to be the best method to assess its impact and evolve the component.

7.3.3 Roles

The benefit of the roles component depends upon the team structure adopted for a project (for example a *simple* project team structure such as a single project team located at one site, or a *complex* project team structure such as a multisite project utilising a number of project teams).

[30] It should be noted that a potential conflict exists here as Company A also see the need for less specialisation, where engineers have a broader knowledge and are more adaptable.

Considering a typical simple project team structure, project teams normally remain together usually having some specific design expertise, for example MPEG. Due to the consistency and experience as a team the PL and team members have a tacit understanding of the roles required. When a project is initiated, roles are filled by the staff available, whom will be retrained if necessary. Thus, the component would be too large an overhead for some projects, for example a simple project team structure carrying out a *repeat* design project.

Knowing which roles are unfulfilled within a team structure requires prior experience, which may not be known for an *innovative* design. If the roles typically required for a project are unfulfilled, it is likely that this will be introducing risk which needs to be acknowledged. These issues are particularly pertinent when considering a complex project team structure, where the contact and understanding between the manager and their team(s) is stretched further. Furthermore, a multi-site project would normally not be restricted to a limited set of staff, as discussed in 7.3.2.2, which further complicates the management of complex team structures.

Due to the increasing size and complexity of projects, complex project team structure are likely to become the norm. As a result Company A initiated a Human Resource Management department study of the design department's roles and skill sets with a view to developing this component. Further development must also consider the following two issues :

- The value of this resource is undermined if the roles are not actively carried out. Ryan (1995) and Tampoe and Thurloway (1993) concur with this view and argue that the incentive to adopt a role is strongly influenced by the perception of the career path associated with a particular position, for example management positions are seen to be the route of personal success. Ryan (1995) cites two main reasons why companies should adopt structures which help to link essential technical knowledge to strategic decision making. First, that technical expertise does not guarantee good management. Secondly, the shelf life of a newly promoted manager is often far shorter than anticipated. In her study in a number of domains, but in particular an electronics company, the use of consultancy roles was adopted to alleviate these problems. Consultants typically have a career structure equivalent to the managerial, less supervisory responsibilities; are encouraged to maintain their expert technical knowledge; and are involved in the decision making at strategic levels in the company. Company A concur with this idea and are developing such roles;

- The types of role available must be carefully considered as *pigeon holing* effects, discussed in section 7.3.2.2. TMS[31], and roles based on psychometric evaluations were considered to be open to misuse.

The conclusions of the present work concur with Cross & Cross (1995) who argue that as team work is a social process, roles can not be ignored when considering design team activity. The results of Company A's H.R.M. study should be enhanced by Sonnenwald's model (1996), Hales (1993) roles, and Cross and Cross (1995) requirements, and used in conjunction with the present work to provide a basis for future development.

7.3.4 Management of risk

The concept of explicitly categorising risk permits the specialisation of metrics, which can evolve independently of one another, and highlights which aspects of a project are of highest concern. Providing different perspectives of risk also enables personnel to identify their contribution, and its significance, within the project. This explicit and quantifiable expression of risk could emphasise, and improve, the communication of the consequences of actions and decisions taken.

Whilst the use of techniques such as checklists were considered useful the development of quantitative metrics, for example the Four Path Model (4PM) of design risk (Culverhouse, 1995b), was considered to be of most importance. The control of risk in current design projects has proven difficult. The control of risk in

[31] The TMS requires a roles resource to assist in providing possible attributes for personnel, and the roles resource requires a mechanism which monitors role use, i.e. the TMS & Product Books.

multidisciplinary teams increases the complexity of risk management, as different opinions and knowledge are brought to bear on the problem. As the use of such teams are thought to increase in the future, the need for techniques such as the 4PM is likely to increase[32].

Risk management methods require long term development before metrics may be profitable, for example "*a history of previous assessments must be built up as risk is tied in with the company's ground rules and history*" (Parsons 1997b: P9, PM1). Whilst the metrics evolve constraints imposed may cause unnecessary delays in project development. Therefore initial estimates must be considered to be highly negotiable. What will be key is the interpretation of information. Automatic transformation of information from other components into a risk assessment component could become extremely complex, and it may be that approaches such as case based reasoning could be appropriate here. Risk assessment was deemed a vital area which required further research to develop these ideas.

7.3.5 Planning & reviews

Within the prototype system Microsoft Project was linked to the TMS to illustrate how its functionality may be enhanced through an appropriate framework using DDE links. However, Company A already consider existing planning tools to be difficult to drive at their current level of complexity. For example, Company A employ an external consultant to generate their Microsoft Project plans. On their own planning tools were only considered to be of real value at the outset of a project, after which the effort to update them as events occur and project situations change is not seen as profitable. This is especially true if relying upon external assistance in their use.

The key benefit from this component was seen as a resource of past plans and planning techniques, possibly supported by case based reasoning techniques.

[32] In addition, its value as a metric in guiding decisions regarding levels of innovations permitted in a project are vital in facilitating the dynamic contingency approach.

Applying appropriately supported tools for certain strategies and providing standard but flexible approaches should enable such reuse.

As discussed in chapter 4 the review process was impeded by deficiencies in other areas, for example planning problems made resource allocation for reviews difficult. The development of the other components was judged to alleviate these problems, and a resource of review techniques such as using Fagan (1986) inspections and anonymous peer reviews was thought to improve the activity of reviewing.

Drabble (1995) argues that often a project is driven by the '*schedule on the wall*' rather than the projects requirements. This perspective is shared by Minneman and Harrison (1997) and Suchman (1987) who both believe that the plan should be a tool for sharing understanding not a pathway from which we can not deviate. The studies described in this thesis concurs with these views, and suggest that the plan will always change, and that it is design management's response to the change in terms of timeliness and action that should be our focus. Finding a balance between the flexibility to accommodate the design process, and manage team coordination and reusability will be difficult. This will rely in part upon supporting the social process of negotiation. The further development of this component was considered to be the least important in the system, as the emphasis for this type of support was judged to be the dynamic contingency approach.

7.3.6 Dynamic contingency approach and software agents

Due to the pressures under which the PLs work it is not feasible to capture or analyse the data that currently exists; the situational factors discussed in chapter 5, merely adding to this problem[33]. Consequently, the possibility of the system harnessing and analysing such data was seen to be extremely beneficial, as the factors in conjunction with the framework enabled more proactive action. For example : " *[The System] provides a much richer picture allowing us to run a project. Microsoft Project is fine for running a bakery, [but] electronic engineering needs human factors*" (Parsons 1997b: P10, PM1). In particular, Company A thought that access to the 'morale' and 'coherency of intent' situational factors would be extremely beneficial. This concurs with the psychological analysis (see Reid, 1997a), and Frankenberger and Pabke-Schaub (1997) and Hales' (1993) work. However, the number of possible situational factors which could be assessed (for example see chapter 5) is already complex and is an area which will require careful study. Furthermore, it is the capture of the more social factors such as morale which will prove difficult.

Whilst the use of a mechanism such as the timesheet component for capturing some of the more social factors was thought to be viable by both the engineers and managers[34], it is an area of the work which needs careful consideration, particularly on the impact upon the social system. Any further work must also consider the following four issues:

- Workloads are likely to be affected in two ways : tasks are captured earlier on, consequently workloads will be better distributed over a project; and the DCA will require information not presently available from other areas and therefore workload would be increased in those areas[35];

- The system's activities must be both controlled by, and transparent to, the Stakeholders to instil confidence. If concepts such as software agents and the DCA appear to fail, due to their nature (that is, they utilise intangible soft factors which may be viewed sceptically), the mechanisms would not be used. For example : *"we're talking about engineers relying on soft factors, if this doesn't look like it's working it would be dropped very quickly"* (Parsons 1997b: P12, PL2). As the effectiveness of the system relies upon its use by all of the stakeholders involved, issues such as this would undermine the system as a whole;

[33] This process would be further impeded when the PL and/or team are in a non-vigilant state, which is arguably the point at which the factors as most valuable.

[34] It was suggested that the input of values be unfolded if any contentious issues arose. In other words, if 'all is well' then only a few values are recorded, 'if something is up' then more values would be elicited.

- The DCA could further emphasise the divide between managers and engineers, something which Company A is trying to soften. Jirotka et al (1992) concur and report a key concern with the gathering information such as morale, is that what would normally be informal interactions or '*coffee break conversations*', becomes open to deliberate surveillance. Jirotka et al argue a typical effect of this situation is that some party will use the information in a way not originally intended that will be detrimental to the 'users';

- The DCA will provide a picture of the project's situation which will enable more flexibility to deal with events. For example : `"Flexibility would be improved hugely...Came as a revelation that as a manager you could changed [sic] your management style depending upon the project type or its current situation"` (Parsons 1997b: P11, PL2). However, the implications of introducing such a potentially flexible environment are far reaching. For example, Flemming and Koppelman (1996) argue that projects often span years, but funds are typically authorised per fiscal year, and multidisciplinary team approaches tend to accelerate functional efforts to earlier stages of a project. Thus whilst the overall cost of a multidisciplinary project may be less than a sequential approach, the early indications may be that the multidisciplinary project will be increasing costs.

A by-product would be the automatic capture and availability of a variety statistics. The PLs' have little evidence of their intuition for problem events and felt the DCA would help to provide such data. For example unproductive episodes due to personal problems, appear to repeatedly occur in some form due to the length of time of projects (for example see Culverhouse 1996a). Being able to justify for allowing for these events could improve future project planning.

The development of the DCA relies upon the other components in the support system, hence their development will constrain the implementation of the DCA. Despite the

[35] The consensus was that information which is currently not available, was work which was being

softness of the concept, the DCA, in conjunction with the software agents, was considered to be one of the most beneficial in the system. For example : "*the system enables engineers to get on with their job, it's like a doctor, he diagnosis the patient but then has to know which form to fill and how, and then where it must go etc. His skill is in diagnosis but he must know the admin[sic] to administer the cure. The system does the admin[sic] letting the engineers find the cure*" (Parsons 1997b : P3, PM1).

7.4 Considering the system as a whole

The following three sections consider the affects of the system as a whole upon the stakeholders, the design process, and the future design environment at Company A.

7.4.1 Implications to the stakeholders

This section considers the implications to the stakeholders of introducing this system into the design environment in terms of the affect upon status, recognition, efficiency, support, interest, decision making, and personal development.

Plowman et al (1993) argue that CSCW systems fail if the benefits and reasons for sharing information and collaboration are not made clear. The system could be viewed as a management monitoring device, as discussed in section 7.2.6. Alternatively the system could be viewed positively, in that its existence indicates evidence that management are getting involved in the project. The consensus was that the system should support managers in exercising their social managerial skills, rather than act on the manager's behalf.

The effects on peoples' status were all based around the TMS component, and are summarised in the following three points. First, positively or negatively dependent upon their perception of themselves against the attributes for which they have been accredited. Secondly, that tasks for which staff do not receive recognition, for example authoring of documentation, would be better acknowledged. Thirdly, that

neglected at present due to the lack of attention to the planning needs after the inception of the project 'expert' status may be undermined, due to alternative contacts for knowledge[36]. The key influence on these issues will be the criteria and validation of assigning TMS attributes, as discussed previously in section 7.3.2.2.

With regard to the recognition that people receive two main issues arose. First, that recognition may be improved if the effect upon status is positive (see previous point). Secondly, that success may be accredited to the systems' support, and failure may be seen to look worse if the tool is thought to provide support, for example : "*Success is expected, and failure is recognised. If you succeed maybe the tool will be given the credit; if you fail with the support of the tool it may make you look worse.*" (Parsons 1997b, P13, Eng1). The consensus was that the system should improve efficiency and thus improve the users recognition.

Opportunities for personal development could be affected, as success was seen to facilitate personal development, a view shared by Tampoe and Thurloway (1993). Whilst Company A felt that the system would increase success and thus improve opportunities for personal development, a key concern was the risk of staff becoming pigeon holed as discussed in section 7.3.2.2. In contrast Company A consider the current half life for an engineer to be 2-3 years. Consequently staff must continually be trained in new techniques in order that the company survives. Thus the effect of the system on personal development is difficult to predict and will require further, more intrusive, investigations to truly gauge its impact.

Providing support for managers such as earlier problem identification and enabling a better match and use of engineer's skills, was thought to improve the support an engineer receives. In addition, components such as the Product book structure and TMS should improve engineers access to information and knowledge.

Considering the implications to the interest that people have in their roles, the TMS, Roles and Product Books should provide a better picture of a person's contribution to

[36] It should be noted that it was thought that the influence of the system, may not be as great as

the project and make them more conscious of new skills attained. Two issues were raised which will require further consideration : it was expressed that one aspect of a managers skill is to 'filter' information to maintain interest[37]; and the possible effects of pigeon holing staff (see section 7.3.2.2).

Introducing such a system may be seen to affect the opportunities to take decisions in three main ways :

- the system will map sufficiently onto the real world to not affect decision making;
- the system should provide richer information earlier on, allowing a more proactive approach. For example : *"Due to the lack of time you have you juggle the small problems as they happen, therefore lots of smaller problems are not dealt with until they build into one big problem and you have to deal with it."* (Parsons 1997b: P15, PL1);
- the system will constrain peoples actions to Company A's chosen philosophy, thus the ability to be make intuitive decisions may be stifled.

7.4.2 Impact on the design process

This section discusses the impact of the system on the design process in terms of constraints, access to knowledge, ability to apply knowledge and skills, workloads, working pressure, and collaborative work.

The validation and verification of resources in the system is a key issue for the system's acceptance. If the controls of the system, for example adding DPM's, are not trusted then there will be no faith in the system. As discussed in section 7.2.1, the authorisation process must be rigorous and explicit.

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interpersonal communications, concerning 'expert' status.

[37] The issue of filtering information also affects concepts such as the product books and will require a more in-depth analysis.

The overheads of the DCA would not justify its use for projects involving less than two man years work. However such projects may still use some of the components in the system such as the TMS and product books.

The TMS and product books were thought to adequately capture knowledge that is required, and be flexible enough to adapt with the environment. However Company A consider the means of retrieving knowledge as a key[38] issue, a problem common to engineering (see Court et al, 1994). Whilst the concept of a book structure and templates should assist information retrieval, it is likely that a more sophisticated system wide mechanism will be required (for example, further developing the Personal Information Agent - see section 6.4.6.3).

The approach will support the application of stakeholders' skills and experience to deal with situations as they deemed necessary. However, whilst concepts such as software agents carryout tasks on behalf of users, agents and possibly the DCA have the potential to deskill stakeholders.

In the long term workloads should be reduced due to the opportunities for reuse, and as problems can be tackled earlier on before knock on effects occur. However the following three issues need to be considered :

- In the short term workloads would increase, particularly for managers, for example : *"The system cuts both ways - does more for you, but flags work which may previously have [been] ignored"*[39] (Parsons 1997b : P16, PL1);

- As the system develops and becomes more proficient it may be possible to shift workloads, for example managers could delegate tasks which have become

[38] To cope with technological platform constraints Company A are currently using an intranet system for storing and retrieving information, however they are encountering difficulties when attempting to locate relevant information, for example either too much irrelevant information is retrieved or a match is not found.

[39] These tasks could of course still be ignored, but the implications of ignoring the tasks would be clearer.

better understood. This may have a negative effect upon other stakeholders, for example design engineers;

- The TMS may make other peoples' knowledge more accessible and thus increase their workload. It could be argued that this may also better distribute the workload around the workforce, but this could in turn make resource management more difficult.

Company A consider their design environment to be a high pressure working environment. The support provided by the system to managers and designers should alleviate working pressures. For example : "*...although writing things down does formalise targets, everyone is aware of the pressures anyway. The system should support you and therefore reduce them.*" (Parsons 1997b : P16, PM1). However as the system evolves it is likely that the company would expect factors such as time-to-market to shorten, which may increase pressure; for example "*the very fact that a system such as this is being introduced implies that the pressures on TTM [Time-To-Market] are increasing*" (Parsons 1997b : P16, Eng1).

Heath and Luff (1992) state that "*collaboration necessitates a publicly available set of practices and reasoning, which are developed and warranted within a particular setting, and which systematically inform the work and interaction of various personnel*". The system should improve awareness and understanding of information requirements between people, team building, ease multi-site work, and the coordination of work would be improved through the application of agents and the dynamic contingency approach. However, Company A consider the PL and the dynamics of the team to have a more significant impact on the collaboration of project personnel than any support system. This concurs with Cockburn and Jones (1993) who argue that forming and maintaining collaborative relationships requires continual trade-offs, which are essentially social processes, and introducing technology into this '*complex balance is often counter-productive*'. Furthermore, as has been discussed in this chapter, potentially the system could further divide the managers and engineers.

Therefore the system must support the stakeholders in determining their own social processes for coordinating work.

7.4.3 Overall assessment

Although this system will initially require a large investment of time and effort it was judged to have the potential to offset the initial cost. Company A must address the issues identified in the rich picture to be able to cope with future[40] projects, for example : "`providing point tool solutions won't work, it's like a chain with a missing link`" (Parsons 1997b : P18, PM1). Company A considered, that with further research as described above, the system was viable and the "`First tool which appears to take the burden off of the design manager`" (Parsons 1997b : P18, PL1).

7.4.4 The future

In addition to the issues discussed in the preceding section, three key issues were raised concerning the future of the design environment at Company A :

- Change was considered to be inevitable, likely to happen quickly, and be difficult to predict long term. Therefore the system must work with these conditions and not attempt to control them;

- Products and projects will become increasingly complex;

- To cope with the increases in complexity Company A have to improve their reuse of design and project knowledge. Company A's aim is to achieve 80-90% design reuse within three years[41];

- To cope with the increases in complexity Company A will employ resources external to the company for specialist tasks, via contracted consultants[42] or joint

[40] The latest Company A project is estimated to require 200 man years using existing techniques.
[41] To encourage re-use a *reuse police* role has been developed, to check upon the provisions for reuse being made within projects.
[42] A common requirement for design projects (Culley et al, 1993)

ventures with other companies. This is likely to require remote working, in other words projects will increasingly become multi-site and eventually multi-country. This increases the need for coordination and risk assessment tools as the implications for changes to plans and designs will become even more costly and far reaching.

Company A considered the system to support the direction in which the company wishes to move and capable of meeting their requirements.

7.5 Further work

This section outlines the future development of the approach[43], which was determined in conjunction with Company A. The key development stages, outlined in the table below, were determined to be : assess the impact of the TMS component; derive metrics for the Risk Management component; develop a stock of process models; and investigate and calibrate the appropriate metrics and structure for the DCA.

Further development

Stage	Tasks	Resources
Approach Elaboration	- Develop TMS - Develop Risk Metrics - Develop Process models - Investigate and develop DCA	UoP research staff employing ethnography and systems analysis at Company A.
Rapid Prototyping	- Prototype key components - Evaluate with target project - Generic evaluation with other projects.	UoP staff to develop prototypes. Company staff to consult and evaluate.
Software Development	- System development - Alpha release	UoP and Company A staff to consult and evaluate. Collaborating systems development company to develop system.

In any future work other areas within Company A should be more heavily involved in the project, for example Test, Manufacture, Marketing and Human Resource Management. Company A are at the time of writing initiating the next phases of the project in collaboration with a European software company and the UoP research team.

[43] The subject of future work is also discussed in the concluding chapter.

Issues such as a method for implementing the system remain unresolved, however these issues can be determined more effectively once the more focused studies have begun and a better understanding of the actual functioning and impact of the components has been developed. What is certain is that the system's introduction will change the current environment. Reducing intersubjective requirements to functional requirements to enable a more conventional systems development paradigm is likely to remove the social contingencies of any findings (Stowell & West, 1994). Furthermore, Sommerville and Rodden (1996) found that the introduction of new technology in an engineering environment caused resentment because the engineers, "as professionals", were not involved in the process of selecting an appropriate development method. Such issues suggest a continued soft approach to developing the system. A key difficulty in the approach for the present work has been the time and resources required. However with the use of RAD tools such as Delphi, and the increased resources as mentioned above, the development of the project using a similar approach was considered feasible.

7.6 Conclusion

This chapter has discussed the concluding evaluation of this work by Company A. This was essentially the final stages of SSM, where the conceptual model of support was compared to the rich picture of the current situation. The evaluation method also introduced pertinent topics from CSCW evaluation literature, to encourage the consideration of wider issues. Much of the conceptual model was well received, but this would be expected to an extent as the thrust of the exercise is reconfirming the stakeholders own thoughts. However, the exercise did reveal further requirements and identify issues which require further study.

Hales (1993) and Cross (1994) amongst others argue for a more systemic approach to design : " *this is a challenging and complex task involving the handling of diverse influencing factors, continuos team building, monitoring of design progress and facilitating technical reviews*" (Hales, 1993). In the industrial setting of a design project, using current methods it is not feasible for design management to carrying out these tasks. Company A have judged the concept of a dynamic contingency approach based upon the system presented here, to viably support the issues raised in this thesis. Its further development is being actively encouraged by Company A who believe that without such a system their future design projects will be extremely difficult to manage.

"This is not the end.
It is not even the beginning of the end.
But it is, perhaps, the end of the beginning"
(Winston Churchill, 10/11/42)

8. Conclusion

Reflection is a fundamental aspect of improving understanding (Collins et al, 1989). This final chapter comprises five sections which reflect upon the work contained in this thesis with the benefit of hindsight. The fist four sections reflect in a fairly practical manner upon key issues of the work. First, the aim of the work is discussed. Secondly, the UoP project method of research is critiqued. Thirdly, the deliverables of the present work are discussed. Fourthly, the further development of the present work and the UoP project is considered. The final section of this thesis discusses the author's more philosophical reflections on the project as a whole.

8.1 The aim of work : *where we started*

This section reflects on the aim of the work discussed in this thesis, as outlined in section 1.1, with the benefit of hindsight. As the aim of the present work was formulated as part of the UoP research project aim, the issues raised below are discussed within the context of the UoP project[44].

In summary, the aim of the UoP project and specifically the present work, was to build theory and develop support for the management of the early stages of team electronic design. This fairly broad aim was adopted due to the poor understanding of the environment of the management of team electronic design. The management of design teams being a task which Hales (1993) describes thus : " *this is a challenging and complex task involving the handling of diverse influencing factors, continuos team building, monitoring of design progress and facilitating technical reviews*".

The emphasis taken at the outset of the UoP project has been described within this thesis as holistic, that is, assuming that wholes evolve which are greater than the sum of their parts (Hayward & Sparkes, 1991). By this we mean that the objective was to evolve an understanding of the interdependencies of aspects of the environment such the social, technical and organizational factors through emergence, rather than focus upon a particular aspect of the management of the design environment. To this end the longitudinal psychological study adopted ethnographic techniques, and the present work adopted SSM to generate an emergent rich picture of the whole.

The UoP project research method of combining SSM and a longitudinal psychological study utilising ethnographic techniques, was fairly innovative. Without a model for combining these approaches it proved necessary to rely upon an emergent relationship, rather than attempt to detail the dependencies between the studies at outset. As a result the relationship between the longitudinal psychological study and systems analysis evolved during the course of the project. This necessitated a relaxation of the normal expectations of the different disciplines and open communication amongst the research team. Whilst a more defined aim may have eased the working relationships amongst the research team this may have constrained the investigation and hence the outcome. Thus whilst a multidisciplinary research approach can be uncomfortable for the participants, particularly in the formative stages of the work, working relationships did improve as the work progressed and the results appear to be beneficial. In terms of future projects using techniques such as ethnography and systems analysis in concert, the UoP project team should now be able to better define the relationship and aims between such techniques.

Although an holistic stance was taken at the commencement of the present work, it is evident from the deliverables that a process of focusing took place, that is the work began to focus upon components within the whole[45]. It could be argued that any modelling of a situation is intrinsically reductionist. Whilst it is not the purpose of this thesis to debate this issue, what can be gleaned is that the deliverables of the present work should be resituated in the context of the whole. In other words, the conclusions of the longitudinal psychological study will provide rich ethnographic

[44] It should be noted that at the time of writing work is still in progress to complete the final conclusions of the longitudinal psychological study.
[45] As discussed in section 8.2, due to such a broad aim and rich method of research, the resultant data was difficult to structure which also contributed to the need for focusing.

descriptions of the state of the social and organizational aspects at a given time which provide the context for the dynamic contingency approach. Anderson, Button, and Sharrock (1993) described such use of ethnographic data as illustrating 'the social institution of courses of action'.

Whilst this 'view of the whole' as an aim may have receded during the development of the present work, it has still proven to be valuable. For example, as discussed in chapter 3 a key issue when developing support for groups, particularly through technology, has been that the work is typically management led and myopic. The aim of evolving an understanding through a number of stakeholders rather than just the design manager, combined with the ethnographic viewpoint, has helped to lessen these problems.

The social dynamics which are still emerging from the analysis of the longitudinal psychological study are paramount to the success of the dynamic contingency approach. As discussed in chapter 1, the present work adopted Warboys' (1995) focus that engineering management face three social challenges: the development of personnel so that they can achieve their best; how to give personnel the fullest opportunity for contribution; and how to unify the various contributions, that is, the problem of coordination. The work described in this thesis has not aimed to directly address such issues, but their implications have been considered. As discussed in chapter 7, the application of the dynamic contingency approach has the potential to both support and detract from these challenges. For example, the Transactive Memory System (Section 6.4.3.2) could assist in making people's skills more accessible, but could also pigeon hole them. Furthermore whilst the coordinating mechanism such as the agents and product books could assist in unifying contributions, as discussed in chapter 1, Bucciarelli (1988) would argue that team design is a social process and managed through social skills. For these reasons whilst EDAPT may be supportive, or indeed a hindrance, the responsibility for these three social challenges lies within the social aspects of the working practices adopted by design management. These working practices are still the subject of analysis by the

UoP team. As such the aims of the present work have been realised, but the full aims of the UoP project can not be fully assessed until the whole project is completed.

8.2 Critique of the method of research

This section critiques the research method which was evolved for this work. The need for evolving such an approach for an investigation of this nature is discussed in Parsons et al (1997). In summary, it was considered that the social, multidisciplinary, and complex nature of design team environments was not amenable to 'hard' structured analysis techniques. Accordingly a 'soft' approach, utilising a multidisciplinary research team drawing upon a longitudinal psychological study conducted by a fellow researcher employing ethnographic techniques, was adopted. Whilst this section focuses upon the system's analysis, any critique for such a multidisciplinary approach must consider the method in the context of the UoP project.

The longitudinal and soft nature of the UoP project provided three clear benefits which concur with Sommerville et al (1994). First, it revealed the speed of change within this environment. Secondly, it revealed how often a company's formal structures prove inadequate and have to be bypassed or adapted. Thirdly, it revealed the effect of organisational influences upon requirements for the system, and events in a design project.

The longitudinal and soft nature of the UoP project also enabled the requirements for improving the current situation to evolve with the formative development of the stakeholders' and the research team's understanding of the situation. This served to increase company A's confidence in the results, for example one engineer stated that '*we weren't jumping to conclusions and solutions*'.

In contrast to these two positive points, the length of time for development also proved frustrating for some of the stakeholders, and meant that vital staff were no longer available for this work (for example, two stakeholders left the company). In a long term project in a domain where there is a fairly high turnover of staff this can have major impacts upon the research and should be considered at the outset of the work.

The use of soft analysis techniques can also prove difficult. May and Barnard (1995) cite the difficulties of controlling the application of informal techniques as a typical cause of their failure, and this has been a key problem encountered with the method of research used in the present work. When utilising a multidisciplinary systems analysis approach such as SSM, each member of the development team will have their own perspective and aims for the work, often these may conflict with other members. For example Marketing would like to keep design requirements fluid for as long as possible, whilst an engineer would like to see a clearly defined concrete problem to solve. Attempting to steer debates towards consensus in such potentially contentious forums required the improvement of managerial skills by the research team, and the attainment of a level of appreciation of the perspectives of all those involved in the development process, that is the growth of empathy. Whilst SSM provided a workable framework which enabled these forums to function, due to the diverse interests of the stakeholders the present work is unlikely to have reached its findings without the support of the multidisciplinary research team in which close cooperation via negotiation and debate were vital.

Another key factor in facilitating the research method was the development of the prototype system, which provided a tangible means of representing the conceptual model. The earlier representations of the system were less tangible, consequently some key assumptions and issues were not revealed until the prototype was developed. The prototype also proved particularly useful when discussing the work with stakeholders who had had limited involvement in the development process, for example where they were introduced to the work in place of staff that had left the company (a problem mentioned above). Although the use of the prototype in this manner may have biased the views of stakeholders introduced at the latter stages of the work, given the resource and time constraints this was a necessity.

The rich quality of the data gathered for the work enabled the approach proposed in this thesis to be developed. However as discussed in chapter 3, the volume and richness of the data produced by the techniques and methods used in this approach proved difficult to structure and interpret. In particular the longitudinal psychological study, conducted by a fellow researcher, and the evaluation exercises conducted by the author, generated large volumes of extremely rich information which was difficult to structure. As discussed in chapter 3, whilst the intention of preserving an unpolluted perspective is important for theory building work, the initial stages of the longitudinal study had to be progressively focused. Even after focusing the study a large of amount of rich data exists. If a different perspective were taken for analysing and structuring this data it may well reveal new information. A similar problem occurred, although to a lesser extent, with structuring and analysing the data from the final evaluation exercises. This problem has been noted by Lloyd and Deasley (1997) who report having successfully utilised software tools to categories their ethnographic data captured from case studies of design teams. Such tools should be considered for any further work involving such rich data.

A concern which has not been directly addressed in this work, but is certainly important for any future work, is the use of SSM and ethnography techniques concurrently. The underlying principles of ethnography is non-intrusiveness but SSM is an intrusive approach, in that at the very least it causes the participants to re-evaluate their current thinking. Within the UoP project there appears to have been no detrimental effect on either study, although we have no means to test this assumption. It is possible that the 12 month delay[46] between the commencement of the psychological study and the systems analysis help to negate this potential conflict; although again we have no means to test this assumption. Nonetheless, any future work most consider implications such as this when determining appropriate approaches. If we assume that the fundamental difference between an action research based approach and the ethnographic approach is the intent of the investigator, then the key to the use of ethnography is the careful consideration and awareness of the effects of the investigator's presence. In other words, an ethnographer aims to capture

[46] Some of this delay was unintentional, but it has appeared to be beneficial to the work.

a rich description of the environment without changing the environment; whilst being aware of the effects of their presence. Whereas, an action researcher would be acting more as a facilitator in changing the environment. Thus ethnographic techniques may be useful providing the implications of their use are understood.

Whilst the present work's research method has appeared to be beneficial for the early stages of the system's development, its suitability for any further work on this project has yet to be resolved. As Twidale et al (1994) argue it is difficult to truly evaluate the system in isolation from the work place. Further, Jirotka et al (1993) state that ethnography is not capable of determining whether features of an environment should or will be preserved when new technology is introduced. In contrast, Hughes et al (1994) present 'evaluative' and 'quick and dirty' ethnographic models which may suit the future development situation. However, as the later stages of the development of the system is likely to require more intrusive research it is likely to become increasingly difficult to maintain ethnography's non-intrusiveness. Plowman et al (1995) conclude that the use of ethnography will vary with the phase of a project and as such we should start to consider where and when it is applicable. As the changes due to the introduction of the system will need to be determined within the context of the workplace there appears to be a place for ethnographic techniques in any future development. However as Twidale et al (1994) state, the effects of the system's introduction may take years to manifest themselves. As a consequence they call for evaluation to extend well beyond a systems implementation. Whilst this is a rational viewpoint, this situation may trouble a commercial company reliant upon such systems.

The concluding evaluations focused upon validating and verifying the requirements and not on assessing the effectiveness of the proposed system. As discussed in chapter 7, whilst the evaluations included topics taken from the CSCW field, the main thrust of the latter stages of SSM is the comparison of the conceptual model with the rich picture. The exercise focuses upon verifying that what is being represented is what the stakeholders have asked for, that is, a process of re-confirming the issues and the requirements for their support. However, the effectiveness of the system will also be dependent upon many factors including the re-design of the work process and practices. The details of these elements of the socio-technical system design are outside the scope of the present work and have been regarded as being in the domain of the longitudinal social psychological study. Whilst some the social elements of the UoP project have been outlined within the present work, the detail of the social elements of the longitudinal social psychological study have not been elaborated upon here. Thus, the findings and recommendations of the longitudinal social psychological study are a vital component to the further development of the present work.

Twidale et al (1994) argue that the influence of the scientific paradigm upon the perceived benefits of evaluation techniques has led to formal techniques as being regarded as "*more proper*" where their aim is *proof*. In contrast the engineering paradigm accepts that "*proof by construction is permissible*". Twidale et al suggest that typically successful commercial systems evolve through a mixture of both formal and informal techniques, and that informal techniques can be considered to be oriented towards the incompleteness rather than the completeness of the system as : "*all problems scale up and out; any success may not*". Whilst informal techniques may not obtain such fine grain findings as formal techniques, within the present work they have revealed information which has enabled the evolution of the dynamic contingency approach in a far shorter period of time than more formal methods would have permitted. Furthermore, if we accept the arguments put forward above, it is unlikely that the effectiveness of any system can be truly assessed outside of its environment of use.

The method of determining requirements does not just affect the establishment of requirements, but will also affect any eventual system design, because it contributes key rationale for design choices (Budgeon, 1995). Whilst our aim has been the development of requirements, a by-product has been the beginnings of a system's architectural design, as discussed in chapter 6. At this stage of the work the architecture has been viewed as a beneficial by-product of the work. However further developments may prove that the architecture may constrict design choices with negative consequences.

The effectiveness of the research method may be partly gauged by considering the results of the work. On this basis the research method can be considered to be effective in establishing requirements for support at company A (see appendix D). However the points raised above should be considered in any future use of such a research method, as discuss in section 8.4. Furthermore, whilst the research method appears to have been successful in establishing requirements it is not a until a product is realised in its intended environment that we can accurately gauge the success of the initial phases of the work. Therefore we would concur with Hughes et al (1994), who state that the claim for using ethnographic techniques in this way remains promissory rather than proven.

8.3 Assessing the contribution of the work : *what was delivered*

This section considers the contribution from this thesis. The UoP project aimed to build theory and develop support for the management of electronic design teams. In the context of the present work this meant two deliverables : first, the identification of requirements for supporting the management of design at company A; and secondly the identification of requirements for support which could be useful for the engineering design community as a whole. This thesis has presented these two deliverables: first the work developed with, and validated by, company A; and secondly by framing the issues in the wider engineering design management context.

The contribution from this thesis, the dynamic contingency approach, has been evolved and evaluated through a socio-technical prototype system entitled EDAPT: Engineering Design Ally for Project Teams, using a soft systems approach (Checkland, 1981) in conjunction with company A. This system may be termed an *informate system*, which Norman (1993b) describes as a system which provides a rich variety of information, that would not be accessible without technological support, and which enables people to see the 'larger picture' and therefore make more informed decisions on a day by day basis. Furthermore the approach should facilitate more proactive management, and support the establishment of a design team environment with a better match of resources and coordination mechanisms for a project's current situation. The letter of support to the EPSRC (appendix D) illustrates company A's opinion of the work.

The results of the present work can be framed in the engineering domain in general by considering the "Current issues in design - survey 1995/6" (Culley, Owen & Pugh, 1997). Culley et al's (1997) survey, which was conducted by the Institution of Mechanical Engineers and the University of Bath, had two objectives. Firstly, to '*establish the current position on a number of key issues associated specifically with innovation, training, and new working practices*'. Secondly to '*assist in the formulation of policies and support strategies*' to inform appropriate bodies such as the Institute of Electrical Engineers, and assist in determining the future of engineering design. The survey focused upon the following specific areas : design activity and organisation; support tools; business strategy; people issues; training aspects; and drivers and constraints for innovation. The following three recommendations from Culley et al's (1997) work were identified and explored in the present work.

First, whilst a great deal of literature exists upon team building and cooperation strategies, this area is still viewed as a major problem in the design process. The present work has indicated that this could in part be due to a lack of information, a lack of time and experience at the outset of a project, that often a project situation will change requiring different tactics for these issues, and that the change in situation is difficult to perceive and the corrective action unclear. The dynamic contingency approach suggested in the present work aims to support the management of these issues.

Secondly, incremental (that is, variant) design should be nurtured through the establishment and development of design practice, processes and standards. Whilst the survey proposes that these needs should be addressed at the educational level, as has been discussed due to the current approaches that are taken (for example, the lack of a TMS), designers often have to develop their own experience through mistakes rather than reusing previous models. EDAPT has made provision for the evolution and utilisation of such resources to be enhanced through the company knowledge base, as described in chapters 6 and 7.

Thirdly, communication systems within design are more deficient than in other UK business areas. Culley et al (1993) hypothesise that this is due to engineering design being of a different nature to other types of business. Certainly within electronic engineering the complexity, dynamic nature and length of the design phase of projects requires support in guiding and maintaining an appropriate balance between flexibility and formality. The approach suggested in the present work aims to help manage this conflict.

In these three areas, identified by Culley et al (1997), the present work can be seen to have shed some light on some common complex problems in engineering design. However one of the precepts of ethnography, and to a lesser extent SSM, is that work environments and practices are highly situated and together can often be considered to be unique (Plowman et al, 1995). Consequently, the use of such methods results in systems for specific situations, and any theory postulated should be viewed in this light. Nevertheless, whilst the work described in this thesis is based upon the requirements of the electronic engineering environment at company A, from the findings of Culley et al (1997), Andreasen et al (1997), and the outcome of Engineering Design Debate 1996 (Duffy, 1997) there are clear indications that the issues considered in this work may be common problems in engineering design.

Whilst the dynamic contingency approach offers support in the areas discussed above, the following three points raise a number of social issues, which remain unresolved at the present time, which could to varying degrees affect the value of the dynamic contingency approach. The weight of such are issues likely to become more evident in further, more intrusive development, as discussed in section 8.4.

- the system's 'soft' nature (for example, *feelgood* factors) could easily be distrusted by some personnel, as discussed in chapter 7;

- the system could potentially be used as a monitoring agent for management, as discussed in chapter 7;

- the resultant approach is very much management positive. The intention of the research method was to allow for bias when gathering requirements by eliciting the issues and the requirements for support from all of the stakeholders. From the evaluation exercises it appears that the engineers and other stakeholders are pleased with the results. However the resultant approach appears to be very management positive (for example the potential for misuse). Consequently, concepts such as Agency Theory (discussed in chapter 5), where managers aim to fulfil their own personal objectives which may be detrimental to the project as a whole, should be re-examined;

- The approach is reliant upon issues such as people actively using EDAPT and agreeing to buy in to the approach in terms of the effort involved versus the benefits gained.

Company A consider such issues to be of an organizational concern, that is, pertaining to the mind set of the company's personnel. Company A suggested that some of these issues may be alleviated through using the conclusions of the longitudinal psychological study as material for organisational learning. However some issues will remain the subject of personal characteristics, and must be considered in the future.

Plowman et al (1995) discuss how the practical offerings from soft studies, such as the present work, often feel meagre compared to the rich accounts of the workplace which are developed; typically because the '*sociality of work can not be reduced to metrics*'. The development of a dynamic contingency approach which synthesises technical and social situational factors could begin to bring the product of the UoP project closer to the richness of the raw data. As Anderson, Button and Sharrock (1993) argue the incorporation of social factors in to a research method is not just a case of implanting the data, rather it illustrates the social institution of courses of action; where we are "*not so much at the interface as in it*". Thus, as discussed in section 8.1 a key element on which the dynamic contingency approach relies is the final conclusions from the longitudinal psychological study.

8.4 Further work : *where next*

A plan of further work was derived with company A as part of the concluding evaluation exercise as discussed in chapter 7. The plan outlines the main areas of concern for the next phases of the work and the potential means by which the development of the approach could be progressed. However in addition to the points raised in chapter 7, the issues discussed in this section will need to be resolved prior to such work commencing.

As discussed in the preceding sections of this chapter, the final conclusions of the longitudinal psychological study will be vital in illustrating the social institution of courses of action, and providing more guidance in managing the social factors which affect this environment. The culmination of the present UoP project is therefore a priority before any further development of the present work commences.

The dynamic contingency approach proposed in this work has been evaluated, and deemed viable and beneficial by company A. However, as McCarthy (1994) argues it is the further development of any CSCW type system that will be the real measure of its value. Two key problems reported with the introduction of systems of this type are that the social issues become lost as the system hardens up, and what has become known as the discrepancy problem[47] (Plowman et al, 1995). To counter these issues Plowman et al suggest the use of 'gardeners' who nurture the co-evolution of the work and the system. Based on the present work this method could be applied through action research using a rapid prototyping approach. Whichever methods are adopted

[47] Where the introduction of a support system merely shifts work to others, for example from the management to the workforce.

the further development of the system is therefore likely to require more intrusive techniques than those used to date.

The use of more intrusive techniques may, as discussed in section 8.2, increase the complexity of applying ethnographic techniques. However the abandonment of the soft approach to development could cause the loss of valuable context based emergent information, as discussed above. The further development of this work will need to carefully consider which techniques will best progress the development of the dynamic contingency approach. Regardless of the research method adopted the magnitude of the next phases of the development will necessitate much larger resources than those available for the present work. This will increase complexity in co-ordination and consensus, key factors in the research method used for the present work. The increase in magnitude of the work must therefore become a key driver when considering a method of research for any further development. The conclusions from the present work would suggest that the best approach is likely to be a blend of methods suitable for the context of the future work, an approach advocated by Bansler and Bodker (1993).

8.5 Reflections on the project

Collins et al (1989) argue that *reflection* is a fundamental aspect of improving understanding. The preceding sections in this chapter have reflected, in a fairly practical manner, on the present work with the benefit of hindsight. This final section presents the author's reflections on the present work in a more philosophical manner.

The present work commenced with the aim of theory building, the intention was that through emergence the problems and requirements for support would evolve. The work began with the generation of a rich picture of the problem situation. This rich picture continued to evolve and become richer throughout the project. The issues from the concluding rich picture stem from a conflict which revolves around the need for formal structures and processes in design projects to enable growth and coordination, versus the need for flexibility to cope with the dynamic and interrelated nature of design. To improve the current problem situation a series of conceptual models of support were developed. The continual development of the rich picture necessitated the refinement and progression of these models of support. In this way the support progressed from providing a passive interrelated homogeneous environment; to actively supporting the communication of significant events occurring in the environment; to the rationale for proactive support via a dynamic contingency approach. This last concept synthesises the earlier models of support into an approach which provides an environment which supports the management of the conflict between the need for flexibility and the need for formality. The approach reconceptualizes the concept of a macro level contingency theory, where significant factors are identified to guide the current organisational structure, into a micro level highly dynamic theory which incorporates both technical and social factors, and considers the strengths from alternative organisational paradigms such as organizational learning, to compensate for the known deficiencies of contingency theory.

In this way the emphasis of the present work shifted from the immediate problems at the 'coal face' to the root issues in the environment. This emphasis may be compared to the ideas of Giddens (1989), which have been adopted by Scott Poole and DeSanctis (1990), concerning Structuration Theory (ST). In essence ST views any organisation as having a structure which is composed of rules and resources, which are fairly stable. A group can adopt and use the structure in anyway they deem necessary. In this sense the use of the structure becomes the system. Scott Poole and DeSanctis (1990) adopt this theory and apply it to groupware technology. They postulate an Adaptive Structuration Theory (AST) where the system emerges from the groups' use and adaptation of the structure available, and its affordance. The rationale for the approach discussed in this thesis concurs with this idea, where support is not just directed at the structure, but also at enabling and supporting the dynamic emergence of the system, and the affordances of the structures to meet this purpose. This emphasis may be contrasted to the SSM perspective (Checkland & Scholes, 1991) used in the present work. SSM emphasises the different perspectives of different stakeholders, where the difference between stakeholders is typically their function or role within the environment of interest. AST postulates that for example, two groups of stakeholders with the same role or function will, due to the particular context of use, build a different system from the same structures to meet a similar aim. Both the SSM and AST perspectives are valuable in generating an understanding of the environment, and could potentially provide a framework for further work.

In section 8.1 the issue of personal development was discussed within the context of the social challenges facing design management. Taking a wider perspective any further development of this work should revisit the organisational learning (OL) paradigm. What has been postulated in this thesis, particularly in the preceding paragraphs, falls neatly within the three level of organisational learning proposed by Argyris and Schon (1978) discussed in section 5.5.2. Specifically the key aspects of the approach presented in the present work reflect Argyris and Schon's 'Deutro' learning level, where the use of structures to create systems, is itself viewed as an AST system. As such the OL paradigm in conjunction with AST and SSM would seem to offer tools for supporting the further conceptualisation and development of the dynamic contingency approach.

The development of the contribution from the present work, a dynamic contingency approach, was made possible by the emergent research method adopted. This relied upon taking a multidisciplinary perspective to the study, in a forum which enabled each perspective to be considered and synthesised into a coherent opinion. The use of the Soft Systems Method as a framework for the research model enabled such a forum to exist. Hales (1993, page 9) argues that design management require " *a framework... within which the design manager has room to move about, fitting together bits of the jigsaw as they come together and applying a variety of techniques to maintain steady overall progress towards a finished product*". The dynamic contingency approach presented in this thesis provides a foundation for developing such a framework. Further study and development will be necessary to provide the design environment that has been proposed in this thesis. Such further work will require the resolution of issues identified in this chapter and throughout the thesis. What has been achieved is a design management worldview with sufficient detail to help people expect and anticipate what might happen, and how others may behave in a team design environment, together with the foundations for a system which enables and supports this perspective. In essence the approach provides a way of conceptualising the design environment which should enable improvements in the management of design teams at the early, conceptual stages of electronic engineering design projects.

9. References

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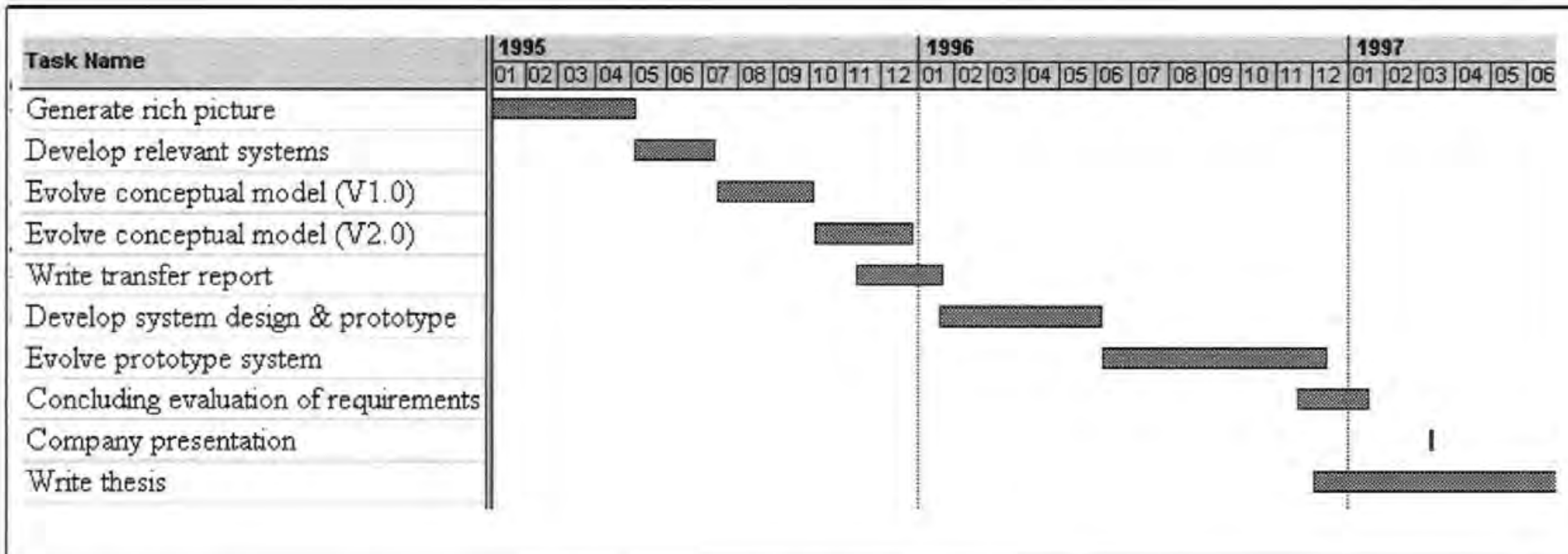
10. Appendix A : gantt chart illustrating a normalised schedule for the project's development



NB. Whilst the actual process was iterative and concurrent, this normalized schedule offers an idea of the input to a deliverable.

11. **Appendix B :** Relevant systems' CATWOE definitions

This appendix details the CATWOE definitions for the three key relevant systems discussed in chapter 5.

Relevant system 1:

➢ ***Customers***	: The members of the design team (i.e. both engineers, PLs & PMs);
➢ ***Actors***	: The members of the design team;
➢ ***Transformation process***	: Produce design specifications which meet the needs of the requirement specifications;
➢ ***Weltanschauung***	: Due to the complex interdepencies inherent in a team design project, unaided issues such as the coordination of work become too complex for the design team to manage effectively;
➢ ***Owner(s)***	: Marketing function and Senior Management;
➢ ***Environmental constraints***	: That the company will continue to exist.

Relevant system 2:

➢ ***Customers***	: The PLs & PMs;
➢ ***Actors***	: The PLs & PMs;
➢ ***Transformation process***	: Realign the design environment so that it is appropriate for the current project situation;
➢ ***Weltanschauung***	: Due to the complexities and pressures inherent in the design environment, a project's environment (i.e. the way in which it is conceptualised and structured) may not reflect the actual situation of the project, which is continually changing. Unaided the project may be allowed to function in an inappropriate environment which can have negative effects upon productivity, and the goodness of fit of the solutions delivered.
➢ ***Owner(s)***	: Senior Management
➢ ***Environmental constraints***	: That the company will continue to exist, and that Senior Management will permit the actions deemed necessary by middle management.

Relevant system 3:

➢ *Customers*	: The PLs & PMs;
➢ *Actors*	: The PLs & PMs;
➢ *Transformation process*	: An appropriate project environment to meet the requirements of a project's situation;
➢ *Weltanschauung*	: The structuring and conceptualisation of a project environment is dependent upon a variety of factors. Deciding upon the appropriate structure can be difficult and is not currently available as a resource to company A. By providing a framework to guide such decisions, company A can support this activity at the inception of projects and whilst they are in progress. By continually referencing and refining the resource the company and progress their understanding of the design process.
➢ *Owner(s)*	: Senior Management
➢ *Environmental constraints*	: That the company will continue to exist, and that Senior Management will permit the actions deemed necessary by middle management.

12. **Appendix C :** the structured interview model for the concluding evaluation

Preamble

· **Please name the components that comprise the socio-technical system** ?

- [ ] Process Models & Methods
- [ ] Roles
- [ ] Documentation
- [ ] TMS
- [ ] Risk Management
- [ ] Planning & Review
- [ ] Software Agents
- [ ] Contingency Management framework

· **Approximately how much of your time was spent with each component** ?

- [ ] Process Models & Methods
- [ ] Roles
- [ ] Documentation
- [ ] TMS
- [ ] Risk Management
- [ ] Planning & Review
- [ ] Software Agents
- [ ] Contingency Management framework

· **What do you understand the function of each component to be** ?

Process Models & Methods:

Roles:

Documentation:

TMS:

Risk Management:

Planning & Review:

Software Agents:

Contingency Management framework:

Component :

- **Flexibility of the component ?**

Too rigid ⟵⟶ Too flexible

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

- **Benefits gained in using the component versus effort involved ?**

More benefits gained than additional effort required ⟵⟶ More additional effort required than gained in benefits

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

Component :

- **Are workloads being shifted to other people ?**

whole of workload would be shifted to others ◄——► no additional work for others

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

- **Would the component be used ?**

definitely ◄——► definitely not

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

Component :

- **Overall benefit of component to design process ?**

beneficial ◄——► useless

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

- **Are there any changes that you would suggest to improve the component ?**
  open question.....

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

Topics for the system as a whole : *Implications to the users of introducing the socio-technical system into the design environment.*

- **To what extent would the socio-technical system be considered a management monitoring mechanism ?**

completely ◄——► not at all

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

- **Will the socio-technical system effect people's status ?**

positive effect ◄——► detrimental effect

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

Topics for the system as a whole : *Implications to the users of introducing the socio-technical system into the design environment.*

- **How would the socio-technical system affect the recognition that people receive ?**

it will affect recognition ◄——► it will not affect recognition

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

- **Would the socio-technical system improve or worsen the efficiency of the design environment ?**

improve ◄——► worsen

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

Topics for the system as a whole : *Implications to the users of introducing the socio-technical system into the design environment.*

- **Would the socio-technical system worsen or improve the level of support offered to designers ?**

worsen ◄——► improve

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

- **Will the socio-technical system increase or reduce people's interest in the role(s) that they have to perform ?**

increase ◄——► reduce

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

Topics for the system as a whole : *Implications to the users of introducing the socio-technical system into the design environment.*

- **Will the socio-technical system reduce or increase people's opportunities to take decisions ?**

reduce ◄——► increase

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

- **Would the socio-technical system improve or worsen opportunities for personal development ?**

improve ◄——► worsen

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

Topics for the system as a whole : *Benefit of the socio-technical system to the design process.*

- **Does the socio-technical system provide the knowledge that you need to refer to in the design environment ?**

completely ◄——► not at all

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

- **Does the socio-technical system increase or reduce opportunities for you to apply your knowledge and skills ?**

increase ◄——► reduce

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

Topics for the system as a whole : *Benefit of the socio-technical system to the design process.*

- **Will the socio-technical system reduce or increase your workloads ?**

reduce ◄——► increase

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

- **Will the socio-technical system increase or reduce workloads for other people ?**

increase ◄——► reduce

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

Topics for the system as a whole :*Benefit of the socio-technical system to the design process.*

- **Would the socio-technical system reduce or increase working pressures e.g. Time To Market ?**

reduce ◄——► increase

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

- **Would the socio-technical system improve or worsen collaborative working between colleagues in the project team ?**

improve ◄——► worsen

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

Topics for the system as a whole : *Benefit of the socio-technical system to the design process.*

- **Under what circumstances would the proposed socio-technical system fail to meet the needs of the design environment ?**
  open question....

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for use)

Topics for the system as a whole : *Covering Questions (all open) ......*

- **Are there any additional components or features required, which have not been raised in the previous topics ?**
- **Are there any information channels or personnel that the socio-technical system requires input from who are not identified ?**
- **Are there any impending changes or ways in which the design environment is evolving that will impact upon the proposed socio-technical system ?**

Topics for the system as a whole :*Overall Socio-technical system Assessment*

- **To what extent is the proposed socio-technical system capable of matching real world needs ?**

capable ◄──► not capable

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using *the* component)

- **To what extent is the overall socio-technical system viable ?**

not viable ◄──► viable

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

Topics for the system as a whole : *Overall Socio-technical system Assessment*

- **To what extent would the socio-technical system be beneficial to the design process ?**

vital ◄——► worthless

1	2	3	4	5

Evidence (i.e. example of being beneficial or not)

Motivation (i.e. positive or negative incentives for using or not using the component)

13. **Appendix D :** Company A's letter of support

BL:JSB:EPSRC2

2 April 1997

Tracey McGuire
EPSRC
Polaris House
North Star Avenue
Swindon SN2 1ET

Dear Ms McGuire

Re Grant GR/H43526 : The Surrogate Design Manager Project

I write to provide feedback on the above project.

I confirm that COMPANY A (C.A) provided free access to design staff to the project team within the company over the period January 1993 to October 1996.

Following a final presentation of the results by Phil Culverhouse, Peter Jagodzinski, Fraser Reid and Richard Parsons on the 19th March 1997 I am also pleased to state that C.A has found the work stimulating and useful. The combination of psychological research and technical & systems analysis has proved valuable and seems to provide answers to questions that we have been searching for as well.

In particular I believe that the work on Design Environments will find direct application within C.A. We plan to collaborate on the further development of the socio-technical system developed at the University of Plymouth.

I am therefore very pleased with the outcome of the programme.

Yours sincerely

J Brothers
Director of Technology

cc P Culverhouse