Janus: the multiple faces of engineering design

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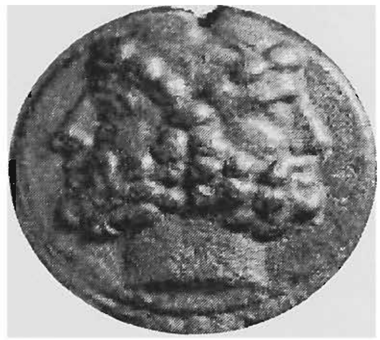
Janus



The Multiple Faces of Engineering Design

A Thesis Submitted in fulfilment of the requirements for the award of the degree

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CERTIFICATION

I, Ross D. Wotherspoon, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Department of Management, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Ross D. Wotherspoon

5 September 2001

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List of Abbreviations

5MTPA	Five Million Tonne Per Annum
BHP Pty Ltd	Broken Hill Propriety Limited Company
BHP	Broken Hill Propriety Limited Company – Steelworks Port Kembla
BOS	Basic Oxygen Steelmaking
LK	Lime Kiln
PLC	Programmable Logic Controller
WTP	Water Treatment Plant

Abstract

This study is a sociological exploration of the work of engineering design. The data for this research were generated from a two-year ethnographic study of three engineering design projects within an Australian iron and steel producing company. This study provides an account of the activities undertaken, by engineers and others, during the design of human computer interfaces for process control.

The study takes a symbolic interactionist perspective and acknowledges its criticisms. The study draws on Strauss's social worlds/arena theory, and Clarke's subsequent conceptualisation of the theory in an organisational context, to provide a broad set of sensitising concepts focussed on the interactive aspects of the construction of meaning amongst the social collectives involved in the process of engineering design.

The findings of this study are organised around five interlinked and over lapping themes – *trajectories of technology and work, design boundaries, engineering and operator social worlds, arenas in the process of design,* and *routine and non routine action.* These themes reflect emergent concepts identified through the constant interplay between observation and analysis.

The accounts given describe design negotiations riven through with ideologies of engineers, plant operators, and others, as individuals and as members of social collectives, such as occupational groups. I have come to understand these negotiations can be seen as battlefields with winners, losers, and only sometimes agreeable truces.

These battles are conducted according to what appear to be predetermined rules of engagement that reflect - and define - who has power and over what elements of the battle that power can be exercised. The outcomes of these battles are design specifications that guide the 'trajectory' of a technology from an initial concept toward its final shape.

This study is intended to provide a needed addition to the literature - detail on how individuals and groups go about creating new technological artefacts in an industrial design context. My hope is to assist both academics and practitioners in improving the process of engineering design.

Acknowledgments

This study has been made possible through the collaborative efforts of the workers and management of BHP Steel, the BHP Institute for Steel Processing and Products (ISPP), the University of Wollongong Department of Management, and the Australian Research Council.

The BHP ISPP was established in 1995 and consolidated a long history of collaboration between the University of Wollongong and BHP Steel. The institute is multi-disciplinary and concentrates on focussed academic research. The institute derives much of its project funding from competitive government funding schemes, creating a triangular alliance between government, industry, and university.

This study has been conducted under the auspices of ISPP 'Management of Innovation and Organisation Change' Program. This program is typified by in depth, long term ethnographic and action research studies that aim to contribute to academic research on innovation, technological change, and organisational learning.

Throughout the course of this study I have had the pleasure of the supportive assistance of three wonderful supervisors - Richard Badham, Karin Garrety, and Will Rifkin. They have each freely given their time and knowledge, greeting every one of my new ideas, directions, and tangents with genuine enthusiasm and rigorous academic debate. The final form of this dissertation is a testament to their combined input and guidance.

Special thanks go to Richard Badham for initially creating the industry and academic opportunities for this research to take place.

Finally, I am most indebted to my lovely wife Catherine and our two beautiful daughters, Jessica and Emily, whose gracious love, support, and sacrifice has made this dissertation possible.

Preface

Prior to embarking on this study I had spent twelve years working as an engineer in the Australian iron and steel industry. I performed many roles during this period, starting as an engineering cadet and then moving through the professional ranks into management positions. These roles required the performance of a variety of tasks, including technology design, project management, technology support, technology maintenance, and technology operation.

Many of the engineers whom I met during this period spoke at one time or another of their dreams of a 'technological utopia'. In these dreams, they envisaged industrial plants where the tasks of operators were usurped by the marvels of technology. The foibles and frailties of the human race were forgotten in the blaze of precision machine measurement, movement, and reasoning. Unfortunately for most of these engineers, when they awoke from their dreams, they faced a reality far removed from their utopia - a reality where machines broke down, technology failed, and in the end, human operators remained to pick up the pieces.

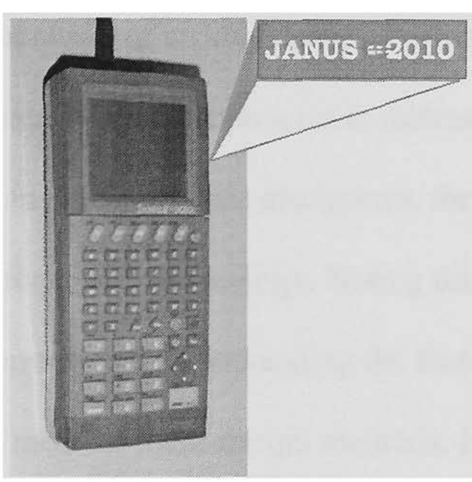
The idea for this study was born from my observations of one such engineer's search for his small slice of technological utopia. His particular quest involved the replacement of a manual, paper-based, warehouse inventory management system with hand-held computers, bar codes and readers, and radio frequency data links to a mainframe computer system. His quest was conceived at a trade-show where his eyes were drawn to the latest hand-held computer terminal, the Janus 2010, developed by Intermec.

Unfortunately, for the engineer in question, the reality he faced upon awaking from his project was one where the Janus technology remained locked in the cupboards of the operators, untouched and lifeless. The paper-based system endured and does so to this day. Although the technology performed within the requirements of the engineer's specifications, he was unable to overcome what seemed to be well founded and well managed operator resistance.

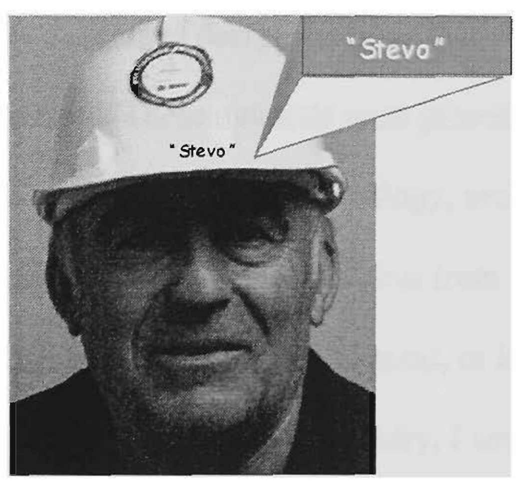
The ageing, predominantly migrant, workers were unable to read the small liquid crystal displays on the hand-held terminals whilst operating them in the dimly lit warehouse. Nor were they able to understand the complex training sessions. Further to this, these workers had for many years performed manual labour tasks in the plant. As a result, their large callused fingers were unable to accurately press the small keypad buttons. In addition, the workers appeared to perceive the Janus project as a threat to their continued employment due to an ongoing distrust between workers and the management.

Under the combined weight of these factors, the workers instigated what appeared to be a well organised campaign of overt and covert resistance. One of their more ingenious covert schemes involved the gradual removal of the bar code labels from the products. Inch-by-inch, day-by-day, the workers would secretly peel the edges of labels from the product. This ongoing process appeared to the engineer as an incompatibility between the adhesive and the product surface. For more then six months, specialist label consultants from 3M endeavoured to select an adhesive that would successfully bond the label to the product. Eventually, a shipment of products was dispatched directly to China with test labels attached. After two weeks in transit, and four weeks in a Chinese warehouse, it was reported that all labels remained completely intact. This result alerted the engineer to the covert scheme of label removal, though no punitive actions were ever taken.

Intermec's decision to name their hand held computer 'Janus' was perhaps more apt for this project than they might have imagined. Janus is the mythical Roman God of gates and doors, depicted with two faces looking in opposite directions. To the chagrin of the instigating engineer, the Janus project had a technological face and a social face, both of which required his equal consideration.



A Technological Face



A Social Face[1]

There is a multiplicity to these two faces of the Janus Project. The technological face can be seen as including the Janus 2010 hand held computer, bar code labels, bar code readers, systems of radio frequency links, mainframe computer system, and software, to name but a few. Likewise, the social face can be considered to include Stevo, the

[1] This photo and all other forms of collected field data presented in this dissertation have been done so with written permission of the human subjects involved.

engineer, and every other actor involved in the process of design and implementation, both overt and covert, and the social collectives that they may represent. Further to this, the technological faces are a reflection of the social processes through which they were created. In turn, these social processes are a reflection of the participants', as both individuals and representatives of their social collectives, interpretation of technological, social, cultural, political, and economic circumstances within which the Janus project was undertaken.

My goal when I first conceived of this study was to develop a design method that encompassed the multiple faces of engineering design. In pursuing this goal, I quickly became aware of an abundance of previously developed design methods that were purported by their proponents to address this need. These methods were presented in a wide range of academic disciplines, for example, engineering, psychology, sociology, and information technology. Noting this proliferation, I shifted my focus from 'methods development' to understanding the factors that influenced the deployment, or lack of deployment, of these design methods. In following this avenue of inquiry, I sought out studies that depicted the social processes of engineering design in the hope that they might illuminate relevant factors worth studying. This inquiry highlighted for me the dearth of literature describing in detail the social process of design. This 'gap' inspired the final focus of this study - the development of an understanding of the actions of humans engaged in the process of engineering design.

Part (A)

This dissertation is presented in two parts. Part (A) – Chapters (1)-(3), introduces the main aim of this study to provide a sociological account of certain processes of engineering design. This account has been developed through an ethnographic study of three engineering design projects. Part (B) – Chapters (4)-(8), presents the empirical findings of this study and their analysis. Chapter (9) draws these findings together in a condensed account and discusses the broader implications of the findings.

Chapter (1) – Introduction

1.1 Introduction

This study is a sociological exploration of the work of engineering design. The data for this research were generated from a two-year ethnographic study of three engineering design projects within an Australian iron and steel producing company. This study provides an account of the activities undertaken, by engineers and others, during the design of human computer interfaces for process control. The account illustrates the interpreted meanings and functions of the observed human actions.

The primary aim of this study is to further develop our understanding of the actions of humans engaged in the process of engineering design. The study takes a symbolic interactionist perspective, and acknowledges its criticisms, to provide a set of sensitising concepts for addressing this aim.

1.2 Why is it Important to Study Engineering Design?

There are two important factors which justify the study of the process of engineering design. Firstly, there are a number of 'gaps' in the literature on engineering design. These gaps include a dearth of sociological studies on the work of general engineering design (Downey 1995, p.186) and, more specifically, a seemingly complete lack of sociological studies on the work of designing human computer interfaces for industrial process control systems. The aim of this study is to generate knowledge to fill these gaps. Secondly, 'inadequacies in the useability of human computer interfaces have been widely recognised' (Landauer 1995). A typical response to these inadequacies, from both academics and practitioners, has been to develop new and improved design methods prior to examining the social processes of design. In spite of these attempts, inadequate human computer interfaces continue to be designed. This study's exploration of social processes in the work of engineering design aims to extend our understanding of the activities of design and in doing so potentially reveal why the existing methods are not being used more effectively[1].

[1] From an ethnographic perspective, it is important to note that this is not a prescribing focus for my study; it merely identifies a potentially interested and benefiting audience.

Useability Inadequacies

In a scene from the movie *City Slickers*[2] (Castlerock 1991), the writers have used the common frustration of programming a video cassette recorder (VCR) as a source of comedic interplay. Three friends, Mitch (Billy Crystal), Phil (Daniel Stern), and Ed (Bruno Kirby), who are all coping with personal problems, embark on a journey of self-discovery in the Wild West. They sign up for a cattle drive in the hopes of curing their various depressions – Mitch is about to turn 40, Phil was caught in an affair and lost everything, Ed is having mixed feelings about whether or not to marry his girlfriend.

During the second half of the movie, a scene opens with a panoramic shot of a majestic mountainside in New Mexico. As the camera zooms in, two riders, Mitch and Phil, come into focus. They are seen guiding a herd of cattle, and as the camera continues to zoom in, the haunting Western music fades and a seemingly deep conversation unfolds.

[Mitch]	It's nothing to be ashamed of … I've had the same problem.
[Phil]	Didn't you feel stupid? … I mean … didn't you feel inadequate?
[Mitch]	Yeah, for a while … but then I overcame it. Can I explain it to you again? … I mean … promise me you won't get upset.
[Phil]	OK … but … it's not going to do any good.
[Mitch]	OK … if you want to watch one show but record another show at the same time, the television set does not have to be on the same channel.
[Phil]	It does! … It does!
[Mitch]	No, it doesn't …
[Phil]	It does! … It does!
[Mitch]	No … If you're watching what you're recording it has to be on the same channel.
[Phil]	What? What? The TV or the video?
[Mitch]	The TV.
[Phil]	You're saying I can record something I am not even watching!?!
[Mitch]	Yes! That's the point! You don't even need the TV to record.

[2] The movie *City Slickers* is a comedy produced by Castlerock Entertainment, directed by Ron Underwood, starring Billy Crystal, Bruno Kirby, Daniel Stern, Helen Slater, and Jack Palance.

[Phil] But how would I see it!?!

At this point, Ed rides into picture.

[Ed] SHUT UP!! ... JUST SHUT UP!!
He doesn't get it!
He will never get it!
It's been 4 hours, the COWS can tape something by now!
Forget about it ... PLEASE!!
[Phil] (Very timidly) How do I change the clock again?

Phil and others like him (myself included) seem unable to master the use of the ubiquitous VCR. We are not 'stupid' or 'inadequate', but rather, designers have created VCR operating systems that are unable to fulfil the requirements of a large proportion of users. Norman (1988; 1998) has made similar observations about many other simple and complex, common pieces of technology in his popular books, *The Psychology of Everyday Things* and *The Design of Everyday Things.*

Unfortunately, inadequacies and failures in design are not exclusive to the domain of everyday things. They also exist in human computer interfaces in control systems for nuclear power plants, chemical plants, and steel plants. However, in these situations, the inadequacies do not just cause frustration; they may also cause catastrophe. Three Mile Island, Bhopal, and Chernobyl are all examples of large scale industrial disasters where the root causes were traced to design inadequacies with the human computer interface in the control systems (Reason 1990).

Due to the disastrous ramifications of the design inadequacies in the three industrial incidents cited above, it seems to be relatively straightforward to label them as 'failed designs'. However, it is usually a very contentious issue whether or not a specific design is designated as being a 'failure' or 'inadequate'. The *Handbook of Reliability*

Engineering and Management (Ireson 1998) states that "it is imperative to have a firm grasp of how the ideal product works before one can begin to enumerate the many ways in which it can fail" (Smith 1998). Understanding how a normal, expected, or ideal human computer interface works is extremely difficult. Each user, in each context, is likely to have a different notion of what he or she would constitute as normal, expected, or ideal performance. The result is that assigning the status of success or failure to a human computer interface design is problematic. The *Handbook of Human Computer Interaction* (Helander 1997) goes some of the way toward addressing this problem by providing a list of useability factors that, if met, are 'most likely to produce a system that is easy to learn, easy to use, contains the right functions, and is generally liked' (Gould 1997 p231). However, the allocation of success or failure remains problematic as this list is open to a variety of potentially conflicting interpretations.

Several recent studies have highlighted the continuing proliferation of purported inadequate system designs. Majchrzak, Findley, and Fredrick (1997) report that, in a survey of 2000 US firms implementing new information systems, the failure rate was sixty percent. Majchrzak et al also cite the American Production and Inventory Control Society and Automotive Industry's estimate that the failure rate, in terms of meeting customers' original requirements, for new advanced manufacturing systems was seventy-five percent. Hopkins (2000, p.42) reported similar findings on the explosion at the 1998 Esso Australia Longford gas plant, where two workers were killed, eight others injured, and a city of 3.2 million people was left without natural gas for more than two weeks. He concluded that the human computer interface with the control system was a significant contributing factor to the disaster. Czaja (1997) cites studies by Dougherty and Fragola (1988), Jensen (1992), and Rasmussen, Pejtersen, and Goodstein

(1994) to conclude that approximately eighty percent of industrial accidents, fifty percent of pilot accidents, and fifty to seventy percent of nuclear power plant accidents can be attributed to inadequacies in system design.

Such purported 'failures' with respect to systems and human computer interface design have stimulated academics and practitioners to develop an abundance of systematic design methods to redress the problem. Yet, the studies listed above indicate that inadequate systems continue to be designed. Pelle Ehn, a prominent Swedish researcher and proponent of 'work-oriented' design of computer artefacts, seems to shed some light on this conundrum.

> What we don't need is another design methodology.
> Bookshelves around the world are already full of them.
> What we need is an understanding of why they are not being effectively used. (Ehn 1998)

As one of its outcomes, this study seeks to address why such methods are not being more effectively used. The sociological account provided aims to extend the general understanding of the process of design, for both practitioners and academics. This understanding is based on the actual design practices observed in three projects aimed at redesigning human computer interfaces.

1.3 The Setting for this Study

This study was undertaken in BHP Pty Ltd, one of Australia's largest companies[3]. It was incorporated in Melbourne, Australia, in 1885 and began its operations as a miner of silver, lead, and zinc at Broken Hill in New South Wales. It has since grown into a multinational resources company with a worldwide workforce of 65,000 employees, offices in fifty-nine countries, and total annual sales exceeding AUD$18 billion. The company has separate divisions for mining, energy, steel, and transport (BHP 1996, p.1).

Three separate case studies[4] were undertaken at BHP Pty Ltd's integrated steel plant located on the South Coast of New South Wales, Australia, 100 km south of Sydney. BHP Steel Port Kembla is the largest steel producing facility in BHP Pty Ltd's Steel Division (from now on this one plant will simply be referred to as 'BHP'). The plant produces approximately 4.6 million tonnes per annum (MTPA) of steel, has almost forty kilometres of internal roads, a thirty-kilometre private rail network, covers almost eight square kilometres of land, and directly employs more than 7000 people (see Fig 1.1).

[3] BHP was rated No.4 based on market capitalisation at the close of trading on Friday, April 20, 2001 (Australian Stock Exchange 2001)

[4] The three case studies were conducted on three design projects, each of which was part of a larger plant upgrade project. As part of an economic rationalisation, the third design project was cancelled by BHP management several months after it commenced. The details of the three case studies are outlined in Chapter (2) – Research Methodology and Case Study Overview.

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Figure 1.1 - BHP Steel Port Kembla (BHP 1992)

The steel industry is characterised by continuous and batch processing of various products by means of physical and/or chemical transformations. The plants are large and very complex, present high levels of risk, high levels of operator workload, complex real time dynamics, and a need to integrate the activities of many people at many levels, from management to maintenance workers. The equipment within these plants is generally large with high levels of automated control (Moray 1997, p.1949).

The iron and steel making process at BHP is composed of eight distinctive operational stages, each of which is required for the conversion of raw materials into finished products (see Fig 1.2). These stages are briefly described in the following section (BHP 1999).

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Figure 1.2 - BHP Integrated Iron and Steel Plant Process (BHP 1992)

Stage (1) – Cokemaking

In the first stage, coal is converted to coke by a process of heating. The cokemaking plant has 331 coke ovens. Each of these ovens is filled with coal and heated for approximately eighteen hours. The oven is then emptied and filled again. The continuous rotation of this process produces the coke required for the subsequent stages of steel production.

Stage (2) – Sinter Production

The second stage, sinter production, parallels that of the cokemaking. In this case, crushed limestone and iron ore 'fines' are mixed and heated to produce a 'fluxing' product called 'sinter', which assists the melting and fusing of ironmaking ingredients in a blast furnace.

Stage (3) – Blast Furnaces

In the third stage, iron ore, sinter, and coke are mixed in a blast furnace to produce iron and slag. There are two blast furnaces. Each is a shaped like a giant bottle and stands as tall as a twenty-seven storey building. Air, which is heated to approximately 1200°C, is blown into the furnace through nozzles, called 'tuyeres', which are spaced around the lower section of the bottle. The air causes the coke to burn and produce carbon monoxide which reacts with the iron ore (iron oxide), separating the iron from the oxygen and leaving molten iron. About every two hours, a 'taphole' at the bottom of the furnace is opened, and the molten iron is drained.

Stage (4) – Basic Oxygen Steelmaking

In a fourth stage, the molten iron is transferred from the blast furnaces to the Basic Oxygen Steelmaking Plant (BOS). There are three, 275-tonne, egg-shaped BOS vessels, which are filled with a combination of recycled scrap steel and molten iron. The filled vessel is injected with pure oxygen through a hollow lance causing chemical reactions that raise the temperature of the already molten iron to about 1700°C, melting the scrap and starting an iron purification process. After approximately twenty minutes of processing, the impurities have been removed and the refined iron, now called steel, is ready to be cast into slabs.

Stage (5) – Slab Caster

The fifth stage of the process, continuous casting, involves pouring the liquid steel into a bottomless, water-cooled mould at the same rate that a continuous solidified slab is extracted from the bottom. There are three continuous casting machines that can each cast approximately 4,500 tonnes of slabs a day. The steel slabs can be sold directly to customers or further processed.

Stage (6) – Plate Mill

A sixth processing stage, plate rolling, involves reheating the slab and squeezing it through a series of rolls to decrease its thickness. Upon completion, the flat plates are dispatched to customers.

Stage (7) – Hot Strip Mill

The seventh stage, hot strip rolling, is similar to plate rolling. The slab is further reduced in thickness and then wound up into a continuous coil of steel. The coils of steel can be sold directly to customers or further processed.

Stage (8) – Tin Mill

The eighth stage involves re-rolling the steel coils, this time at room temperature, at very high speeds using lubricants to reduce friction. This 'cold rolling' process increases strength, makes the steel strip thinner, and produces a bright smooth surface. Following this process, the steel sheet can be coated with a thin layer of tin, usually applied by an electrolytic process. Tinplate is then sold and used to make cans for food, aerosols, paint, etc.

The description of the physical setting for the study should give an impression of the scale, heat, and complexity of the iron and steel making process at BHP. Because of these characteristics the men and women who operate the equipment and processes are typically located in cool, quiet, semi-remote control rooms. The physical separation is afforded by extensive use of automation and computer control. This level of automation and increasing degrees of computer control make the steel industry an appropriate setting within which to study sociological processes of the work of engineers designing human computer interfaces.

1.4 Theoretical Perspective

This study is meant to contribute to our understanding of the actions of humans engaged in the process of engineering design. There is currently an inadequate amount of literature on this phenomenon for the development of a theoretical[5] explanation for the activities that occur during an actual design process. This study develops such a theoretical explanation through three ethnographic case studies. A symbolic interactionist perspective on social action has influenced the analysis and theory building activities in these case studies.

Symbolic interactionism provides a view of society that focuses on the way in which 'people act toward, respond to, and influence one another' (Robertson 1987, p.21). It is a 'distinctly North American branch of sociology, developed from the work of the philosophers John Dewey, William I. Thomas, and George Herbert Mead' (Haralambos 1990, p.798). Its major assumptions can be defined as follows:

> First, human beings act towards things on the basis of the meanings that things have for them. The second premise is that the meaning of such things is derived from, or arises out of, the social interaction that one has with ones fellows. The third premise is that these meanings are handled, in and modified through, an interpretive process used by the person in dealing with the things that he [*sic*] encounters (Blumer 1969, p.2).

[5] My use of the term 'theoretical' in this context is derived from its occurrence in the grounded theory literature as a means of delineating between explanations of observed phenomena based on 'concepts and statements of relationships' as opposed to 'descriptive' explanations involving 'simple themes devoid of interpretation (Strauss 1990, p.29).

Part of the symbolic interactionist tradition is the notion that people organise their activities within and across 'social worlds'. These worlds are loosely or rigidly structured units in which people share resources and information. They can be organised around work, leisure activities, family life, or political or religious convictions, for example a football club, an environmental group, or a church congregation. They are characterised by a commitment to assumptions about what is important and worthwhile. Membership can be fluid, with individuals typically participating in several social worlds at any one time. Often, several worlds have a common interest in a particular task or problem (Strauss 1978; Clarke 1991; Strauss 1993; Clarke 1997; Garrety 1997). For example, the feminist movement and conservative church groups may share a common interest, albeit antithetical, in the abortion debate.

Symbolic interactionism does not prescribe what I should, and should not see, in my study. Rather it merely provides a set of '*sensitising concepts* – suggesting ideas about what might be potentially fruitful to examine and consider' (Clarke 1997, p.65). The emphasis of the interactionist perspective on interaction amongst individuals and social collectives is well suited to the micro sociological frame of my case studies. It generates questions about what things have meaning for designers, how these meanings are generated and/or modified, and what influence these meanings may have. Such questions, as I show later, can be quite useful for understanding the overall process of design and help to generate what I have defined as a theoretical explanation of a process of design.

Another reason for using symbolic interactionism in this study arose from my concerns as an engineer embarking on an ethnographic research project. Although I had extensive guidance from researchers experienced in fieldwork, I was concerned with the 'twin dangers of becoming overwhelmed by data and being drawn into narrative rather then theory building' (Cassell 1994, p.217). Symbolic interactionism provided a way in which to view my ever-expanding collection of data that highlighted phenomenon worth pursuing in order to provide a theoretical interpretation, rather then a simple retelling of the activities observed in my study.

As with any theoretical perspective, critics abound and debate rages about validity and use. Although dated, Meltzer, Petras, and Reynolds (1975) provide a good summary of many of the criticisms directed at symbolic interactionism. Their summary subsumes the various criticisms into a single general criticism - symbolic interactionism may have an astructural, or microscopic, bias; and a perspective with an astructural bias is one that by definition will tend to be non-economic, ahistorical, and apolitical. In spite of these criticisms, the perspective is not incompatible with sociopolitical dimensions. For example, Hall (1997) provides a detailed discussion that illustrates the usefulness of interactionism in explaining relationships between power, structure, and social action. Hall's discussion demonstrates that the criticisms listed by Meltzer et al are not endemic in the interactionist perspective itself, but rather, are representations of certain interpretations and previous applications of the perspective.

The following section describes the chapters of this thesis. The themes of the chapters have emerged from my observation and analysis of the case studies. This analysis was influenced by the symbolic interactionist tradition by focussing my attention on how meanings were created and responded to by participants in the process of design.

1.5 Structure of the Thesis

This thesis is presented in nine chapters, including this introduction. Chapter (2) outlines the ethnographic and grounded theory research methods adopted in this study. These methods privilege the sense-making processes of participants rather than a set of *a priori* categories. The justification for using these methods is based on their appropriateness for studying small groups of people within real world settings. Following this introduction of method are descriptive overviews of the three case studies, which represent the real world setting for this research.

Chapter (3) reviews the literature relevant to this study within a schema of four overlapping categories – ethnographic studies of engineering design, design studies, prescriptive design methodologies, and sociology of work and technology.

Chapters (4) to (8) present each one of five overlapping and interlinked themes that organise this study's account of the observed design activities – *trajectories, design boundaries, social worlds, arenas, and routine and non routine action.* These themes were not predefined then externally imposed. Rather, they were emergent concepts identified through the constant interplay between my observation and analysis. Figure 1.3 presents these themes in a diagram akin to a map of a small town. That is, it identifies the relative locations of the culturally significant landmarks, without specifically describing them. A visitor to a small town may use a map to find their way around, stopping to explore the churches, parks, and pubs as they go. In a similar way, Figure 1.3 provides a map of the 'themes' that I stopped to explore during my study of the process of design. The descriptions of what I discovered during these forays are provided in Chapters (4) to (8).

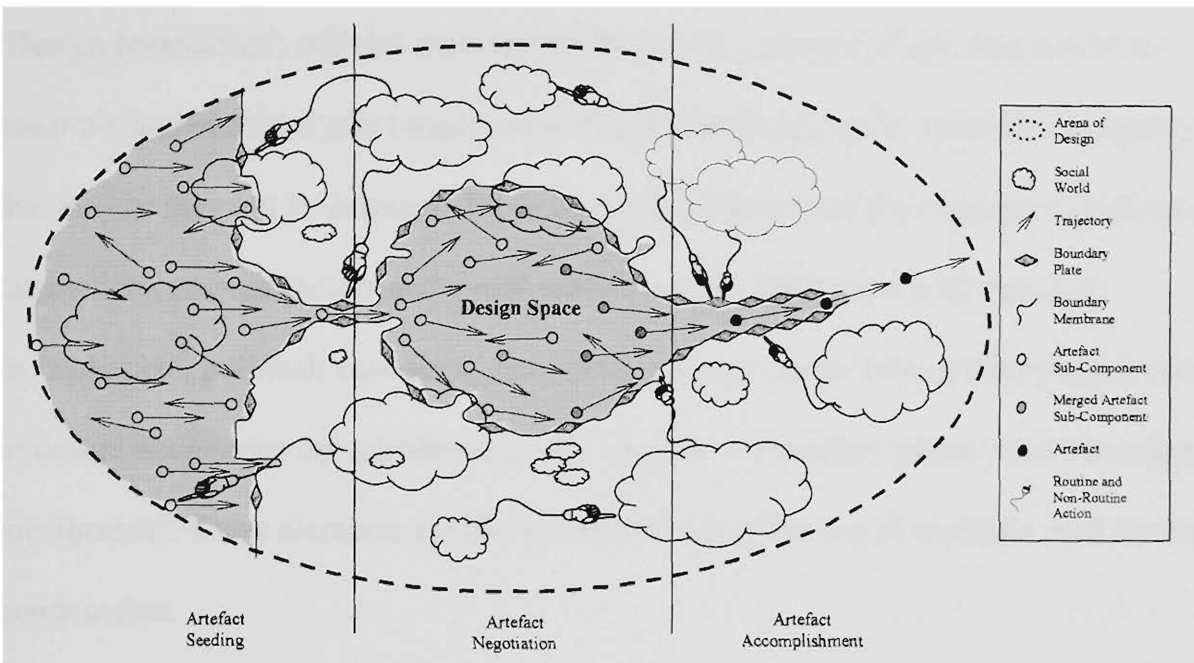

Figure 1.3 - Activities in a Process of Design

The notion that technology develops along a path termed a 'trajectory' is presented in Chapter (4). Other studies derived from social history and sociology of technology have highlighted the limitations of the traditional engineering and economic views that technological trajectories are in some way 'natural', following a linear sequence of stages from inception to maturity. An alternate view, based on my empirical data presented in this chapter, portrays technology as developing via a complex series of phases, each of which contains multiple and interrelated elements. These phases represent changing interactions amongst actors and social collectives around the technology as it progresses through the process of design. Three phases are described in this study – artefact seeding, artefact negotiation, and artefact accomplishment. This complex phase model depicts technology as being made up of sub components. The trajectory of a technology through these phases is an amalgamation of the trajectories of its sub components.

'Design boundaries', which I describe in Chapter (5), are sets of specifications that constrain and enable artefact trajectories by representing specific variations or options that may or may not be pursued. These design boundaries are the negotiated product of interactions amongst actors and social collectives in conjunction with external technological, political, economic, and social circumstances. Two overlapping elements of design boundaries are introduced in this chapter – 'boundary plates' and 'boundary membranes'. These elements are discussed in terms of the social methods used for their construction.

The social collectives within the case studies are the focus of Chapter (6). Pinch and Bijker's 'relevant social groups' model of technology development and Strauss's broader 'social worlds/arena' theory are reviewed. These theoretical perspectives are subsequently used to examine the social collectives involved, both explicitly and implicitly, in the negotiation of design boundaries in the study.

The notion of emerging and diffusing 'arenas' within the process of design is described in Chapter (7). An arena can be defined as a socially constructed space within which social collectives interact with one another around specific issues. 'Actions concerning these issues are debated, fought out, negotiated, and even coerced amongst the social collectives' involved in the arena (Strauss 1993, p.226). The activities that occur within these arenas are examined and standard patterns of action, or 'routines', that are used in a variety of situations are highlighted.

Chapter (8) examines the routines used in ordering exchanges amongst social collectives around design boundary issues. It also draws together many of the elements of the previous four chapters. These routines, inculcated with the characteristics of the social collectives involved, influence design boundary negotiations, which in turn affect the trajectories of the sub components and hence determine the final form of the technology.

The concluding chapter, Chapter (9), draws the five central themes of the study together in a condensed account of a process of design. This account uses the concept of a design boundary to demonstrate the ways in which individuals and social collectives are able to influence the final shape of a technology in the absence of direct physical contact between themselves and the technology. The contribution to our understanding of the broader process of design afforded by this study, and potential uses of this knowledge in improving design, are also enunciated in this chapter. The chapter concludes with a recommendation for future research into the micro aspects of artefact seeding and boundary membranes.

1.6 Summary

This thesis is an ethnographic study that provides an account of the activities undertaken by engineers and others during the process of designing three separate human computer interfaces for process control in BHP's integrated iron and steel plant. The steel plant in this study involves a large, complex, multiple-stage process with high levels of risk, high levels of operator workload, complex real time dynamics, and high levels of automated control. This study aims to use the analysis of the case studies from this industry to redress the dearth of sociological studies on the work of engineering design, especially in the area of human computer interface design. Analysis of the data collected in the case studies has been informed by a set of sensitising concepts from the symbolic interactionist tradition in sociology. This tradition is particularly apt for this study as it provides a focus on the ways in which people act toward, respond to, and influence one another and the technology in question. The following chapter addresses more specifically the methods used, and case studies followed, during this research project.

Chapter (2) – Research Methodology and Overview of the Case Studies

2.1 Introduction

The terms 'quantitative method' and 'qualitative method' are often used to represent two ends of a continuum of sociological field research. The proponents of qualitative field research immerse themselves in the social phenomenon being studied, producing from this experience 'thick descriptions' (Geertz 1973) and interpretations of the meanings and functions of human action. Counter to this, supporters of quantitative field research extol the virtues of survey data and statistical analysis, whilst casting aspersions on the 'scientific status' of qualitative methods.

This study is positioned within the qualitative genre and employs both ethnographic and grounded theory methods. These methods have been selected because of their proven capacity in facilitating exploratory research within real world settings such as those encountered in my case studies. My rationale is explained further in this chapter.

The chapter also provides a descriptive overview of the three design projects within which this research has been performed. The three projects studied, one of which was eventually cancelled by BHP, addressed separate process improvement initiatives based on developing new computerised control systems. Together they provide data to detail the social dynamics of the process of design, underlining key processes of negotiation and accompanying issues of identity that affect a technology's development.

2.2 Ethnography

All ethnographic methods 'rely to some extent on fieldwork', frequently in the form of participant observation (Atkinson 1994, p.248). Anderson (1997) makes the point that there is more to ethnography than just doing fieldwork: it also involves an 'analytic mentality'[1]. That is, it is not just a matter of bringing back a description of what was observed, but rather, it involves constructing an account or an interpretation of those observations in terms of the roles that they play in the lives of the people observed.

The origins of modern ethnographic fieldwork are usually associated with the shift by social and cultural anthropologists in the late nineteenth and early twentieth centuries toward collecting data first hand (Atkinson 1994, p.249). The seminal work in this area is often identified as Malinowski's (1922) fieldwork in the Trobriand Islands (see Burgess 1982; Van Maanen 1988; Atkinson 1994; Agar 1996; Anderson 1997; Button 2000). Today this tradition continues in many forms, with one branch of ethnographic work focussing on life in modern organisations (for examples see Geertz 1973; Van Maanen 1988; Goodall 1994; Anderson 1997).

It is difficult to provide an agreed definition of the term *ethnography*. However, Atkinson and Hammersley (1994, p.248) characterise it, in practical terms, as social research that has a substantial number of the following features:

[1] The issue of analytic mentality versus the pure descriptive in the context of ethnographic studies of engineering design is discussed in more depth in Chapter (3) – Literature Review.

- A strong emphasis on exploring the nature of particular social phenomena rather than setting out to test hypotheses about them.
- A tendency to work primarily with unstructured data, that is, data that have not been coded at the point of collection in terms of a closed set of analytic categories.
- Investigations of a small number of cases, perhaps just one case, in detail.
- Analysis of data that involves explicit interpretation of meanings and functions of human actions, the product of which mainly takes the form of verbal descriptions and explanations, with quantification and statistical analysis playing a subordinate role at most.

The degree of researcher participation in ethnographic studies can vary[2]. At one end of the spectrum are studies in which the researcher is purported to be a neutral observer, at the other end are researchers 'playing established participant roles' in the scene being studied (Atkinson 1994, p.248). I started in my first case study as an observer, watching what was done; when it was done; who was doing it; where were they doing it; and speculating why they might be doing it. This allowed me to gather initial data on the participants and begin my interpretation of what roles the activities and artefacts that I saw might play in their working lives. I used the knowledge gleaned from the first case to play the roles of a participant and an observer in the ensuing two case studies. Details of this aspect of my research are discussed in the case study overviews presented later in this chapter.

[2] The orthodox scientific perspective places the researcher outside and separate from the subject of his or her research, researching for objective knowledge and for one separate truth. An alternate world view, one that this study reflects, is that 'we partake of what we describe so that our 'reality' is a product of the dance between our individual and collective mind and 'what is there'' (Reason 1994, p.324).

Van Maanen (1988) discusses three loosely defined and overlapping ethnographic writing styles – realist tales, confessional tales, and impressionist tales. The *realist tales* are the most prevalent and popular styles of ethnographic writing. They can be characterised as narratives presented in a dispassionate third-person voice. The result is an author-proclaimed description and explanation of a set of observed cultural practices (Van Maanen 1988, p.45). At the other end of the continuum the *impressionist tales* reconstruct in dramatic form those periods from the fieldwork that the author regards as especially notable and hence reportable. The impressionist's tale is a representational means of opening the culture and the fieldworkers way of knowing that culture so that both can be jointly examined (Van Maanen 1988, p.102). Between these two extremes are the *confessional tales,* within which I place my study, which attempt to demystify the "ubiquitous, disembodied voice of culture presented" in realist tales (Van Maanen 1988, p.74). For example, there are no "the engineers do X" statements in my confessional tale. In their place are observations that underline my potential bias and areas of attention, such as, "I observed the engineers do X".

In writing up my interpretations of field observations and experiences, I deliberately included myself in many of the descriptions of the scenes. My personal background, outlined in the preface, and my implicit biases, many of which even I am unaware, have no doubt influenced this study. Because of this influence, I felt it necessary to remind the reader of my imperfect and potentially biased presence by including myself in many of the scenes presented throughout this study.

To construct my confessional tale, I was on site for an average of two and a half days a week, over a two-year period. I had a desk and computer in the project site office and was (supposedly) permitted unlimited access to all meetings and documentation associated with the projects. Further to this, I was free to wander, within the limits of safe working practices, around the plants to talk to operations, maintenance, and technical support personnel.

The research design for this study has been explicitly planned, for example, the cases were selected based on a set of carefully considered factors – size, duration, level of access, and comparability, to name a few. However, once engaged in the actual fieldwork I followed the advice of Buchanan, Boddy, and McCalman (1988, p.74) and adopted a flexible approach. The result was that, in conflicts between the theoretically desirable and the practically possible, the possible generally won. For example, in recording my observational data, I almost exclusively used hand written field notes, as opposed to other potentially more accurate methods such as audio and video recordings. This approach was developed in response to the reality of performing fieldwork, in a noisy, dirty, hectic, sometimes dangerous, steel plant. This reality included - climbing ladders, inspecting pumps, measuring water levels, playing computer games, inspecting drag cars, demonstrating emergency procedures, attending meetings, entering hazardous environments, discussing issues in corridors, drinking beer in pubs, and deciphering complex engineering drawings. These were just a few of the activities that may have been missed if my fieldwork was restricted by video and audio recordings. Following on from this, the task at the end of each day in the field was to review my hand written notes, and then, piece by piece, reconstruct the rich details of the scenes observed from a combination of memory and the written word. These details were then dictated onto micro-cassette and forwarded to a typist for transcription. The transcripts were then edited and analysed using the grounded theory approach outlined below.

2.3 Grounded Theory

As noted earlier, Anderson (1997) makes the point that there is more to ethnography than just bringing back a description of what was observed in the field. There is also an accompanying theoretical interpretation. In constructing my own theoretical interpretation I have used a *grounded theory* approach. Grounded theory is a general methodology developed and described in the 1960s by the prominent proponents of symbolic interactionism Glaser and Strauss The method facilitates the systematic development of theory that is 'grounded' in gathered field data (see Glaser 1967; Strauss 1987; Strauss 1990; Strauss 1997). Following this approach, my theoretical interpretation of the data began during the actual field research where there was a 'continuous interplay between the evolving theoretical analysis and the data being collected' (Strauss 1994, p.273).

Strauss (1990, p.41) introduces the concept that researchers, myself included, have an initial level of *theoretical sensitivity*. That is, researchers have a particular awareness of certain subtleties of meaning of data. My theoretical sensitivity was the product of my professional experience, the symbolic interactionist perspective taken for this study, and the various insights gleaned from the literature on other related studies.

The grounded theory approach incorporates a process of *open coding*. This coding involves breaking down the data into discrete parts for detailed examination and questioning (Strauss 1990, p.62). In performing open coding, I examined my data line by line whilst asking the questions: "What is the main story here?" and "What does it represent?" (Strauss 1987, p.27). The answers to these questions were framed as theoretical concepts and statements of relationships, rather than as simple descriptive themes (Strauss 1990, p.29). For example, one line of my data from an interaction between an engineer (Steve) and an operator (Leo) reads as follows:

> "The problem is, Leo, we are limited by technology," said Steve.

Examining this line of text in a simple descriptive frame may lead the researcher to develop the plausible theme that technology limits the options of designers. Alternately, looking beyond the descriptive and asking the theoretical question "What else might be happening here on a deeper, more abstract level?" may lead to the development of a different theme. When I examined the line of text during my open coding process, I made the following rough notes:

> Is the technology really limiting the design options?... or is Steve using the limitations of technology as an excuse... is the technology limitation being used to legitimate Steve's resistance to Leo's requests ... if Steve really wanted this option would technology limit him? ... or would he search for new and novel solutions ...

These rough notes are an eclectic mix of ideas that 'sprang to mind' when I re-read the line of text within the theoretical frame. These rough notes were then re-examined in detail in conjunction with the line of text. This process of detailed examination and crosschecking of the rough notes with other evolving concepts will eventually produce a theoretical concept. This continued process of open coding generates more and more concepts, eventually these concepts begin to overlap with one another and certain repeated themes start to emerge from the data. The themes from each of the three cases in this study converged as my analysis of the data progressed. These convergent themes, and the relationships amongst them, are the bases upon which I have constructed my account of the process of design.

As one might imagine, this type of grounded theory approach to exploring and questioning the extensive field data gathered over a two-year period will generate a cumbersome and unwieldy set of notes on concepts, ideas, relationships, etc. In order to cope with this, I made use of a software program called NUD*IST[3]. This program was specifically designed for the collection and analysis of large amounts of qualitative data. By using NUD*IST, I was able to import all of my field data, transcripts, procedures, memos, meeting minutes, etc, in electronic format into one central data base for the grounded analytic process of my ethnographic study[4].

After the coding was complete, and the final themes became apparent, I started the process of composing my written account. To do this I went back to my NUD*IST data base to look for particular scenes and events that might best represent each of the concepts, themes, and relationships being discussed. The scenes and events, or what I refer to in this study as vignettes, have been selected to serve as illustrative examples of certain recurrent phenomena from which this account has been constructed.

[3] "NUD*IST" is an acronym for – Non-numerical Unstructured Data Indexing Searching and Theorising.

[4] See Appendix (1) for a sample of 30 of the 570 conceptual nodes developed in NUD*IST through the open coding of my field data.

The previous two sections have provided an overview of the ethnographic and grounded theory research methods that have been adopted in this study. These methods were selected because they provided a way of studying the small groups of individuals that were involved in the real world design projects. The following sections provide general descriptive summaries for each of the cases examined.

2.4 Overview of the Case Studies

Three BHP design projects were selected as suitable case studies[5]:

Case study (1) – BOS Flux PLC Project (BOS Project).

Case study (2) – Caster Water Treatment Plant Project (WTP Project).

Case study (3) – BOS Lime Kiln Project (LK Project).

These three design projects were selected because they provided me access to a wide range of design activities, from initiation through to implementation, within my four-year funded research period. They each addressed the same basic issue, that is, the replacement of hard-wired, push-button operated, control desks with computer based, icon-driven graphical user interfaces. This made them, to some extent, comparable with one another and compatible with the focus of my study. Additionally, the relevant BHP stakeholders from each of the projects were willing to allow me the level of access required to achieve the methodological and theoretical objectives of my study.

[5] See Figure 1.1 for the relative geographical locations, and Figure 1.2 for the relative process locations, for each of the projects with BHP

These projects were part of a single BHP-wide project referred to as the 5 Million Tonne Per Annum Project (5MTPA Project). The 5MTPA Project was approved by BHP Pty Ltd in early 1995, with AUD$98M being allocated for plant improvements with the objective of increasing BHP's steel making capacity from 4.6 MTPA to 5.0 MTPA. The project was focused on improving plant reliability and reducing bottlenecks in the process stream from the earliest process stages of raw materials unloading through to dispatching the steel slabs to customers. Underlying any plant improvements in the 5MTPA Project were to be associated gains in safety, environment, and operational security (Russell 1998, p.6).

The 5MTPA Project was based on a BHP study completed in 1994 that identified twenty-seven primary constraints to the achievement of a steel making capacity of 5 MTPA. The organisational structure of 5MTPA Project involved a central project management team, and twenty-seven sub-project design teams, each of which addressed a separate constraint. For example, the intent of the BOS Project was to redress a reliability issue with the control system that was causing production delays and hence limiting plant capacity. The relay logic control panels were more then twenty years old requiring relatively high levels of maintenance and repair and spare parts were scarce.

Figure 2.1 depicts the formal project structure[6], including project members, for the BOS, WTP, and LK Projects. The individuals identified by this structure represent the set of actors who were followed at the start of this ethnographic study. As the study

[6] The project teams listed have been structured by BHP so as to have members from a number of its different organisational silos – engineering, maintenance, and operations. This deliberate strategy incorporates individuals with the requisite skills and knowledge from each of these silos within the

progressed, other actors and social collectives that influenced the process of design were identified and followed as discussed in detail in Chapter (6).

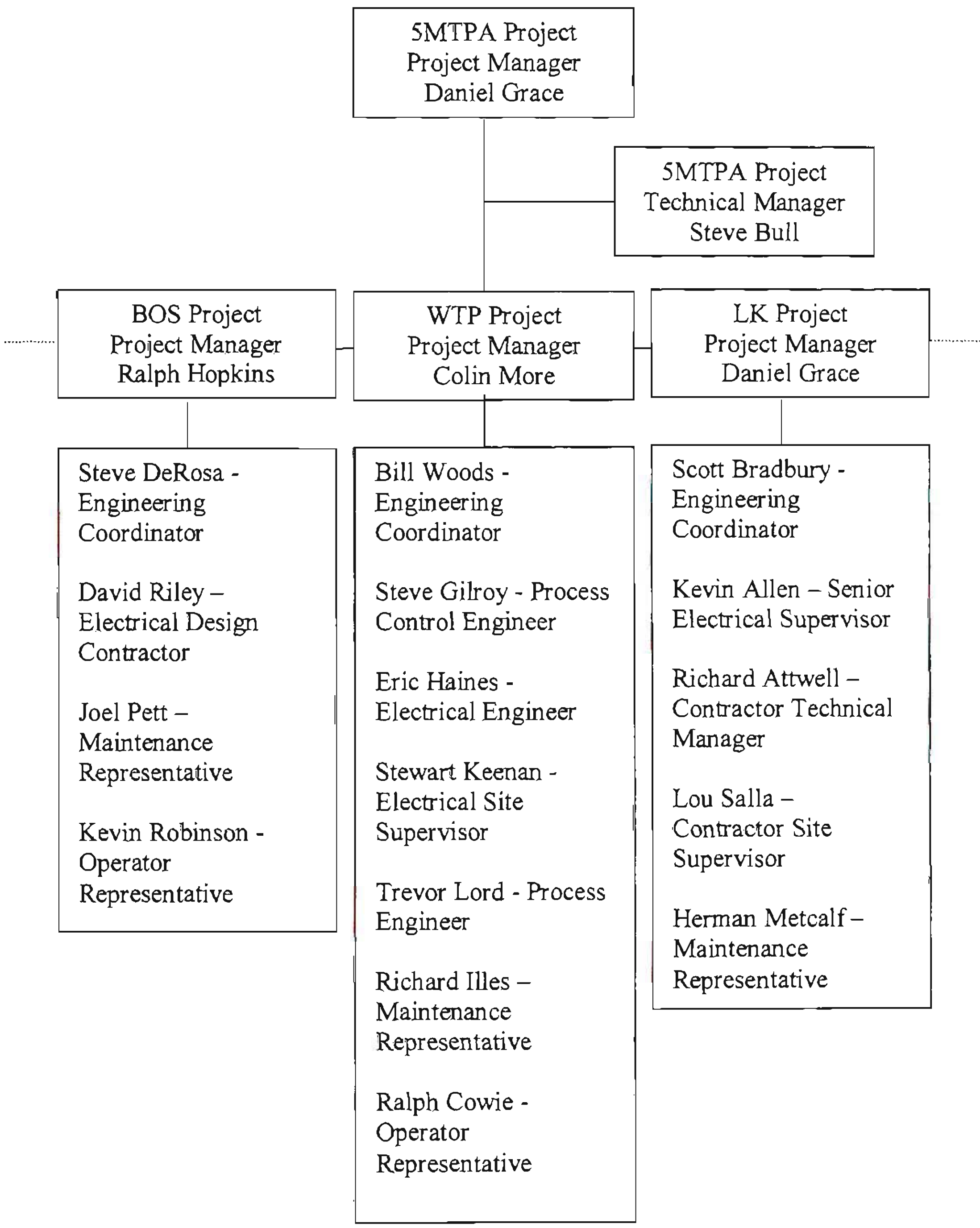

Figure 2.1 5MTPA Project Case Studies Structure

structure of the sub projects. This and other BHP standardised approaches to the process of design are discussed in more detail in Chapters (7) and (8).

As stated previously, I approached the first case study (the BOS Project) as an observer: standing back and watching what was done; when it was done; who was doing it; and where were they doing it. In the second and third case studies (the WTP and LK Projects), I sought greater understanding of the sociological processes as a participant observer: stepping forward into the fray with a recognised role as a facilitator for the design of a section of the human machine interface. This involved facilitating interface design workshops, the specifics of which will be discussed in the ensuing sections. The following sections provide a general overview of each of the three case studies.

2.5 Case Study (1) – BOS Project

The BOS Project had a budget of AUD$1.0M and involved the upgrade of the three main control rooms in the BOS plant. The project commenced in May 1998, with the first control room being commissioned in February 1999. The BOS control room is located within the BOS plant and is staffed twenty-four hours a day, seven days a week. During each shift there is a three-person collaborative team within the control room and a further ten individuals controlling sub-systems from various other locations in the plant.

The following is an excerpt from the official 'scope of work' for the BOS Project.

> This project will replace the existing control system with current supported technology equipment to achieve plant availability for guaranteed 5MTPA slabmake. Existing flux additions control system and relay panels are over 20 years old and no longer

supported by suppliers. Hence, the risk of increasing unreliability and long down times due to repair and spares difficulties which will reduce the plant availability below that required for 5MTPA.

The main components of the scope of work include:

- Replace existing PLC [programmable logic controller], microprocessors and relay panels with A-B PLC 540B [Allen-Bradley] processor and remote racks.
- Install ethernet PLC comms [communications].
- Remove existing ABB [Asea-Brown-Boveri] weigh room alarm.
- Remove all redundant cables.
- Replace all control room desks with new to cater for Macroview screens, computer screens, CCTV [closed circuit television] monitors, and emergency hard-wired functions.
- Provide two (2) additional Macroview terminals per control room.
- Develop new Macro view screens for flux system (BHP 1998a).

The basic task of the project was to design and install a new human computer interface for process control of the flux system. The function of the flux system is to deliver selected quantities of a variety of mineral products and chemical compounds that assist in the melting and fusing process of making steel. The project replaced the aging push-button, hard-wired, PLC and relay-based control system with mouse, keyboard, monitor, and associated computer technology[7]. Figure 2.2 provides a 'before' and 'after' picture of a section of the updated BOS control room operator interface desk.

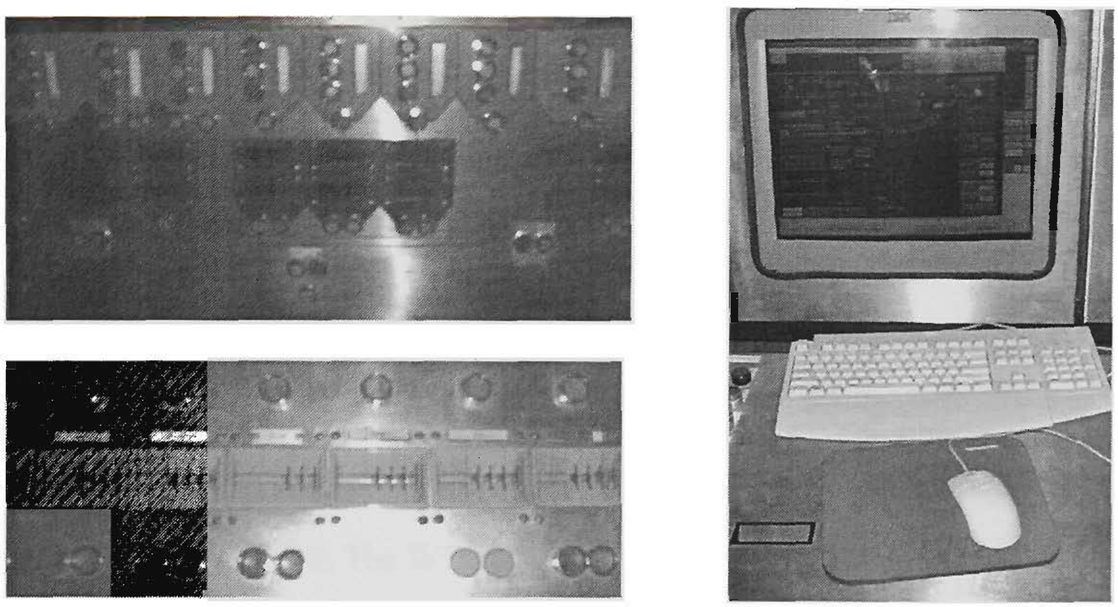

Figure 2.2 Section of BOS Control Room Desk - Before and After.

The BOS Project seemed to follow the documented internal BHP procedures for management of design projects[8]. It was presented by the participants as a traditional, reductionist approach to engineering design with each stage serving as input for the subsequent stage. The project structure was a hierarchical combination of engineering, contractors, maintenance, and operations. The engineers provided the management, coordination, and technical requirements for the project. The contractors, under close collaboration/supervision of the engineers, provided the detailed hardware design,

[7] See Appendix (2) for a BOS plant process schematic, proposed control desk layout drawings, and hardware configuration diagram.

[8] BHP has a standard procedure for management and control of the design process (see BHP 1997). This and other observed standard practices are discussed in detail in Chapters (7) and (8).

software design, purchasing, and installation. Operations and maintenance provided input on the local plant requirements for the project. I played no designated role within this design process. I attended meetings, observed participants, questioned actions, reviewed documents, and generally 'hung around' with actors involved in the project.

2.6 Case Study (2) – WTP Project

The WTP Project had a budget of AUD$1.12M and involved the upgrade of the WTP control room. The project commenced in January 1998, with the first stage being commissioned in May 1999. The WTP control room is located within the Slab Caster section of BHP and is staffed twenty-four hours a day, seven days a week. During each shift, there is only one person on site located in the control room.

The following is an excerpt from the official 'scope of work' for the WTP Project.

> The control equipment for the No.1 Caster Water Treatment Plant is based on relay technology some 25 years old. It is proposed to replace it with PLC technology to avoid potential long down times due to spares difficulties. The new equipment will also allow improvements in control.
>
> The control sequencing for No.2 and 3 Casting Machines Water Treatment Plant is carried out by a single PLC. This will be upgraded and a 'hot' stand-by spare installed to optimise availability.

The main components of the scope of work include:

- Remove existing relay logic complete with mimic boards, control desks from No.1 machine and provide software to control these functions in the PLC's.
- Provide a PLC for No.1 machine.
- Provide a 'hot' spare PLC for No.2 and 3 machines with automatic swap over in the event of failure.
- Program for start/stop functions to control the D&F pumps.
- Provide all hardware and software for new PLC control, including operator screens to replace mimic boards.
- Provide adequate redundancy for control system
- Rearrange switch room to accommodate additional hardware and provide equipment separation and isolation enabling safe maintenance. (BHP 1998b)

The requirements of the WTP Project were similar to those of the BOS Project, that is, to replace a deteriorating push-button, mimic panel, relay-based, control system, with current computer technology[9]. Figure 2.3 provides a 'before' and 'after' picture of a section the WTP control room.

[9] See Appendix (3) for a WTP plant process schematic, proposed control desk layout drawings, and hardware configuration diagram.

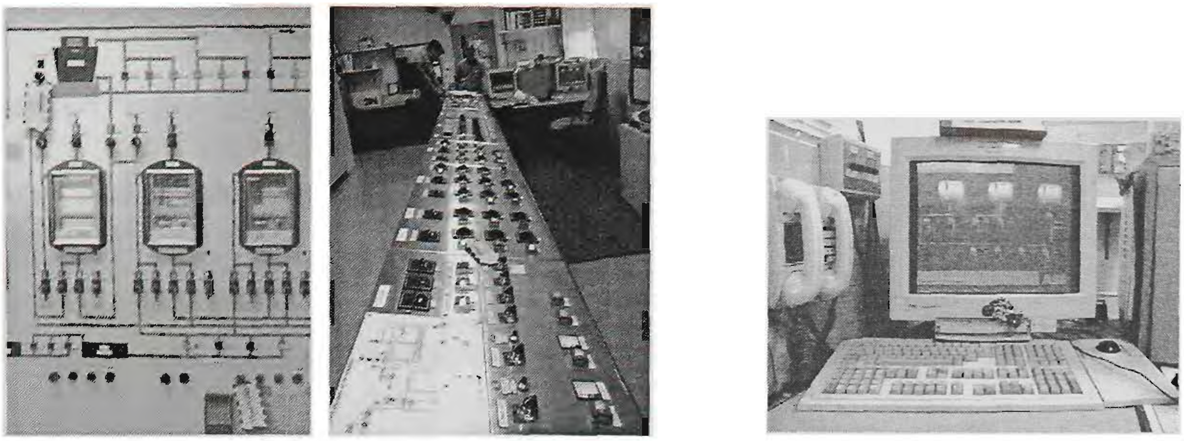

Figure 2.3 Caster Water Treatment Plant Control Room - Before and After

As with the BOS Project, the WTP Project seemed to follow documented internal BHP procedures, was presented as a traditional reductionist approach, and employed a hierarchical project structure. However, unlike the BOS Project, the WTP Project was restructured mid way through the project. In early 1998, a new Chairman of the Board of Directors of BHP Pty Ltd was appointed, Paul Anderson. Upon taking up the position, Mr. Anderson directed a general review and rationalisation of all capital expenditure throughout BHP Pty Ltd. As part of this process, the WTP Project was selected as a rationalisation target and subsequently restructured. The restructure involved an extension of the timeframe and the removal of contractors in an attempt to reduce cash flow 'out the door'; instead all work was done with 'in-house' personnel.

Unlike the BOS Project, in the WTP Project, I played the roles of a participant and an observer. That is, I became a functioning member of the design team where I had negotiated for myself the role of "human machine interface coordinator for the back wash water handling system". This role involved coordinating and directing the activities of a sub team of seven project members in designing the control system interface for back wash water handling in the WTP. In order to perform this role, I applied KOMPASS[10], a prescriptive design methodology identified during my literature review (see Chapter (3)).

KOMPASS was developed by the Swiss Federal Institute of Technology, (ETH), Work and Organisational Psychology Unit, Zurich, Switzerland. The term KOMPASS is an abbreviation of the German version of 'Complementary Analysis and Design of Production Tasks in Sociotechnical Systems'. The method was selected because of its applicability to context of the WTP Project, its positive results reported in the literature, and a collegial relationship between its developers and the University of Wollongong, within which I was located. To develop a working knowledge of the approach I visited Zurich to observe the process in use and receive first hand tuition.

In applying the method, I facilitated a series of workshops involving a cross section of system designers, system operators, and system maintainers. The workshops led the participants through a systematic review of the WTP process and its potential variations and disturbances, for example, power failure, pump break down, or cooling tower outage. Based on this review, initial detailed screen layouts and requirements were developed for the human machine interface.

[10] The focus of this study is on the *process of design* not *methods for design*. Hence, I will provide only a brief overview of the KOMPASS method and its results in Appendix (5). Further to this, in applying this method it was not my intention to evaluate its efficiency or efficacy with respect to the process of design. It merely represented a suitable vehicle through which to gain greater personal access to the internal dynamics of the process of design.

2.7 Case Study (3) – LK Project

The LK Project had a budget of AUD$1.08M and involved the upgrade of the LK control room. The project commenced in January 1998, with intended completion in December 1998. The LK control room is located in the BOS section of BHP and is staffed twenty-four hours a day, seven days a week. During each shift, there is a two person collaborative team within the control room and plant.

The following is an excerpt from the official 'scope of work' for the LK Project.

> This project will replace the existing MCC [motor control centre] and relay panels and will contribute to the lime kilns production of 280,000 t/yr of fluxes required for the 5MTPA. The existing MCC and relay control system is over 25 years old and no longer supported by suppliers. Hence the risk of increasing unreliability and down times due to repair and spares difficulties will reduce plant availability below 95% and therefore limits flux production. The briquetting, KA, and KB switch room MCC's and relay panels will be replaced with current technology and reliably supported equipment.
>
> The main components of the scope of work include:
>
> - Replace briquetting, KA and KB switch room MCC's

- Replace briquetting, KA and KB switch room relay panels with A-B PLC control.
- Replace current control room mimic panel with A-B panel view operator interface.
- Removal of redundant cables identified during the MCC and relay panels replacement. (BHP 1998c)

The basic scope of work for the LK Project was similar to that of the BOS and WTP Projects. That is, remove the existing, outdated control system with its switches, buttons and relays, and replace it with a modern computer control system[11]. Figure 2.4 provides a 'before' picture of the display panel in the LK control room.

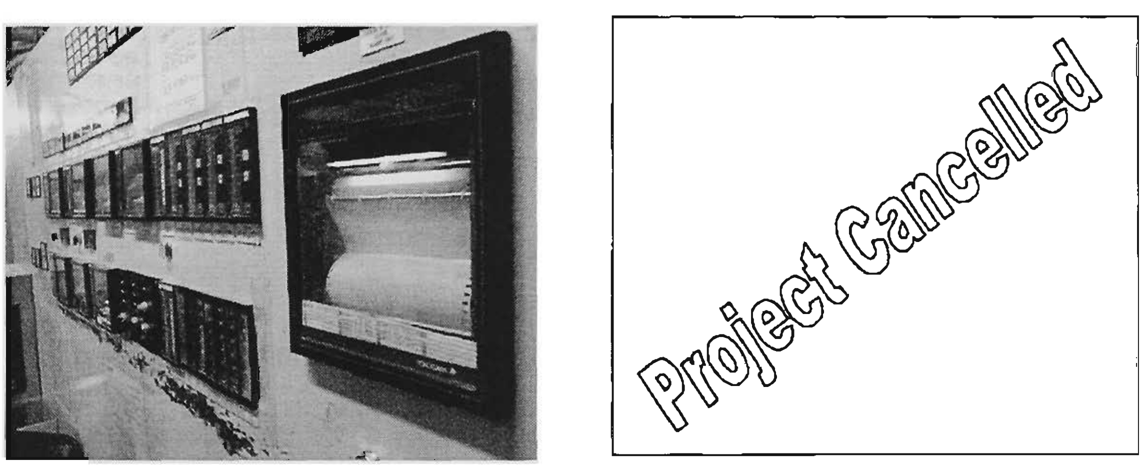

Figure 2.4 Section of Lime Kiln Plant Control Room Before and After

Unlike the BOS and WTP Projects, the LK Project did not follow the BHP standard operating procedures and practices. In these projects, there was a duplication of

[11] See Appendix (4) for a LK plant process schematic, proposed control desk layout drawings, and hardware configuration diagram.

management and supervision systems between BHP and contractors. This meant, for example, that a BHP supervisor would check on a contractor supervisor whilst the contractor supervisor was checking on the contractor workers. This constant crosschecking throughout all aspects of the project consumed a large quantity of the available person-power. To alleviate this drain on resources, BHP restructured the LK Project around an experimental 'integrated team approach'. The intent of this approach was to form a single integrated BHP/contractor team and in doing so to increase the efficiency of the project.

The LK Project team produced an 'integrated team charter', signed by all participants, that said:

> The Integrated Team Approach is about going back to the way people used to do business and putting the handshake back into business.
>
> This approach empowers those involved in the project with the freedom and authority to accept responsibility to do their jobs by encouraging decision making and problem solving at the lowest possible level of authority. It encourages everyone to take pride in their work and tells them it's OK to get along with each other.
>
> The process provides mechanisms for cooperation between the participants, so that energy sapping disputation is removed and

> productive working relations are carefully and deliberately built, based on mutual respect, trust, and integrity (BHP 1998c).

As in the WTP Project, I was to play the roles of a participant and an observer in the LK Project. In this case, the role that I negotiated for myself was to implement a second prescriptive design methodology, TOP Modeler[12].

TOP Modeler is a software package developed by the University of Southern California that contains a knowledge base to help designers, managers, engineers, or shop-floor workers make design choices about integrating technology, organisation, and people. To help develop my competence with the TOP Modeler software, I visited its developers at the University of Southern California to receive first hand tuition.

In applying the TOP Modeler method to the LK Project I introduced the software to a number of members of the design team and provided initial training. The proposal was to follow the use of, and reactions to, the software. Unfortunately, in late 1998, before any site work commenced, the LK Project was cancelled by BHP as part of Mr. Anderson's review and rationalisation of all capital expenditure. As a result, the software was never fully applied to the design project.

[12] See Appendix (6) for a brief overview of TOP Modeler and its LK results. As noted earlier, the focus of this study is on the *process of design* not *methods for design*. Hence, I have not evaluated the efficiency or efficacy of TOP Modeler with respect to the process of design. Instead, I have simply used it as a suitable vehicle through which to gain greater personal access to the internal dynamics of the process of design.

The cancellation of the LK Project, although a personal disappointment to me, represents a not uncommon ending for design projects. I originally selected three design projects as the suitable number to follow because of this risk of cancellation. In light of this, the empirical data gathered from the cancellation still forms part of my exploration of the process of design.

This section has provided a descriptive overview of the 5MTPA Project and three of its sub projects – BOS, WTP, and LK. My role within these projects varied from an observer, endeavouring to record the events that I observed, to a participant personally involved in the processes of design. The 'scope of work' for each of the sub projects was similar, that is, to design and install a process control system incorporating a human computer interface. These cases have provided access to actual design projects from which I have constructed my account.

2.8 Summary

The field research methods adopted in this study are ethnography and grounded theory. These approaches provided a means for gaining access to, and motivated interpretations of, the social processes that occurred within the three design case studies. The discussion of these case studies in this chapter has been restricted to a descriptive overview in order to provide a foundation for my detailed interpretations of the activities undertaken by actors during the process of design, which are presented in Chapters (4) to (8). The literature on theory that is relevant to this interpretive account is discussed in the next chapter.

Chapter (3) - Review of the Literature

3.1 Introduction

An ethnographic exploration of the social processes that occur during engineering design projects inevitably crosses many academic and practitioner boundaries – sociology, psychology, management, engineering, human factors, human computer interaction, and computer supported cooperative work, to name a few. An overview of the literature from these fields helps to position my particular study within the milieu of potentially relevant research. It demonstrates a general gap in the literature that this study endeavours to address, an absence of ethnographic studies of engineering design of computer interfaces for industrial systems. Breaking the literature into four distinct, yet overlapping, categories provides a basis for review and discussion with respect to my study.

3.2 A Schema of Relevant Literature

Four overlapping schema categories have been used to classify the literature relevant to my research: (1) sociology of work and technology, (2) prescriptive design methodologies, (3) design studies, and (4) ethnographic studies of engineering design. These categories have been selected for consideration here because of their specific focus on technology. Figure 3.1 displays the notional positions and boundaries[1] of the four categories relative to this study.

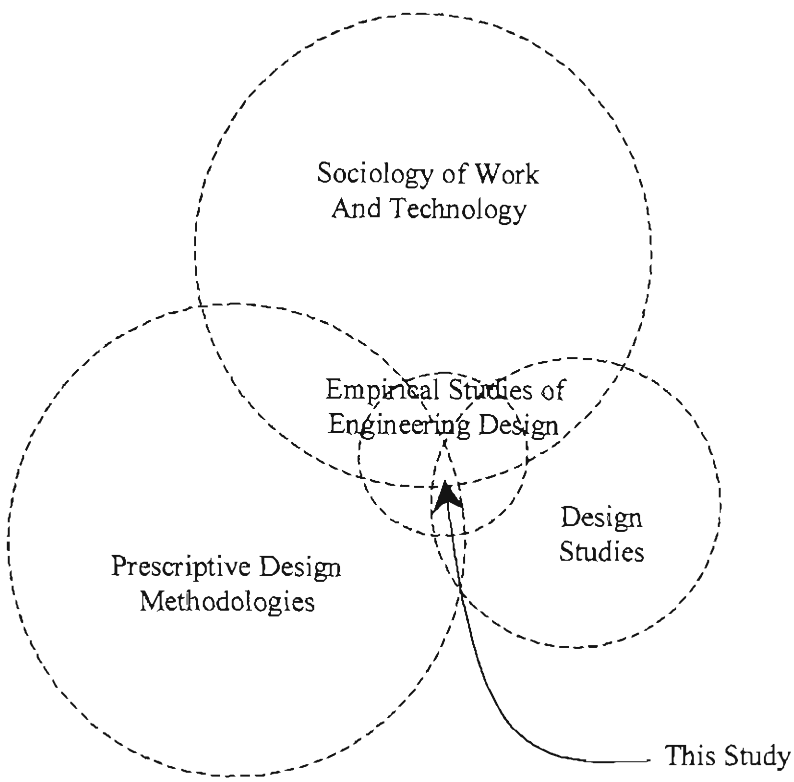

Figure 3.1 A Schema of Relevant Literature

Sociology of work and technology encompasses theories on the relationships generally between technology, work, and society. These theories can help us understand how technology emerges in particular configurations. *Prescriptive design methods* encompass approaches to design of technology that specify design rules or heuristics based on what the methods' originators purport to be important and worthwhile. *Design studies* represent a forum for the discussion and development of theoretical aspects of design, including its methodology and values. They draw upon, and compare,

[1] The boundaries around the schema categories are depicted in a broken line format to reflect their permeability and flexibility.

design processes in many areas, including engineering, architecture, planning and industrial design (DRS 2001). *Ethnographic studies of engineering design* specifies a body of research that has been developed by individuals and/or groups, from a variety of theoretical backgrounds, with an interest in engineering design. The studies are characterised by ethnographically-based analysis of the various aspects of engineering design. Each of these four schema categories is discussed in greater detail and related to my study in the following sections.

3.3 Sociology of Work and Technology

Sociology of work and technology encompasses theories on the general relationships between technology, work, and society. They are relevant here as a way of positioning this study within a set of overarching theoretical perspectives on technology and society. Four specific theories predominate within this genre are - *technological determinism, labour process theory, sociotechnical systems theory,* and *the social shaping of technology.*

Technological Determinism

Technological determinism contains two central ideas, that technological development is autonomous and that societal development is determined by technology (Bijker 1995). Technology development is viewed as an autonomous process that coerces and determines social and economic organisations and relationships (Grint 1997). The critics of this approach are many (see Roy 1976; McLoughlin 1992; Bijker 1995; Grint

1997) and the supporters few. Even the two frequently cited supporters Woodward (1958) and Blauner (1964) are not completely aligned with the approach (Grint 1997).

Technological determinism is criticised for ignoring the social context and processes behind the introduction and operation of technology. Insufficient weight is given to managerial choice in decisions over the introduction and use of new technology. Finally, the approach is apolitical in terms of assuming consensus between management and the workforce (McLoughlin 1992) (for further readings on technological determinism see Silverman 1978; Grint 1997). In response to these criticisms, social determinist views, such as labour process theory, were developed.

Labour Process Theory

Labour process theorists claim that there is a fundamental and structurally determined conflict underlying the relationship between capital and labour. The theory has its origins in the work of Karl Marx, but its re-emergence has been attributed to the work of Harry Braverman (1974). In his book *Labor and Monopoly Capital – Degradation of Work in the Twentieth Century*, Braverman set out to challenge technological determinist assumptions by arguing that automated technologies were introduced by management with the intention of deskilling job content and increasing management control (McLoughlin 1992).

Labour process theory, as it addresses technological change, assumes that the pursuit of profit requires that management wrest control of the labour process from the workforce. This argument has been questioned on the grounds that there are other strategies available to management that do not involve job deskilling and reduction in worker autonomy (see Friedman 1977). The approach also assumes that the implementation of management strategies is unproblematic. Empirical studies document many instances of workforce resistance and its capacity to modify management strategies (for examples, see Friedman 1977). Finally, the approach views the relationship between management and the workforce as being in conflict on all issues. Burawoy (1979) argues that, rather than being in continual conflict, some worker groups actively promote some technological changes (for further readings on labour process theory see Wood 1982; Noble 1984; Blackburn 1985; Knights 1988; Thompson 1989).

Labour process theory and technological determinism both consider the shape of technology to be predetermined by, respectively, social or technical circumstances. An alternate perspective, sociotechnical systems theory, presents a non-deterministic view about technology and society.

Sociotechnical Systems Theory

Sociotechnical systems theory stresses the interrelationship between the technical system of production and the social system of work. The theory has its origins in the Tavistock Institute of Human Relations with Trist and Bamforth (1951), and Rice (1958). The theory was generated as a backlash against the theoretical swing away from technological determinism toward social determinism and the total rejection of technology as an influencing factor. In redressing this, it attempts to find some middle ground, avoiding determinist extremes in favour of a conceptual position encompassing many different elements: technology, people, organisations, genders, interest groups, and many others (Grint 1997) (for further readings on sociotechnical systems theory see Emery 1978; Passmore 1978; Silverman 1978; Mumford 1980).

Sociotechnical systems theory is founded in a 'scientific' and 'systems theory' approach to organisational analysis. This perspective takes a positivistic, conservative view of organisations as goal seeking systems. This conservative view fails to account for the independent influence of individual actors (Silverman 1978; Grint 1997). The approach has also been criticised as being prescriptive and consultancy based managerialist sociology (Silverman 1978). Finally, the approach takes the nature and effects of technology as given and fails to interrogate the essential character of the technology itself (Grint 1997).

Social Shaping Approaches

The three theoretical perspectives outlined above have left the "black box" of technology relatively untouched. The social shaping of technology approaches, within which I would position my study, encompasses a disparate grouping of research areas that have a general commitment to opening the "black box" of technology for sociological analysis (Grint 1997).

Two perspectives from within this genre are the social construction of technology (SCOT), and the actor-network approach. The SCOT approach was pioneered by Bijker and Pinch (see Bijker 1987; Bijker 1992; Bijker 1995a; Bijker 1995b). The approach highlights the interpretive flexibility of objects and social phenomena. The stable form of an artefact is not predetermined by the nature of the object itself. Rather, it is contingent, an outcome of complex social and political processes (Garrety 2000, p.104).

The actor-network approach, associated with Callon, Latour, and Law, describes 'sociotechnical ensembles as heterogeneous networks of human and non human actors' (Bijker 1995, p.251) (see Callon 1980; Latour 1987; Law 1987; Latour 1996). The development of these networks is analysed as a series of translations. Where actors in the network move other actors to different positions, and, in doing so, alter the meanings associated with these actors. Within these networks the power of an actor is not inherent to the individual but originates from the networks they control (Bijker 1995a, p.251).

Social shaping of technology approaches suggest that the final forms of technology are the outcomes of people's interpretations of social and political circumstances. This way of thinking has its roots in sociology of scientific knowledge (SSK), which argues for the socially constructed character of scientific knowledge (Grint 1997) (for further discussion see Latour 1979; Collins 1982)

The previous sections have described four general theories encompassed by sociology of work and technology – *technological determinism, labour process theory, sociotechnical systems theory, and social shaping approaches*. Although these theories present a series of overarching notions on the general relationship between technology, work, and society, they do not address the specific day to day actions of the humans engaged in the process of design. Though I have positioned this study within the social shaping paradigm, it is not my intent to provide another study supporting the notion that technology is socially shaped. Rather, it is my intent to provide an account of the social processes that occur when engineers design technology, an area that Downey (1995, p.176) suggests requires 'further conceptual advancement.' A section of the literature that begins to shed light on some of the social processes of design, at least in a descriptive sense, is that of prescriptive design methodologies.

3.4 Prescriptive Design Methodologies

Prescriptive design methods encompass approaches to the design of technology that specify design rules or heuristics based on what the originators of the methods purport to be important and worthwhile. These methods are relevant here as representations of the ways in which certain individuals perceive that design should occur. Some of the practitioners who make use of these prescriptive methods have provided reflective commentaries on the nature of design as work. Although these reflections are not explanatory frameworks for the process of design, they are useful in that they provide sensitising concepts for this study. A selection of relevant design methods has been reviewed to identify their insights and blind spots in relation to the aims of my study - traditional engineering, software engineering, human factors, human computer interaction, and computer supported cooperative work[2].

[2] This review is by no means a comprehensive summary of all prescriptive design methods available nor does it provide a critical evaluation of the methods. The methods have been selected based on relevance to the context of the study and their contribution to understanding of some of the practical aspects of design.

Traditional Engineering

The traditional engineering model of the design process describes a sequence of activities where the output of each stage serves as the input to the next stage. The stages are generally seen to proceed logically from the conceptual level through physical design and evaluation stages (Czaja 1997, p.29). The typical design stages identified are; (1) recognition of problem, (2) definition of problem, (3) exploration of problem, (4) search for alternatives, (5) evaluation and decision making, (6) specification of solution, (7) communication of solution (see Vidosic 1969; Hill 1970; Dieter 1983; Lewis 1989; Samson 1997). These methods are characterised by a reductionist approach, with systems and designs being broken into increasingly smaller components. Each component is designed as a separate entity and then fitted together to form the whole.

A number of engineering authors provide personal reflections on the traditional engineering design process. Clegg (1972) produced a book to help young engineering designers based upon his own engineering experiences. He argued that logical systematic approaches to design were of little use when actually designing something new. He did, however, argue that they were useful once a design was selected and a logical explanation for the selection was required. Petroski (1996) and Constant (1980) provide a series of historical case studies of the design of artefacts that demonstrate the influence of individual engineers, companies, communities, economics, politics, aesthetics, and ethics.

Software Engineering

Similar to traditional engineering, software engineering in theory follows a logical, reductionist approach to design. The Institute of Electrical and Electronics Engineers (IEEE) provides a comprehensive listing of forty-five separate standards, developed over a sixteen-year period, relating specifically to software engineering design. These standards cover software engineering design in three main phases. Phase (1) commences with analysing user needs and producing a set of requirements (problem description). Phase (2) uses these requirements to develop several levels of design (sub-problem solution). Phase (3) uses the design to build the smallest units then combines and tests them to produce the final system (combination of partial solutions) (Phillips 1998, p.77) (for further accounts of software engineering approaches to design see Gibson 1992; Bennatan 1995; Purba 1995).

A number of software engineering authors have provided reflective commentaries on the design process. For example, Phillips (1998, pp.35-41) discusses the causes of software project failures, defining failure as "software engineering projects being delivered behind schedule, over budget, or by being inoperable" (Phillips 1998, p.5). He argues, based on experience, that such failures can be traced to four main causes: (1) a failure to balance the people involved with the process used and the product's characteristics, (2) a failure to communicate ideas and create a shared vision of the product that is being developed, (3) a failure to explicitly and systematically manage all the countless details of a project, and (4) a failure to implement and strictly adhere to agreed standards.

Thimbleby (1990, pp.133-148) elaborated on his experiences and identified twelve systemic design issues that can lead designers to design badly. (1) Designers and users have diverging goals and desires. The designer is concerned with software, hardware, and optimum selection. Users are concerned with the information manipulated by the systems. (2) Designers design for themselves. They view themselves as exemplary users and evaluators. (3) The programming languages available to designers control the way they think. (4) Designing computer systems is too easy. The faster a program is written the harder it is to modify and improve. (5) Satisfying technical software design parameters can override user requirements. (6) Design tends to grow from the bottom up satisfying feature sets without understanding the overriding purpose. (7) Design is fun; work is not. Designers have creative licence in system design, whereas users have to live with the completed design. (8) Designers add certain features, (mouse, colour, sound, etc,) because they are considered generally desirable rather than meeting any specific user need. (9) Programs, and their coding mess or elegance, are invisible to the user. (10) Technology changes faster than its impacts can be quantified. (11) The dialogue between the user and the designer is restricted due to language, information, and training. (12) Even with perfect information, mistakes are still made.

Authors such as Clegg, Phillips, and Thimbleby have not explicitly set about studying the process of design, nor have they attempted to provide explanatory frameworks for their observations. Rather, they have produced descriptive commentaries based on their personal experiences as engineers engaged in design activities. The proponents of the prescriptive design methodologies discussed in the following sections include a broader range of professionals (eg, psychologists, sociologists, and physicians) interested in design than those cited in this section.

Human Factors

Human factors (HF), or ergonomics, is a field that uses knowledge of human abilities and limitations in order to design systems, organisations, machines, and products for safe efficient and comfortable human use (Helander 1997, p.4). As a field concerned with the implementation of its knowledge in design practices, it uses a number of prescriptive design methodologies. Three common methodologies supported by HF practitioners are; sociotechnical systems approach, participatory ergonomics, and user-centred design.

The sociotechnical systems approach[3] represents a complete process for the analysis, design, and implementation of systems. The approach is based on open systems theory and emphasises the joint optimisation of social, technical, and organisational factors (see Passmore 1978; Taylor 1988). Participatory ergonomics involves the application of ergonomic principles and concepts to the design process by individuals who are part of the work group and users in the system. These individuals are typically assisted by ergonomic experts who serve as trainers and resource centres (Czaja 1997, p.31) (also see Ehn 1989; Schuler 1993). The user-centred design approach[4], which locates HF as the central concern in the design process, is based on an open systems model and considers human and technical subsystems within the context of a broader environment. These approaches suggest processes for incorporating HF specifications into design,

[3] Proponents of the sociotechnical systems approach developed the TOP Modeler software package that was used in the LK Project case study.
[4] Proponents of user-centred design developed the KOMPASS method that I used in the WTP Project case study.

specifications such as 'maximising user involvement at the task level, support of cooperative work, and maintaining user control of the system' (Czaja 1997, p.32).

A number of authors have provided practical discussions on their attempts to apply HF real world design processes with a consensus that the knowledge of human abilities and limitations is ignored or at best marginalised (see Lim 1992; Czaja 1997). For example, Perrow (1983) provides five key observations. (1) There is a lack of organisational commitment to HF, in terms of, rewards, sanctions, and management beliefs. (2) There is a contradiction between good design logic and good operating logic. (3) The small size and non-core nature of the activity gives HF departments and practitioners very little power or influence in an organisational context. (4) The social structure of the organisation affects the design; for example, highly centralised authoritarian organisations will desire designs that match this template. (5) Many HF practitioners see the operator as a rational, logical, information processor only, ignoring the social context of the operator and the organisation.

Clegg (1993) lists seven observations that seem to be consistent with those of Perrow. (1) End users are in general viewed as a source of error and unpredictability that should be designed out. (2) End users are also viewed as problems, and recalcitrant actors, resistant to progress and change. (3) The costs of poor system design fall on users not on the designers. (4) The focus of system development methods is on technical concerns to the almost absolute exclusion of psychological and organisational factors. (5) The criteria for good systems design are technical. (6) There is a lack of clear, communicable and enforceable psychological and organisational standards applying to the development, implementation and use of new technologies. (7) New technology investments are under resourced in terms of time, money, expertise, management commitment, and especially in their human aspects.

The reflections of the practitioners cited in this and previous sections indicate concepts such as changing technologies, social structures, unequal distribution of power, and organisational commitment may prove to be fruitful themes for consideration during the development of an explanatory framework for the activities of design.

Human Computer Interaction

Human Computer Interaction (HCI) is a relatively new interdisciplinary field that is concerned with people interacting with computers and information technology. One of the motivating factors in HCI is a purported desire to 'help people attain their individual and corporate goals through useful and useable systems' (Nickerson 1997, p.4). The field has developed a number of prescriptive design methodologies to support its general interest in improving human computer interaction (Helander 1997, p.xi). Three common methodologies supported by HCI are; useability design process; prototypes; and scenario-based design. Each is outlined below.

Useability design attempts to create systems that are easy to learn, easy to use, contain the right functions, and are liked by users. To achieve this, the method suggests four key points: early focus on users, empirical measurement, iterative design, and integrated design, where all aspects of useability evolve together from the start (Gould 1997, p.231). Prototypes involve the 'creation of an artefact to represent different forms of an evolving design' (Houde 1997, p.367). The level of sophistication of the prototype can vary from simple paper and cardboard representations through to functioning replicas of final artefacts. Scenario-based design involves the creation of a narrative description of what people do and experience as they try to make use of computer systems and applications. This narrative is sufficiently detailed that design implications can be inferred and reasoned about (Carroll 1997, pp.384-385).

As with the closely related field of HF, HCI practitioners have found that the application of HCI knowledge in supporting design activities 'has not been demonstrated' (Long 1997, p.198). Very few successful case histories are reported (Newman 1994).

Computer Supported Cooperative Work

'Computer Supported Cooperative Work (CSCW) is an interdisciplinary field that has emerged more recently than HCI' (Olson 1997, p.1433). Research within the field has arisen from a range of disciplines including computer science, artificial intelligence, psychology, sociology, organisational theory, and anthropology (Greif 1988, p.5). Its focus has been on using computing and communication technologies to 'support group and organisation activity' (Olson 1997, p.1434).

One of the design methodologies supported in the CSCW community is that of user ethnography. With this approach, designers study users with techniques mainly associated with sociology and anthropology. These techniques include, for example, observation, interview, survey, and document analysis for the purpose of understanding the culture of the user from the user's point of view (Olson 1997, p.1434) (for further discussion see Suchman 1987; Nardi 1997). This type of ethnographic research has a specific interest in the culture of technology users rather than the culture of the technology designers.

As with the other prescriptive design approaches, CSCW practitioners note a variety of difficulties in the application of their methodologies. For example, Blomberg, Suchman, and Trigg (1997) attempted to apply the user ethnography methodology to the development of an electronic document support system in a large law firm in the USA. In their conclusions they stated that 'because of shifting technology directions and inadequate allocation of resources' it was 'difficult to sustain the kind of collaboration that we had hoped for' (Blomberg 1997, p.210).

The previous sections have reviewed general prescriptive design methodologies from, traditional engineering, software engineering, human factors, human computer interaction, and computer supported cooperative work. I have used two of the design methods developed in this area as a vehicle through which to gain participative access to the social processes of real world design. Previous practitioner application of these methodologies has highlighted 'other' influences beyond the reach of the particular methodology employed, such as; shifting technology, inadequate resources, social structures, and low organisational commitment. Although these types of practitioner observations do not provide explanatory frameworks, they do provide sensitising concepts that can be used for more detailed studies, such as my own. Specifically examining the process of design is a body of research 'design studies', which is addressed in the following section.

3.5 Design Studies

The design studies literature represents a forum for the discussion and development of theoretical aspects of design. It draws upon and compares design processes in a wide range of areas, including engineering, architecture, planning, and industrial design. It covers specific aspects, such as design management, design methods, design participation, and design planning (DRS 2001). Goel and Pirolli (1992) argue that the unifying core for this body of research resides with the notion that all design problem solving activities, regardless of discipline, follow the same basic sequence of steps:

1. An exploration and decomposition of the problem.
2. An identification of the interconnection among the components.
3. The solution of the sub-problems in isolation.
4. The combination of the partial solutions into the problem solution (Goel 1992, p.397).

Much of the empirical research in design studies has been carried out within the framework of cognitive psychology (Goel 1992, p.398) with a primary focus on individual designers and, only recently, on teamwork in design (Cross 1995, p.143). Lee and Radcliffe (1990) observed inexperienced designers solving problems in a laboratory setting over a period of a week. Guindon (1990) observed software engineers in an experiment where he presented them with a problem and gave them two hours to produce a solution. Badke-Schaub and Frankenberger (1999) observed four design processes in two companies over a twenty-eight week period. From these studies the authors produced models of the designer's mental processes of reasoning and judgement.

These models, although complementary to this study, differ in two primary areas. Firstly, they have a focus on the cognitive aspects of design by individuals, and only recently by teams. I have taken a sociological focus on individuals and social collectives involved in design activities in order to describe the broader social processes. Secondly, design studies are typically constrained to activities within Goel and Pirolli's four-step sequence of design. Limitations of this focus are identified in a study by Wallace and Hales (1987), who found that designers spent less then half of their 'real-world design' time on these four steps. In line with this, I have not limited myself to the four steps of design. Rather, I have followed a wide range of actors involved in a wide range of activities, pursuing what seemed relevant to the actors engaged in the process of design. When the cognitive and social aspects of design are combined a more complete picture emerges of how new technologies are created. Research that has examined the social process of design in a similar fashion to this study are discussed in the following section.

3.6 *Ethnographic Studies of Engineering Design*

The use of the term "ethnography" as a description for certain studies of engineering design seems to be contentious. Some ethnographies of engineering design seem to be conducted within the tenets of the sociological tradition, whereas others appear to be no more then superficial or cursory studies which provide only glimpses of the cultures in question. Button (2000, p.321) argues that in most cases 'ethnography is being used as a proxy for *fieldwork.*' That is, the theory behind the 'ethnographic approach is an overarching presence, vaguely felt, but never directly confronted.' Ball and Ormerod (2000) support this view and propose a bifurcation of ethnographic studies of engineering design into *pure* and *applied. Pure* ethnographic studies would be characterised as rich, intense, situated, open, and reflexive (Ball 2000, p.406), with a strong anthropological and sociological focus on constructing explanatory frameworks that account for the work of engineering designers, rather than a simple description of what was witnessed (Button 2000, p.322). Counter to this, *applied* ethnographies are characterised as short term, snap shot, theory-testing studies (Ball 2000, p.406), driven by sets of clearly practical goals (Button 2000, p.320).

Bucciarelli's (1988; 1994) ethnographic study of engineers is perhaps the earliest, and most frequently cited, study of engineering design. Bucciarelli performed a participant/observation study of engineering design in two engineering design firms. One firm made photovoltaic modules for the direct conversion of solar energy into electricity, the other made X-ray equipment for medical diagnostics, quality control, and baggage inspection. Bucciarelli's working hypothesis, and indeed final conclusion, was that designing is a *social process*. This social process involves negotiation and consensus, the final artefact being an awkward expression of consensus[5].

In one of the few other *pure* ethnographic studies of engineering design, Button and Sharrock performed a five year study of engineering designers (for further details see

[5] Ball and Ormerod (2000) criticise Bucciarelli's research and argue that the research period was relatively short, that Bucciarelli seemed to approach the study with some strong pre-conceptions about design, for example, 'design is not rational in the managerial or economists' sense', and finally, that Bucciarelli did not achieve the active insider role of a true participant/observer. These criticisms do not seem particularly well founded, especially in light Bucciarelli's clear statement that his premise about the 'social nature of design' was 'based upon what [he] observed' (Bucciarelli 1988, p.160).

Anderson 1993; Button 1996; Sharrock 1997; Button 1998). The study was conducted at a photocopier production firm located in the Southeast of England. The study focussed on engineers acting as 'practical sociologists' by examining in detail the ways in which engineers make sense of the environment in which they perform the work of engineering design. One of the themes that Button et al discuss is the *contingency* approach to engineering design, that is, the notion that the possible routes for a technology to develop are determined by political and social process as much as by logical and rational choice. Button et al argue that they have included this theme in their analysis simply because it was prominent in the working lives of engineers, not because it was a persistent motif in recent sociological studies of scientific and technological work.

I have placed this study, as with Bucciarelli's and Button et al's studies, within the *pure* ethnography genre. Most remaining ethnographic studies of engineering design seem to fit best within the *applied* ethnography genre. These studies do not explicitly pursue general explanatory frameworks to account for the work of engineering design. Instead, they follow narrowly defined research agendas imbued with strong pre-conceptions of what is and is not of interest.

Baird, Moore, and Jagodzinski (2000) performed an eleven-month ethnographic study on engineering design teams at Rolls-Royce Aerospace. The study was commissioned by Rolls-Royce Aerospace to gain further understanding of teamwork, particularly those aspects that are tacit, in order to better manage multi-national, collaborative design projects. The terms of the commission seem to have strongly guided the research. For example, the unit of study, and indeed focus, was predetermined by Rolls-Royce

Aerospace to be the design team. The findings of the study appear to be descriptive summations of key observations rather than an explanatory framework that accounts for the observed activities of the engineering designers.

Jagodzinski, Reid, Culverhouse, Parsons, and Phillips (2000) performed what they called an "ethnographically inspired" study on the conceptual phase of large, team-based engineering design projects. These projects were concerned with the design and production of integrated circuits within GEC-Plessey Semiconductors. Jagodzinski et al considered their ethnographic study to be a preamble to the development of a prototype computer-based support tool for project leaders and design engineers. As with Baird et al, the focus of the study was predetermined, in this case on the problems faced by project leaders and design engineers (for which the authors intend to provide solutions through their computer based support tool). The study also has a theoretical alignment with cognitive psychology rather than sociology or anthropology.

Lloyd (2000) performed a two-week ethnographic study of engineering design in a small automotive testing systems manufacturing company in the U.K. The study focused on the social activities of design and concluded that storytelling was a central mechanism in the development of a common language within design teams. However, as with Baird et al, these findings appear to be descriptive summations of key observations, rather than an explanatory framework that accounts for the observed activities of the engineering designers.

These previous ethnographic studies leave a gap in our understanding of the process of engineering design. They were predominantly concerned with mass produced artefacts (ie, consumer goods) rather then 'one-off' human computer interfaces for process control in the steel industry, as in my study. This difference suggests that the contextual findings of my study may be unique. Also, with the exception of Bucciarelli and Button et al, the previous studies have been a combination of short term, descriptive, and theory testing studies driven by sets of practical goals with no apparent pursuit of explanatory frameworks to account for the work of engineering designers.

3.7 Summary

Literature from sociology, psychology, management, engineering, human factors, human computer interaction, and computer supported cooperative work, makes up an eclectic body of research with relevance to this study. A review of this literature in terms of four overlapping schema categories - *sociology of work and technology, prescriptive design methodologies, design studies, and ethnographic studies of engineering design* – reveals that the studies are insufficient for the development of a sociological explanation of the observed actions of humans engaged in the process of engineering design.

Sociology of work and technology literature provides an overarching theoretical perspective on the relationship between work, technology, and society. Within this field, my study falls within the 'social shaping of technology' paradigm. *Prescriptive design methods* encompass approaches to the design of technology that specify design rules or heuristics. The relevance of this methodological literature is that its practitioners provide reflective commentaries on the nature of design as work. These commentaries serve as a set of sensitising concepts for this study's exploration of the process of design. The *design studies* literature is a forum for development of theoretical aspects of design in many areas, including engineering, architecture, planning, and industrial design. The research within this field focuses on similar phenomena to my study, within a broad interest in theoretical aspects of design. However, design studies are carried out within a cognitive psychology framework not a sociological framework, focussing on individual problem solving rather than individual and collective negotiation and decision making. *Ethnographic studies of engineering design* are predominantly short-term, descriptive, and theory testing studies driven by sets of practical goals rather than, as I attempt here, the pursuit of an explanatory framework for the activities of engineering design.

Such an explanatory framework is introduced in the following empirical sections, which present the overlapping and interlinked themes that organise this study's account of the observed process of design.