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**A Model for Manufacturing Cell
Job Redesign**

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Abstract

Cellular manufacturing is widely viewed as an exemplary form of manufacturing organisation for small batch size production. A UK survey states that over 75% of British engineering industry have introduced or are planning to introduce cellular manufacturing methods in an attempt to improve competitiveness through improved product quality, responsiveness and flexibility (Ingersoll Engineers, 1990).

Cells are known to foster these improvements through a focus on the methods of production and more co-operative work structures. The widespread adoption of cellular manufacturing methods has warranted research into and practical application of human-centred forms of work organisation. This approach seeks to improve the use of people and technology to develop more robust and effective manufacturing systems. The human-centred approach to job design and systems development is considered essential for improving Europe's future competitiveness (EC MONITOR FAST Programme, 1989-1992).

The design of cellular manufacturing systems is a complex task involving the joint consideration of material flow, machines, people and control issues. The development and practice of human-centred job design in cells is an area with little formal process. There is no coherent academic model that embraces all the relevant issues in cell job design.

This research develops and validates a generic model to facilitate human-centred job redesign in cell systems. The model adopts an open systems perspective and unifies three fields of job design embracing socio-technical, work organisation and function allocation issues. These levels provide a structure for the model.

The model explicitly represents factors affecting job design by features defined at the three levels of analysis. The features are comprehensive and are representative of the issues encountered in each field of job design. The features are not independent and are inter-related between levels of analysis. The model describes in quantitative terms the relationships between these features to provide a means for stepping through the cumulative effects of job design changes from one level to the next.

An application procedure to use the model, derived from the research methodology in this thesis, is described outlining the data capture and analysis activities for developing situation sensitive pictures of cell job designs. The combined model and application procedure are tools to help the model users accumulate knowledge on the factors affecting the design of jobs in cells.

Field research was carried out in a British manufacturing company over a period of fifteen months to develop and validate the model. Cell job design models were developed for four dissimilar cell systems varying in terms of cell age, work organisation and technical complexity. The model demonstrates its generalisability and sensitivity by accurately describing job design in four cell systems.

“If only it weren’t for the people, the goddamned people”, said Finnerty, “Always getting tangled up in the machinery. If it weren’t for them, earth would be an engineer’s paradise.”

- from Piano Player by Kurt Vonnegut Jr.

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Contents

Abstract	i
Acknowledgements	iii
List of Publications	iv
Contents	v
Figures	ix
Tables.....	x

Chapter 1

1.1 Manufacturing Cell Design	1
1.2 Job Design and Function Allocation	2
1.3 Research Objectives	3
1.4 Research Methodology	4
1.4.1 Literature Review	4
1.5 Thesis Structure.....	4

Chapter 2

2.1 Cellular Manufacturing Systems	6
2.1.1 Cellular Manufacturing Surveys	9
2.1.1.1 UK Survey	9
2.1.1.2 USA Survey	10
2.1.1.3 West German Survey	11
2.1.1.4 Summary	12
2.2 Cell System Design Methods	13
2.2.1 Group Technology.....	14
2.2.1.1 Traditional Cell System Design Methods	14
2.2.2 Examples of 'Real World' Cell Design	17
2.2.2.1 Example 1: Watervliet Arsenal	17
2.2.2.2 Example 2: Textron	18
2.2.2.3 Discussion.....	19
2.2.3 Human-Centred Manufacturing Systems	20
2.2.3.1 The Origins of Human-Centred Concepts.....	21
2.2.3.2 Principles of Human-Centred Systems.....	25
2.2.3.3 Summary	28
2.2.4 People Implementation Issues.....	29
2.2.4.1 Supervision	30
2.2.4.2 Compensation	30
2.2.4.3 Selection and Training.....	31
2.3 Conclusion	31

Chapter 3

3.1 Job Design Methods	33
3.1.1 Allocation of Functions	34
3.1.1.1 Significance and Definitions	35
3.2 Work Simplification.....	37
3.3 Behavioural Methods.....	38
3.3.1 Activation Theory	38
3.3.2 Motivation Theories	39
3.3.3 Job Characteristics Methods	40
3.4 Socio-Technical Systems Theory	41

3.5 Allocation of Functions Methods	46
3.5.1 Task Analysis and Simulation Methods.....	48
3.5.1.1 Mathematical Methods.....	49
3.5.1.2 Task Analysis Methods	49
3.5.1.3 Simulation Methods	50
3.5.2 Comparative Frameworks.....	51
3.5.2.1 Human-Robotic Systems	53
3.5.3 Complementary and Dynamic Allocation Methods	54
3.6 Discussion and Summary	57
3.6.1 Summary of Current Status	57
3.6.2 Outline of Research Requirements.....	61

Chapter 4

4.1 Model Structure.....	63
4.2 Overview of Research Methodology.....	66
4.3 The Company	67
4.4 Pilot Study	68
4.4.1 Cell Selection.....	70
4.4.2 Summary of Pilot Study.....	72
4.5 Development of Model	73
4.5.1 Overview of the Main Research Period	73
4.5.2 Model Features.....	74
4.5.2.1 Man-Machine Level Features	75
4.5.2.2 Job Design Level Features.....	78
4.5.2.3 Socio-Technical Level Features	81
4.6 Cell Job Design Model.....	83
4.7 Model Validation Methodology	86
4.8 Summary.....	87

Chapter 5

5.1 Validation of Model Using Cell A.....	89
5.1.1 Man-Machine Level of Analysis, Cell A.....	89
5.1.1.1 Features at the Man-Machine Level, Cell A	92
5.1.2 Job Design Level of Analysis, Cell A.....	93
5.1.2.1 Features at the Job Designs, Cell A	96
5.1.3 Feature Relationships Between the Man-Machine and Job Design Levels	97
5.1.4 Socio-Technical Level of Analysis, Cell A.....	99
5.1.5 Features Relationships Between the Job Design and Socio-Technical Level, Cell A	101
5.2 Model Comparisons, Cells B, C and D	103
5.2.1 Quantitative Summary of Features.....	103
5.2.2 Discussion of Quantitative Data, Cell B.....	105
5.2.3 Discussion of Quantitative Data, Cells C and D.....	107
5.3 Summary.....	108

Chapter 6

6.1 Model Use - Sample Scenarios.....	113
6.1.1 Sample Scenario One, Cell A	114
6.1.1.1 Discussion - Scenario One.....	116
6.1.2 Sample Scenario Two, Cell B.....	116
6.1.2.1 Discussion - Scenario Two	118
6.1.3 Sample Scenario Three, Cell C.....	118
6.1.3.1 Discussion - Scenario Three.....	119
6.2 Application of the Model in Job Redesign.....	120

6.3 Conclusion	122
6.4 Contribution To Knowledge.....	123
6.5 Recommendations for Future Research.....	123

References

References.....	125
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Appendix A

A1.1 Research Methodology and Strategy Development.....	148
A1.1.1 Positivism.....	148
A1.1.2 Phenomenology	149
A1.1.3 Research Strategy Design	149
A1.1.4 Case Study Methodology	151
A1.2 Research Methods.....	152
A1.2.1 Semi-Structured Interview Method	152
A1.2.2 Self-Completion Questionnaires	152
A1.2.3 Observational Methods	153
A1.2.4 Critical Incident Technique	154
A1.2.5 Hierarchical Task Analysis	154

Appendix B

B1.1 Establishing Trustworthiness from the Research	156
B1.2 Adopted Interview Protocols	157
B1.2.1 Analysis of Findings	158
B1.3 Adopted Protocol for Observations	159
B1.3.1 Analysis of Findings	159
B1.4 Adopted Questionnaire Protocol.....	159
B1.4.1 Analysis of Findings	160

Appendix C

C1.1 Pilot Study Methodology	162
C1.1.1 Orientation and Familiarisation	162
C1.1.2 Initial Data Collection	163
C1.1.3 Follow-Up Interviews.....	164
C1.2 Analysis of Findings	165
C1.3 Introductory Interview Schedule.....	166
C1.3.1 Pilot Study Findings: Demographic Findings	168
C1.4 Follow-Up Pilot Study Interview	168
C1.4.1 Interview Schedule	168
C1.4.2 Pilot Study Findings: Follow-Up Interviews	170

Appendix D

D1.1 Overview of Main Research Methodology	176
D1.1.1 Sampling Strategy	176
D1.1.2 Field Research.....	177
D1.1.2.1 Research Methods Overview.....	177
D1.1.3 Analysis of Data	181
D1.2 Semi-Structured Interviews	181
D1.2.1 Interview Schedule for the Man-Machine Level	182

D1.2.2 Interview Schedule for the Job Design Level..... 183

D1.2.3 Interview Schedule for the Socio-Technical Level..... 185

D1.2.4 Responses From Semi-Structured Interviews..... 186

D1.2.4.1 Man-Machine Level of Analysis 186

D1.2.4.2 Job Design Level of Analysis..... 192

D1.2.4.3 Socio-Technical Level of Analysis 196

D1.2.4.4 Critical Incident Technique Interview Results 198

D1.3 Description of Qualitative Findings For the Four Cells..... 198

 D1.3.1 The Number and Types of Machines..... 199

 D1.3.1.1 Adaptive Allocation of Functions 200

 D1.3.1.2 Decision Authority and Competence..... 202

 D1.3.1.3 Technical Coupling..... 204

 D1.3.1.4 Transparency..... 207

 D1.3.1.5 Nature of Operator Loading..... 209

 D1.3.1.6 Process Feedback..... 210

 D1.3.2 The Skill Levels of the Cell Members 213

 D1.3.2.1 Skills Use and Retention..... 213

 D1.3.2.2 Task Flexibility 215

 D1.3.2.3 Experienced Responsibilities 217

 D1.3.3 The Number of People in the Cells and Cell Loads 218

 D1.3.3.1 Boundary Regulation..... 219

 D1.3.3.2 Task Inter-Dependence and Sources of Variety..... 221

 D1.3.3.3 Independence of System 223

 D1.3.3.4 Interaction Requirements..... 226

Appendix E

E1.1 Questionnaire Transcripts 229

 E1.1.1 Questionnaire One 229

E1.2 Questionnaire Two..... 239

 E1.2.1 Features Under Analysis 239

 E1.2.2 Questionnaire Schedule..... 241

E1.3 Questionnaire Three..... 248

E1.4 Scoring Mechanisms for Questionnaires..... 252

 E1.4.1 Questionnaire One 252

 E1.4.2 Questionnaire Two..... 253

 E1.4.3 Questionnaire Three..... 255

 E1.4.3.1 Man-Machine Level of Analysis 255

 E1.4.3.2 Job Design Level of Analysis 255

E1.5 Questionnaire Results 256

Appendix F

F1.1 Allocation of Functions Literature Review..... 259

Appendix G

G1.1 Tabulated Summaries 271

G1.2 Functional Diagrams for Cell A..... 272

Figures

Figure 2-1 The Dual Design Approach to Human-Machine Systems.....	27
Figure 3-1 The Job Characteristics Model (JCM).....	41
Figure 4-1 General Systems Diagram	64
Figure 4-2 Combining the Research Methodology and Open Systems Theory	65
Figure 4-3 The Four Case Studies, Cells A, B, C and D.....	72
Figure 4-4 Overview of the Model	84
Figure 5-1 Delta Plot Showing Research Findings for Man-Machine Level Features - Cell A	93
Figure 5-2 Delta Plot Showing Research Findings for Job Design Level Features - Cell A	97
Figure 5-3 Graph Comparing the Features at the Man-Machine Level for Cells B, C and D	103
Figure 5-4 Graph Comparing the Features at the Job Design Level for Cells B, C and D	104
Figure F-1 General Function Allocation Method - Chapanis, 1965a	264
Figure F-2 Aerospace Function Allocation Method - Price, 1968	265
Figure F-3 Human-Robotic System Function Allocation Method - Ghosh and Helander, 1983	266
Figure F-4 Human-Computer System Function Allocation Method - Greenstein and Lam, 1985...	267
Figure F-5 Aerospace Function Allocation Method - Price, 1985	268
Figure F-6 Human-Computer System Function Allocation Method - Hou, Lin and Drury, 1993....	269
Figure F-7 Manufacturing Function Allocation Method - Clegg, 1994.....	270

Tables

Table 3-1	Matrix Outlining Function Allocation Domains	47
Table 3-2	The Original Fitts List	52
Table 4-1	Key Features of Cells A to D.....	71
Table 4-2	Describing The Impact Of Function Allocation Dimensions At The Job Design Level of Analysis	85
Table 4-3	Describing The Impact Of Job Design Dimensions At The Socio-Technical Level of Analysis	87
Table 5-1	Dominant Man-Machine Dimensions	91
Table 5-2	Dominant Job Design Level Dimensions.....	96
Table 5-3	Matrix Summarising the Impact of Function Allocation Features Upon Work Organisation Issues in Cell A	98
Table 5-4	Matrix Summarising the Impact Job Design Features Upon The Ability of Cell A to Self-Regulate.....	102
Table 5-5	Table Summarising the Features at the Man-machine and Job Design Levels of Analysis	109
Table 5-6	Matrix Summarising the Impact of Function Allocation Features Upon Work Organisation Issues in Cell B	110
Table 5-7	Matrix Summarising the Impact Job Design Features Upon The Ability of Cell B to Self-Regulate.....	110
Table 5-8	Matrix Summarising the Impact of Function Allocation Features Upon Work Organisation Issues in Cell C	111
Table 5-9	Matrix Summarising the Impact Job Design Features Upon The Ability of Cell C to Self-Regulate.....	111
Table 5-10	Matrix Summarising the Impact Job Design Features Upon The Ability of Cell D to Self-Regulate.....	112
Table 5-11	Matrix Summarising the Impact of Function Allocation Features Upon Work Organisation Issues in Cell D	112
Table A-1	Comparison of Positivism and Phenomenology	150
Table F-1	Summary Function Allocation Literature Review.....	260

CHAPTER ONE

INTRODUCTION

Manufacturing systems are complex, dynamic environments, influenced by and comprised of many technological, social, commercial, political and legal factors. The design of jobs in such environments must embrace all these issues to ensure their viability. This perspective takes into account the long term development of the technology itself, the people interacting with the technology and each other, as well as the organisation within which the technologies and people are organised to fulfil business objectives.

The objective of the research is to develop a model of the different factors that influence the design of jobs in cellular manufacturing systems.

1.1 Manufacturing Cell Design

Competitive advantage in current world markets compel companies to compete in terms of flexibility and quality factors. Characteristics of these markets include reductions in production volumes, increases in product variety, shorter product life cycles and reduced repeat orders. Cellular manufacturing has been recognised as an essential structural component of World Class Manufacturing for small batch size requirements.

A UK Survey states that over 75% of British engineering industry have introduced or are planning to introduce cellular manufacturing methods in an attempt to improve competitiveness through better quality, greater responsiveness, increased flexibility and set-up time reduction (Ingersoll Engineers, 1990). Although these business drivers provide the initial justification for implementing cellular methods, the people and planning factors are vital for ensuring long and short-term success but are usually, however, the least understood (BAe/Cranfield Seminar Programme, 1993; CLASP Workshop, 1993).

The widespread adoption of cellular manufacturing concepts has necessitated the requirement for research into what could be referred to as skill-based or human-centred production (Brödner, 1988; Corbett, 1988b). Human-centred forms of work organisation are considered essential for improving Europe's future competitiveness and manufacturing base (EC MONITOR FAST Programme, 1989-1992). Human-centred concepts do not advocate an anti-technology approach to manufacturing but one which views the characteristics of people and machines complementary.

The primary focus of contemporary research effort in the area of manufacturing cell design has, however, been biased towards the development of methods for grouping parts and machines. Over seventy new methods have been documented, and the International Journal of Production Research alone has reported fifty-one new methods since 1987. Unfortunately, only a minority of techniques such as Production Flow Analysis have been adopted, and have demonstrated their usefulness in industry.

The number of social, technological and commercial factors on the performance of cellular manufacturing systems are many. Very few of the current cell design processes, however, reflect the true complexity and uncertainties inherent in small batch, cellular manufacturing systems. The importance of people in system operation, maintenance, development, improvement and innovation is widely recognised (Bainbridge, 1983; Corbett, 1985, 1986, 1988; Adler, 1986; Cooley, 1987, 1989; Sinclair, 1988; Clegg, 1984, 1988; Majchrzak, 1988a,b; Kidd, Fan, 1994, 1995a,b). The knowledge and experience of people, as well as their creativity and flexibility are rarely accommodated.

1.2 Job Design and Function Allocation

The design and development of work on the shopfloor in manufacturing organisations, from an historical viewpoint, may be traced back to the work of Babbage (1832), Smith (1904) and Taylor (1911). In this context, the trend over the past hundred and fifty years has been to continuously increase labour productivity by improving the ‘control over nature and over co-operating human beings’ (Rauner, 1988) through technological simplification and standardisation.

Developments in automation has tended to polarise skills requirements at the shopfloor level and has shifted decision competence from man to machine. The enthusiasm for this approach is justified through the belief that in any system people are uncontrollable resources and so their influence and input in the system should be minimised. In this context people are viewed as being unable to sustain required levels of quality, repeatability, reliability, responsiveness, cleanliness and uniformity. Advocates of full automation promote the use of people only where the automation of a function cannot be justified on economic and technical grounds.

In ‘traditional’ systems design, the abilities of people and machines are compared to minimise the roles of people as potential sources of variance and disruption. The human-centred paradigm represents an alternative view to this ‘traditional’ approach. It rejects notions of comparing the abilities of people and machines and focuses instead on how they may complement each other. The experience, knowledge and skills of people are used to complement the functionality, precision and power of machines. This is achieved through the (re)design of technology and the (re)organisation of people and technology to fulfil system objectives - of which each is separately incapable.

The ‘apportionment’ (Price, 1985) or allocation of functions to people and machines is one of the most basic decisions in the design of manufacturing cells. Decisions made at this stage affect which functions are automated, which are undertaken by people and the degree of system flexibility and adaptivity. Often these decisions are made implicitly by system designers or by adopting a specific allocation method. Price (1985) notes that the allocation of functions between people and machines ‘establishes the framework within which job or task analysis, and the requirements for personnel selection, training, procedures development, and design of the human-machine interface [are established]’. This process is viewed as an important stage in

the development of a system (Brennan, 1984; Mital et al, 1994) and can impact significantly upon its long term performance (Bamford, 1959; Chapanis, 1965a,b).

Function allocation methods and theories have been applied in many contexts including: aircraft cockpit design, human-computer interface design, aircraft flight control, nuclear power station control, inspection and surveillance systems, space flight, human-robotic systems and computer integrated manufacturing systems. Although the application domains vary widely, the allocation processes and decision criteria are similar and have changed little over the past forty years.

Contemporary function allocation methods adopt a human-centred approach to job design where functions are allocated to promote work that is intrinsically motivating (Jordan, 1963; Chapanis, 1970; Price et al, 1982; Weik, 1993; Wei and Wieringa, 1994; Weik et al, 1994, 1995; Drury, 1994; Grote, 1994, in press; Mital et al, 1994). This approach embraces not only the individual but also the work-group and whole systems.

Work in this field has tended to focus on fine-tuning existing allocation processes and have changed little from those proposed by Chapanis (1965a) to the approaches of Ghosh and Helander (1986) and Clegg et al (1989). Successive allocation methods recommend increasing numbers of decision criteria in an attempt to fully describe and take into account the many technological and social features of manufacturing systems.

The function allocation process, therefore, has moved beyond merely allocating basic functions between people and machines towards a process of detailing people's roles, responsibilities, tasks and work methods. These methods have blurred the scope and purpose of the function allocation process making this stage less identifiable within the process of job (re)design. Jobs are designed without a clear understanding and analysis of the inter-relationships between function allocation, work organisation and social-technical system issues.

The development and application of complementary function allocation work to embrace the design of jobs in social-technical systems has received little attention. Work in this thesis attempts to provide a model to identify the factors and their inter-relationships relevant for human-centred job (re)design in cells.

1.3 Research Objectives

This objective of the research is to develop a model which can be used as a template to facilitate human-centred job redesign in cell systems. The model builds-up a picture of factors in the manufacturing environment affecting job design in cell systems from high-level work organisation and socio-technical perspectives to a lower-level function allocation perspective.

The model is a tool for capturing the original job design objectives as a references for further cell improvement. It may be re-used to build-up a series of comparable snap-shots to formally record changes in job design and to facilitate learning about the process and benefits of change.

1.4 Research Methodology

The above objectives correspond broadly to the following research activities:

1. Comprehensively review existing literature to map the development of allocation of functions and related theories and methods.
2. Undertake a pilot study to identify a range of suitable manufacturing cells and to develop a model to structure the data collection process. (state academic validation - derivation of model from literature)
3. Develop a robust and flexible research strategy to collect data from manufacturing systems to populate the model.
4. Validate 'industrial' model results - i.e. confirm whether picture is representative.
5. Critically analyse the data gathered to confirm or otherwise the above objectives.
6. State the contributions to knowledge and suggest recommendations for future work.

1.4.1 Literature Review

Manufacturing systems are complex environments composed of a broad range of inter-related technological, organisational, social, political and commercial factors. The content of the literature review reflects this multifaceted characteristic. The following subject areas were reviewed to provide a framework for identifying the advantages and disadvantages as well as trends in manufacturing system design:

- *Cellular Manufacturing Systems*. Examine current practice, implementation and design methods, case studies and underlying theories.
- *Human-Centred, Socio-Technical and Other Job Design Theories*. Examine underlying concepts, philosophies, design methods, tools and industrial significance of the system design paradigms.
- *Allocation of Functions*. Identify application domains, allocation methods, deficiencies and theories.
- *Research Methods*. Examine social science research strategy design methods, research philosophies, strengths and weaknesses as well as research hazards.

1.5 Thesis Structure

The thesis is structured in six chapters:

- 1 Introduction
- 2 People in Cellular Manufacturing Systems
- 3 Job Design and Allocation of Functions
- 4 Model Development
- 5 Model Validation
- 6 Discussion and Conclusion

Chapter two discusses the industrial significance, operation and design of cellular manufacturing systems. They are described with particular emphasis on the importance of adopting human-centred design and implementation strategies. An overview is given of the role of people in the design and operation of cellular manufacturing systems. Chapter three discusses 'traditional' and contemporary job design theories. The objectives and benefits of the research are described in light of the deficiencies outlined in existing job design practice and theory. At this point research requirements are stated.

Chapter four describes the development of the job design model and the field research methodology. Firstly, a systems approach to model and research methodology design is outlined. The company taking part in the research is discussed along with a discussion of four manufacturing cell case studies. Finally, the pilot study and main research period are described in detail and the process of model validation and possible model job redesign applications are discussed. Chapter five provides a further validation of the model by presenting the qualitative and quantitative data in the form of models for the four case studies. At this stage, the value and generalisability of the model in job redesign is discussed.

Finally, in Chapter six three model applications are presented to illustrate the value of the model as a practical tool for cell redesign and improvement. The achievement of this research is discussed in terms of job design research. The contribution to knowledge is stated and recommendations for future research outlined.

CHAPTER TWO

PEOPLE IN CELLULAR MANUFACTURING SYSTEMS

This chapter discusses the industrial significance, operation and design of cellular manufacturing systems. Cellular manufacturing system design methods, with particular emphasis on group technology and human-centred manufacturing approaches, are described emphasising the importance of adopting holistic design and implementation strategies. Finally, an overview of the role of people in the design and long term operation of cellular manufacturing systems is outlined.

It is widely recognised that utilising mass production methods for achieving cost advantages is no longer the central criterion of economic manufacturing activity. Competitive advantage in contemporary, dynamic world markets compel manufacturing enterprises to compete in terms of flexibility and quality factors embracing reductions in production volumes, increases in product variety, shorter product life cycles and reduced repeat orders.

Cellular manufacturing has been recognised as an essential structural component of World Class Manufacturing for small batch size requirements. A UK Survey, based on a random sample of three hundred UK companies with a turnover of over £10 million, states that over 75% of British engineering industry have introduced or are planning to introduce cellular manufacturing methods (Ingersoll Engineers, 1990). Cellular manufacturing methods are adopted in an attempt to improve competitiveness through, for example, better quality, greater responsiveness, increased flexibility and set-up time reduction.

Cellular manufacturing forms of work organisation are central to human-centred manufacturing system design concepts. Models of human-centred systems can be regarded as strategic solutions to these emerging and future economic challenges because of their inherent production flexibility. Although business objectives commonly provide the justification for adopting cellular manufacturing, the people and planning factors are vital for ensuring long and short-term success. The people related aspects of any planned transition to a cellular approach are, however, usually the least understood, and are by far the most contentious (BAe/Cranfield Seminar Programme, 1993; CLASP Workshop, 1993).

2.1 Cellular Manufacturing Systems

The concepts of cellular manufacturing and group technology originated in Russia. The definitive text on the subject is attributed to Mitrofanov (1959, translated 1966) who first discusses the concept of the 'group machining method'.

Ivanov (1961, translated 1968) attributes the original concept to Mitrofanov and reports that group technology methods have been used widely in Russia as far back as the early 1940s.

In the West, Professor John L. Burbidge helped group technology methods gain widespread acceptance through his many practical and theoretical efforts encompassing not least his work on Production Flow Analysis (1975, 1989) and Production Control Methods (1962). The first international seminar on group technology was held at the Turin International Centre in September 1969 where group technology was heralded as an exemplary response for small batch, high variety manufacturing requirements (Burbidge, 1963).

Individually, Burbidge, Mitrofanov and Ivanov saw the dedication of machines for production as the solution to low productivity in job shop environments. The development of cellular manufacturing methods lie with the application of group technology methods as a way of grouping parts and machines. In many contemporary texts, the terms cellular manufacturing and group technology are often used synonymously. A distinction should, however, be made to reflect the development processes and emergent properties associated with these important manufacturing paradigms.

Wemmerlöv (1989) defines a cellular manufacturing system or 'cell' as a 'group of dissimilar machines or processes located in close proximity and dedicated to the manufacture of a family of parts that are similar in their processing requirements'. The Society of Manufacturing Engineers Handbook (1990) states that 'cells can encompass part of a production process, with intermediate products passing from cell to cell, or they can comprise the whole production process for a particular product or set of products'. Edwards (1971) prefers the term 'cell system' which not only encompasses the dedication and co-location of machines but also the grouping of people and skills to form the basic unit or 'island' of production. To gain the maximum benefit from the application of group technology methods with 'virtually all the social benefits', it is essential to rearrange the conventional batch manufacturing operations into cellular groups (Fazakerley, 1976). The above definitions have at their core the concept of a product group which are frequently generated through group technology methods.

Cellular manufacturing systems support the implementation of just-in-time (JIT) and total quality manufacturing methods through their inherent process, labour and routing flexibilities. For JIT applications, the emergent properties of cellular manufacturing systems help to clearly define group responsibilities for controlling material handling activities and promotes line simplification. The design of cellular manufacturing systems for JIT requires the consideration of not only operational issues but must also take into account the resources of subcontractors within the whole system (Schonberger, 1990a).

Cells are frequently defined from two broad perspectives focusing on the *processes* carried out in the cells as well as on the characteristics of the manufactured *products*. In the former case, a change in product type has no bearing on the identity of the cell. In the latter, a change in product would, even if the same machines and processes are used, alter fundamentally the

working practices and overall nature of the cell. The SME Handbook 'Making Manufacturing Cells Work' (cited in Noaker, 1993) provides definitions for three types of cell:

- *Process Cells*. 'These make components for one product or a family of products requiring common processes...Often the core process is one that, for reasons of equipment investment or environmental considerations, should not be installed in multiple product cells...An example is a sheet-metal processing cell with a shear, NC punch and welding area'. Process or functional cells are used to maximise the utilisation of expensive dedicated machines. Process cells tend to reflect more traditional forms of work organisation stemming from the initial development of group technology concepts.
- *Product Cells*. 'These produce finished product groups ready for shipping using a set amount of labour and a compact area'. They are not similar to cells in a product focused factory where groups of cells are interrelated and have a wider business objective.
- *Group Technology Cells*. 'This occupies the middle ground between dedicated equipment and a job shop environment. It produces parts of similar shape that are not necessarily confined to one product or family of products'. The cell is at its most efficient when manufacturing a number of product groups rather than only a single group.

Product and group technology cells began to develop once the concepts of cellular manufacturing were recognised as being conducive to forms of production organisation at all organisational levels - not merely as a method of production at the shopfloor. These cells may be associated with an 'enterprising' approach to manufacturing management as well as the establishment of a 'factory within a factory' or 'customer chain' working environment (Schonberger, 1990b). In the UK, although product cells are implemented predominantly, a significant number of process based cells may still be found.

Extensive use is made of Nagara cells to facilitate product focused, highly synchronised production within the Toyota production system (Shingo, 1989). The philosophy of the approach embraces low cost and high quality production. It aims to make full use of people's skills to achieve quality improvement and cost reductions conducted on a continuous and long term basis. Synchronisation, not speed is important. If only one part is needed per minute, there is no need to invest in expensive equipment to finish the work more quickly. Consequently, the longest cycle time determines output and the pulse rate of the cell. Cell machinery is not technologically complex and involves the use of dedicated fixtures and machines, manual loading with fool-proofing features (pokayoke) and local gauging and inspection equipment. These systems are characteristic of the cells studied in this report and are applicable to medium to high volumes and low to medium variety production.

The general benefits of the approach involve low capital expenditure due to simple, low technology machines; improved quality, ownership and constant inspection between operations; tool life improvements by reducing machine speeds and feeds; high levels of visual control and management (transparency) and is an ideal environment for continuous

improvement (Bessant, 1995). The product and group technology cells outlined above also share these benefits. In reality, however, the experienced benefits of adopting any of these approaches vary according to the suitability of the approach, the implementation and management strategy as well as the state and interaction of the technical, organisational, and commercial environments.

2.1.1 Cellular Manufacturing Surveys

Three surveys identifying and describing cellular manufacturing practices in the UK, the USA and West Germany are outlined in the following sections.

2.1.1.1 UK Survey

The UK Survey was based on a random sample of three hundred UK companies with a turnover of over £10 million (Ingersoll Engineers, 1990). Since 1985, there has been an 'upsurge' in the adoption of cellular manufacturing methods. The survey states that over 75% of British engineering industry have introduced or are planning to introduce cellular manufacturing methods. The main objectives for cell implementations were to improve market response and product quality and to reduce costs. 70% of companies perceived their overall investment levels in cellular manufacturing as 'small' or 'none'.

The main benefits were reductions in lead-time, work in progress and delivery performance, workflow distance travelled and material handling. 62% of companies experienced a 10% improvement in competitiveness, whilst 42% experienced a 10% improvement in financial performance. However, the definition of 'competitiveness', is ambiguous and is left to the respondent to define.

It was discovered that although the majority of the cells were product based, 35% of companies were using both process and product cells. This is in contrast to the overwhelming bias in the literature towards product focused cells and internal 'customer chains'. The top 10% of companies exhibit three crucial characteristics:

- On average, 43% of these companies said they substantially invested in people.
- 90% of the companies viewed team training and flexibility as well as good communication as key success factors.
- The adoption of new performance measures were near completion.

The emergent properties of cellular manufacturing methods are many and tend to revolve around a trend towards 'mini-business' organisations focusing on the manufacturing process itself as well as on organisational and social aspects. These activities are summarised in the survey through the recommendation of a number of generic factors characteristic of successful cells (Ingersoll Report, 1990):

- Clearly defined boundaries of responsibility and accountability.
- Ease of visibility to the cell leader of all the cell contents and facilities.
- Simple, concise and appropriate performance monitoring which each cell member understands, and which is linked with overall business objectives.
- A realistic production programme leading to a believable work-to list and reliable material and component supply to the cell.
- The inclusion of appropriate support functions to enable the cell to control its own performance sensibly, with adequate liaison with other shared functions.
- Well-trained people with an understanding of what can be achieved by continuous improvement and the willingness and incentive to make efforts to achieve more.
- Creation of an environment in which internal mini-businesses can form and flourish.

Throughout the report, the consideration of and investment in people and organisational factors are emphasised as the key element of successful cell implementations.

2.1.1.2 USA Survey

A USA survey collected data on group technology practices from 32 companies (Wemmerlöv and Hyer, 1989). The majority of the companies were from the metal working industries. The range of product lines varied widely in the sample as did the complexity of the products which varied from only four to about 5000 components. Although it is difficult to compare the Wemmerlöv and Hyer and Ingersoll surveys because of sampling, survey and cultural differences, the former survey does bear out many of the findings of the latter:

- The uptake of cellular manufacturing methods is mainly a post mid-1980s phenomenon and is still growing with 70% of companies surveyed planning to introduce cells in the future.
- The majority of cells in the survey are manned and requires minimal overall investment.
- The main benefits are reductions in throughput time (45.6%), work in progress (41.4%) and materials handling (39.3%) as well as notable increases in job satisfaction (34.4%). These figures are for average benefits. Although they are high, individual benefits varied substantially.

Only one third of the companies provided formal education in group technology, cellular manufacturing and just-in-time concepts. This is in contrast with the findings and recommendations of the Ingersoll study. Another difference was the degree of cellularisation in the companies. The proportion of company machining hours in cells ranged from 0.3% to 88%, in 74% of cases, only 25% or less of machine hours were worked in cells. This may imply that managers perceive that cellular manufacturing methods may only be applied satisfactorily to certain activities.

The smallest cell consisted of only two machines. The average size of the manned cells was comprised of six machines. Two thirds of the companies said they had cells composed of six

or fewer machines whilst approximately half indicated cells in the range four to six machines. These are typical of the size of cell studied in this thesis. The majority of the companies (81%) said they had six or fewer cells.

87% of the companies claimed their cell members could perform a variety of tasks and move between different workstations within the cells. 39% companies said their cell members could be moved between different cells.

In process terms, companies had difficulty in forming independent, self-contained cells which may reflect the complex process requirements characteristic of the manufactured products. Cell independence, in terms of the autonomy of cell members, is constrained by the supervisors commonly carrying out many cell controlling activities. Recommended cellular manufacturing strategies encompass:

- Select good people.
- Start with projects with a high probability of success.
- Go slowly.
- Don't underestimate the time requirement.
- Keep people informed.

Despite survey findings, the survey recommends that it is essential that everybody is involved early in the implementation process and trained extensively. It notes that 'the most valuable lessons learned by the companies...were people and not technology oriented' and that 'the firms worked hard to achieve these results and that the change process rested on knowledgeable individuals working together as teams'.

2.1.1.3 West German Survey

A study focusing on large, computerised cells was carried out in the Federal Republic of Germany (Fix-Sterz et al., 1986). The study looked at trends in the use of flexible manufacturing systems (FMS) and flexible manufacturing centres (FMC).

FMSs are comprised of several interconnected machining centres. A central control and transfer system supervises the automated manufacture of parts - satisfying medium batch size and variety requirements. A FMC is a single machine system allowing parts to be manufactured, largely automatically, in smaller batch sizes.

The survey illustrates a trend away from large FMSs towards smaller systems of up to five machines and FMCs. In 1985, 70% FMS/C systems comprised of a single machine. This may be partly attributed to the greater involvement of SMEs with FMSs.

Only in 11% of the cases are FMCs implemented to make highly productive and inflexible systems more flexible. The trend shows a replacement of standalone CNC machines with FMCs. In general, the use of FMCs make systems more inflexible and the larger the system the

greater the division of labour and hence inflexibility. The labour in over 56% of FMCs is highly divisionalised, whilst 70% of FMS use highly divisionalised, inflexible labour systems.

The report concludes that the choice in the type of work organisation is influenced less by the technology itself but rather the forms of work organisation that existed before the FMS Cs were implemented.

2.1.1.4 Summary

From these surveys, cellular manufacturing methods are implemented for two basic reasons:

- 1) As a strategic response to competitive pressures (Ingersoll Engineers, 1990).
- 2) As a way of making low productivity, highly flexible systems more productive (Fix-Sterz et al., 1986; Wemmerlöv and Hyer, 1989).

The US survey points to the separation of standard and non-standard parts for cellularisation and the difficulty in establishing independent systems for the latter. The removal of difficult parts from the cells may indicate one of the important reasons why cells seem successful. Success in the form of reductions in throughput time (maximum 90%), reductions in WIP (maximum 80%) and reductions in materials handling (maximum 83.3%) may, therefore, be overstated: the effects of change on the difficult parts are not stated. Flexibility seems to have a range of definitions which is not helpful in trying to understand the effect of change in the workplace. Specific examples of 'flexible' working are not given.

Broad brush applications of cell practices should be avoided and instead cellular manufacturing methods, whether product or process focused, need to be applied in context and where suitable.

From the survey, training was not given priority in two thirds of the cell implementations which does not concur with the Ingersoll UK survey where 90% of the companies viewed team training as a key success factor. Many of the business objectives and experienced benefits, however, are similar to those described in the Ingersoll survey.

The German survey rejects technological determinism in work design and highlights the importance of the social context and history of a company in job and cell design. Many of the cases had not met the basic requirements for implementing FMS systems as outlined in a UN survey of the implementation and use of FMSs in twenty countries (Kochan, 1986). The basic requirements were that firstly, all stakeholder functions should take part in system design and development and secondly, all personnel should receive intensive training prior to installation. These findings align with Jaikumar's (1986) observations that compared to Japan, US FMSs exhibit high levels of inflexibility and utilisation because of the low levels of stakeholder participation in the system development process.

The UK survey highlights the growth in the adoption of cellular manufacturing methods since the mid-1980s and emphasises the minimal overall investment of many cell implementations. Business objectives commonly justify the adoption of cellular manufacturing methods and are fulfilled through the early and sustained consideration of social and organisational factors. The survey embraces typical cells of between 20 to 30 people, whilst the US survey looked at much smaller cells of on average four to six machines. The latter is typical of the cells studied in this research.

The Ingersoll survey is widely referenced but suffers from a number of limitations. Firstly, the adopted mail survey approach cannot show how changes in an organisation occur; they can only provide a 'snapshot' of an organisation from the viewpoint of a single respondent. Also since the data are generated from one source, responses tend to be biased from the viewpoint of a single function. Secondly, the questions themselves were very nebulous and open to broad interpretation. A study that systematically collects data from both managers and employees is more likely to provide valuable information on work structures and processes from a range of perspectives. This would yield a more low-level and detailed analysis of cellular manufacturing practices.

It is not necessarily the case that cells implementations need be related to the idea of an 'enterprise' where they are conceived in terms of customer-supplier relations. Product cells do appear to be on the increase but process based cells persist and have broadened out to embrace assembly functions. Elements of strategic choice are being exercised which highlight that under some circumstances, process rather than product focused cells yield a better outcome.

Both product and process focused cells are in widespread use in machine and assembly shops and in addition, cellular manufacturing methods will foster the spread of highly-technical computer-controlled cells. Product-based cells are seen to be related to the market and lead by it; process-based cells are seen to be created for production reasons of efficiency and/or for internal company cost reasons. It is unclear, therefore, whether cellular manufacturing will increasingly become a means for creating simulated markets within companies (product based cells) or maintain its more traditional aim of improving production efficiency in process-based cells. In whatever form, however, the cell is recognised as an effective method of production and management organisation and control.

2.2 Cell System Design Methods

The following sections discuss cell design methods. Group technology methods are firstly described in detail. Two 'real world' cellular manufacturing case studies are presented. They emphasise the importance of combining group technology methods with social and work organisation considerations in the planning and development of cell systems. This approach is embraced by human-centred system design concepts. The role and significance of group

technology and human-centred manufacturing system design methods as well as labour issues associated with the design of cellular manufacturing systems are discussed.

2.2.1 Group Technology

Group technology is a fundamental and necessary tool for cellular manufacturing. It is a generic manufacturing technique that exploits product design and production process similarities for identifying part families and machine groups by employing a variety of classification and coding methods. The decisions made and the group technology methods used strongly influence cell structures and procedures and has received much attention. This may be because of the relatively systematic and structured nature of the problem. These methods do not necessarily require the co-location of dedicated machines and can often form the basis for process-based cells. For example, Edwards (1971) proposes that group technology methods were initially developed by engineers who wanted to maintain a functional (process focused) layout whilst improving machine productivity.

2.2.1.1 Traditional Cell System Design Methods

Based on a range of measurable criteria, group technology methods facilitate the grouping of parts which may have previously been viewed as unique and moreover in isolation. A variety of methods are proposed in the academic and practitioner literature that tend to focus on engineering issues and overlook the roles and abilities of people during part and machine selection. Methods classify parts and machines into groups based on geometric, set-up, process and routing similarities. These methods represent one of the most fundamental stages in the design and formulation of process and product focused cells and may be divided into three broad categories (Burbidge, 1963):

- Tacit judgement, rules of thumb and visual identification.
- Formal classification and coding procedures for grouping parts.
- Production flow analysis.

These methods are discussed in the following sections.

2.2.1.1.1 Tacit Judgement

Parts are grouped into families based on past experience, tacit knowledge and judgement and a review of their geometric characteristics. In this context, part families are commonly formed by identifying 'natural' groups often by similar part name or function (Offodile et al, 1992). The approach, although inexpensive, is prone to error and is only viable for a small number of parts. This method has, however, been used to solve large grouping problems involving anything up to two thousand parts (Burbidge, 1989).

2.2.1.1.2 Product Focus

Part Coding and Classification Analysis (PCA) methods were the primary group technology tools in the 1960s and 1970s. This method for grouping parts was first proposed by Mitrofanov (1966). Most coding methods fall into one of three main groups: monocode, polycode and mixed code. These methods use coding systems for assigning values (either numerical, alphabetical or a combination) to the geometric characteristics of components (shape, size and tolerances) and use schemes for interpreting codes and grouping parts based on these values. PCA methods, in focusing on the design and shape of parts, are consequently ideal for component variety reduction. Wemmerlöv reports that 62% of the U.S. companies surveyed used the PCA method which contrasts with the lack of research literature on the subject (Kusiak, 1987; Alford, 1994). Using codes to form part families is easy in principle but difficult in practice. There is also a lack of efficient software tools to handle large quantities of codes.

Several systems have been developed. The first comprehensive classification system was developed by Opitz (1970) and incorporated supplemental production-based codes for production planning although initially this proved to be inadequate. This method places a great emphasis on the shape and dimensions of parts which often has very little relevance to the process planning requirements. For coding systems to be useful, they must be able to represent part characteristics that allude to their manufacturing requirements. Other systems include SAGT (Abou-Zeid, 1975), DCLASS (Kunzler, 1982) and MICLASS (Houtzeel, 1975).

The machine requirements for a cell can be determined by generating 'composite components' (Wemmerlöv and Hyer, 1986). Composite components are hypothetical (and occasionally real) components that represent all the important characteristics of a part family. Consequently, a set of machines that can manufacture the 'composite' will also be capable of manufacturing an entire part family. This approach was first proposed by Mitrofanov (1966) as a means for establishing the setting requirements of individual machines.

2.2.1.1.3 Process Focus

Process focused methods have received the most attention by practitioners and academics alike. Hyer and Wemmerlöv (1986) cite more than seventy group technology methods and identify three approaches for part and machine group formation which focus on machine routings (the basic relationship between a part and a set of machines):

- *Identification of machine groups based of part routings.* Methods use routing data to identify the degree to which pairs of machines produce the same set of parts. Similarity coefficients are defined based on the ratio of the number of parts processed on any two machines to the number of parts processed on either machine, but not both.

- *Identification of part families based on routings.* Methods are used to create part families and then machine groupings. This method does not require (but can use) predetermined routings.
- *Identification of part families and machine groups simultaneously.* Methods select a separate part and machine populations with the view of forming multiple cells. The populations form the axes of a matrix. For each part, marks are placed in the 'squares' that correspond to the machines that process the part. The rows and columns are reordered to form distinct clusters of marks which represent potential product focused cells. Burbidge provides guidelines for manual clustering (1989).

For a long time after its initial development, process focused methods were treated as a set of empirical ideas based on subjective factors (Burbidge, 1975). Various machine grouping methods and taxonomies were developed to formalise the process but were limited in use (McAuley, 1972; Carrie, 1973; Rajagopalan and Batra, 1975; Purcheck, 1975). King (1980) developed an algorithmic procedure called Rank Order Clustering (ROC). It treats each row as a binary word and successively rearranges the columns and rows into descending order until the matrix is unchanged.

These three approaches rely on the availability and accuracy of machine routing data which tend to affect the quality of the resultant solutions. The main drawback of these approaches are that the quality of the data may be uncertain. In addition, routing data are often prepared in isolation without reference to whether they are being used for cellular manufacturing or not. Even if routing data is accurate and optimal for existing configurations, the data themselves may not be appropriate for use in cellular manufacturing systems.

To facilitate the implementation of cellular manufacturing systems, part families generated using group technology coding methods may be contrasted with those determined by process focused methods. In doing so, the benefits of each approach may be exploited. In addition, the implementation of cellular manufacturing systems do not happen frequently enough to encourage the large-scale development of computerised decision aids (Offodile et al, 1992). The majority of companies (apart from the largest who can cost effectively develop their own software) turn to consultancies and academia to facilitate the cell design process, or may use manual methods in-house.

Group technology methods generate data for quality function deployment (QFD) and design for manufacturing (DFM) methods to improve quality and productivity. In addition, they support the implementation of advanced manufacturing techniques encompassing set-up time reduction, departmental integration and the formation of inter-disciplinary teams, greater process control, greater control over part quality. Huq (1992) reports, however, that none of the design literature specifying algorithms for cell formation consider the capabilities of people in formulating the final algorithms. Literature relating to process focused cell formation methods is reviewed by King and Nakornchai (1982), Mosier and Taube (1985), Wemmerlöv and Hyer (1986), Ballakur and Steudel (1987), Kusiak (1987) and Chu (1989).

2.2.2 Examples of 'Real World' Cell Design

The transition from a process focused to a product focused factory often involves the formation of cells with minimal use of automation and with the people in the cells responsible for machine set-ups, planning, inspection and part quality (Burbidge, 1975). The process of cell design differs significantly if cellular concepts are realised by either rearranging existing equipment on the shopfloor or by acquiring new equipment for the cells.

Cells which are designed to work with completely new equipment are often highly automated with minimal input from people and may be formed into, for example, highly automated robotic work cells or flexible manufacturing systems. In the latter case, the activities of people are often limited to performing loading and unloading part magazines, changing tooling and inspection functions. The design of unmanned cells is *technically* more challenging because of the requirement to select appropriate equipment and also to design an 'integrated computer control system for the unmanned operation and management functions' (Williamson, 1989). In contrast, however, the former, less automated types of cell are *socially* (and often politically) more challenging to manage in the long term because of the consequence of transforming well established working conditions, responsibilities and practices.

The following sections outline two 'real world' examples of cellular manufacturing design. These examples are taken from an extensive survey of the following industry journals including: Manufacturing Engineer, Manufacturing Engineering, Machinery and Machinery and Production Engineering.

The examples illustrate the wide range of issues and options involved in the cell design process and the significance of group technology methods. Both examples utilise the Production Flow Analysis method for grouping parts and machines.

2.2.2.1 Example 1: Watervliet Arsenal

Watervliet Arsenal, New York, USA manufactures artillery equipment (Baran, 1991). In the 1980s the company faced the familiar pressures of overseas competition, the requirement for improved quality, greater precision and demand for shorter delivery times. The company invested \$306 million in modernising facilities, refurbishing machine tools and purchasing equipment. The company adopted cellular manufacturing, product focused factory and group technology concepts which were complemented by simulation tools to evaluate investment strategies.

2.2.2.1.1 Design Strategy

A five-year plan was developed based on products, volumes and variations: key business drivers such as reducing cycle time, improving quality were identified to complement the

business strategy. This strategy included an ‘analysis of the industry, sources of competitive advantage, existing and potential competitors and the firm’s competitive position’.

Firstly, a project team was set up comprising a design engineer familiar with part prints, a manufacturing engineer who can set up process plans and an industrial engineer and foreman familiar with the relevant manufacturing processes.

Part prints were sorted manually into broad families based on geometric features, attributes and processing requirements. Each part print was studied to identify machine loading, material flow and design stability. Six major families were identified. A form of Production Flow Analysis (PFA) was adopted to finally group parts with similar production demands. During this process, machine loading was monitored to determine the requirement for duplicate machines and a PFA matrix was used to cross-reference parts and processes. It was calculated that two cells were required. The machines were arranged into U-shaped cells to ensure good visibility and production feedback.

To cope with short-cycle orders, virtual cells are set up using group technology computer-aided process planning (CAPP) and scheduling to reallocate resources into ‘virtual cells’.

2.2.2.1.2 Lessons Learnt and Benefits

Using in-house equipment may pose some problems. Equipment used to manufacture a range of products may not be suitable for manufacturing part families and it may not be possible to release machines required in other areas of the organisation. Virtual cells can be temporarily established using computer-aided process planning to relocate resources to meet short-cycle orders without disrupting other manufacturing projects.

Since the implementation of cellular manufacturing and group technology methods, the company claims to have doubled capacity, reduced machines on the floor by one-third, reduced manufacturing time by more than 50% and improved productivity by 22%.

2.2.2.2 Example 2: Textron

Group Technology became a major eight-year, \$60 million investment for a gas-turbine engine manufacturer, Engineering Design and Analysis Textron, Lycoming, USA (Propen, 1990).

2.2.2.2.1 Design Strategy

The approach was implemented in three phases, setting up a group technology database: grouping parts into families of common shape, function, manufacturing process and tooling; and the redesign of the shopfloor into work centres. ‘Traditional’ group technology classification and coding methods proved inadequate for handling the large number of parts

manufactured by the organisation. Instead, production planners identified parts that could be bought cost-effectively and then defined production levels for all engine models to find machine requirements for the remaining thousand parts for in-house manufacture.

Production Flow Analysis (PFA) was used to group elements with similar processing requirements. This was supported by a decision support tool called OPSNET which allowed production planners to interactively query discrete data on part geometry and processing. Parts were grouped into sets sharing common attributes and design teams standardised existing product requirements, standards and routings data for the PFA. Processing costs were calculated and compared with purchasing costs to eliminate parts where appropriate.

A number of reviews assessed the recurring and non-recurring costs and savings, support from external resources, staffing levels and operating goals as well as quality assurance and corrective maintenance procedures. Finally, all part families, routings, machines and cells were 'rationalised'. Machines were moved once or twice into their new positions without losing a single day of production.

2.2.2.2.2 Lessons Learnt and Benefits

During the transition, the organisation had to move machines around to achieve optimal cell layout design. The adopted methods closed the gap between design and manufacturing and reduced the processing path of a part family from three miles to only one. The group technology programme helped eliminate 700 of 1400 machine tools, production efficiency improved by 50%, and rework and scrap were reduced by 85%. The process of adopting group technology methods helped rationalise all part families, routings, machines and lines.

It was emphasised, however, that staying 'on top' of group technology was essential otherwise workers will drift back to a job-shop mentality, losing track of the total manufacturing concept. Left uncorrected, this drift can destroy everything group technology accomplished.

2.2.2.3 Discussion

The design of the cellular manufacturing systems were contingent upon the manufacturing practices and objectives of each organisation and impacted upon not only the manufacturing system but also upon a range of support functions. In both cases, the adopted design methods involved the use of inter-disciplinary design teams, the physical formation of the manufacturing systems using group technology methods and the fundamental change in the use of technical, people and organisational resources. Group technology methods were used to cope with the complexity of the part grouping process for machine and process selection.

Many of the cell design decisions given in the examples are not restricted to a rigid logical order. In general, however, the structure-oriented (i.e. issues involving the physical

environment and machine locations) decisions tended to precede procedure-oriented (i.e. issues involving the sequence of tasks, quality assurance methods and control mechanisms) decisions and were often carried out iteratively. Resultant structures and procedures experienced change during cell operation as a consequence of changing commercial and technological circumstances.

Both companies approached the implementation of cellular manufacturing and group technology methods to complement their business strategy. The content and focus of the design strategies, however, differ considerably reflecting the wide scope for choice in the design process as well as the nature of the industrial contexts themselves (cf. Brödner, 1991). In both cases, the technological infrastructure was developed initially using group technology, simulation and CAPP methods. Cell designs were primarily technologically and financially based. The social structures were 'added' after the physical layouts were completed.

In both examples, the benefits obtained through cellular manufacturing and group technology were significant. These benefits were, however, not easy to sustain because of underlying resistance to change in the workforce, operator inflexibility and a tendency to drift back to 'well-proven' working practices. It was highlighted, however, that the emergent social and technical properties of cellular manufacturing systems, through the co-location of machines, processes and skills, had a profound impact on the following:

- The requirement for co-operation and teamworking,
- Craft, analytical and interpersonal skills development,
- Routine decision making,
- The requirement for information processing,
- The ability to fulfil the needs of people in terms of their desire to achieve and self-develop.

Human-centred manufacturing job and system design strategies embrace these technological and social design issues and, where applicable, advocate the widespread use of cellular manufacturing methods. This important manufacturing design strategy is discussed in the following section.

2.2.3 Human-Centred Manufacturing Systems

The development and widespread adoption of cellular manufacturing concepts, the diffusion of information technology and the realisation of the importance for new forms of work organisation, has necessitated the requirement for research into what could be referred to as skill-based production (Brödner, 1988; Corbett, 1988b). This concept is embodied by the socio-technical (Trist and Bamforth, 1948; Pasmore and Sherwood, 1978) and human-centred systems design approaches (Walton, 1975; Rosenbrock, 1977; Utopia Report, 1981; Ehn et al., 1983; Wall and Martin, 1987; Rauner et al., 1988; Cooley, 1989; Kidd, 1990a,b; L.E. & S., 1992).

Models of human-centred systems (HCS) are recognised as forms of work organisation crucial for modernising Europe's manufacturing base as well as for improving its future competitiveness (EC MONITOR FAST Programme, 1989-1992). The European Commission report on 'European Competitiveness in the 21st Century' (Cooley, 1989) recognises the centrality of human-centred research and development for the long term technological and economic competitiveness of European nations¹ (ACOST report, 1990).

Human-centred systems (also known as Anthropocentric Production Systems, APS) are forms of work organisation based on the 'optimal utilisation of skilled human resources, collaborative industrial organisation and adapted technologies' (Wobbe, 1992b). Concepts underlying HCS emerged in Britain during the mid to late 1970s and provide a powerful alternative philosophy for systems design and operation.

Cellular manufacturing methods are central to human-centred organisational structures in general and in particular are essential for realising human-centred computer integrated manufacturing (HCCIM) systems (Blumberg and Gerwin, 1984; Brennan, 1988; Martin, 1990; Kidd, 1990a,b, 1991). At one extreme, human-centred concepts encompass machine oriented, human-computer interaction issues which are closely related to the fields of traditional and cognitive ergonomics. At another, it encompasses social and cultural issues relating to the organisation of work embracing the fields of sociology, psychology, macro-ergonomics and anthropology (Cooley and Crampton, 1987; Cooley, 1984; Ehn, 1988; Majchrzak and Rahimi, 1988; Rosenbrock, 1977, 1989). Consequently, human-centredness within a manufacturing context is a difficult concept to define (Schmid et al, 1992; NATO ASI, 1993).

HCS concepts do not, however, advocate an anti-technology approach but one which transcends the scientific traditions of quantification, determinism and statistical control. Indeed, HCS adopts holistic, open systems perspectives embracing not only the technical infrastructures but also the influence of the social environments and the challenges of market and innovation flexibility. The following sections elaborate on the origins of the human-centred approach, underlying principles of human-centred systems and the nature of human-centred system design methods.

2.2.3.1 The Origins of Human-Centred Concepts

The Hawthorne Studies are probably the most well known landmarks in the quest for bettering the condition and quality of working life. The Studies are discussed here to provide a context for the discussion of human-centred design concepts.

¹ The contribution of HCS concepts towards improved competitiveness were supported by an MIT study which verified that the strength of Japanese competitiveness in the 1990s is not based on implementing high-technology solutions but rather through particular forms of work organisation and the management of the whole production chain (Womack et al., 1990).

From 1924 to 1933, the Western Electric Company conducted at its Hawthorne Works a series of experiments on the factors in the work situation which affect the morale and production efficiency of workers. The first of these, the so-called 'illumination experiments', were studied in co-operation with the National Research council of the National Academy of Sciences. In the remainder of the experiments, the company was aided and guided by Professor Elton Mayo and several associates from Harvard University (Roethlisberger and Dickson, 1939).

Three formal experiments were conducted with various groups of workers. In these experiments the intensity of illumination was increased and decreased and the effect on output was observed. The effect was puzzling. Output slightly increased up and down in some groups or increased considerably in others. In no case was the increase or decrease in proportion to the increase or decrease in illumination.

Further experiments were conducted under more controlled lighting conditions. One control group was kept in constant artificial light. For the test group, the artificial light was decreased gradually over time. It was found that the efficiency of both groups increased slowly and steadily until the test group complained the light was so bad they could not see. Conclusions on the Illumination Experiments were:

- 1) Light was only one factor among many which affect employee output.
- 2) The attempt to measure the effect of the light had failed because:
 - a) The other factors had not been controlled.
 - b) Studies in regular shop functions or large groups involved so many factors that it was hopeless to expect to isolate any one of them.

At this point, the National Research Council withdrew from the studies but Western Electric continued them with the collaboration of the people from Harvard University.

The investigators tried to set up situations in which the employees' attitudes would remain constant and unaffected. It appeared that some of the puzzling results of the Illumination Experiments resulted from the way the workers felt about what they were doing, i.e. they speeded up because they thought increased production was expected, or slowed down because they were suspicious of the investigator's motives.

The experiments blossomed into studies of almost everything which might have a bearing on production efficiency. Data collection methods were extended to include in-depth interviews, physical examinations and sociological group analysis. What was discovered is called the 'Hawthorne Effect' in that other factors cannot be held constant in dealing with people who are part of a production process. The mere observation of people, the showing of management concern, the process of experimentation and the interaction of people with those conducting the experiment were themselves a stimulus to increased production efficiency. It can be reaffirmed, therefore, that 'every human being is a more complex system than any other system to which he belongs' (Whitehead, N., cited in Cass and Zimmer, 1974).

The general lesson derived from these studies was that the work organisation should be viewed as a social system. The 'discovery' of the social system with its elaborate norms, rituals, status structure, membership requirements and so on stood in sharp contrast to the mechanistic approach of Frederick W. Taylor and the scientific management movement.

Blauner (1964), in his discussion of how developments in technology, division of labour, social organisation and economic structures have changed the relation between the worker and his work in four industry sectors, concludes that alienation remains a widespread phenomenon in industry. Alienation is defined in four dimensions: powerlessness, meaninglessness, isolation and self-estrangement. He concludes that to infuse industrial work environments with more 'human dignity' there is a need to 'fuse an empirical, realistic approach with the humanistic tradition...that views all human beings as potentially capable of exercising freedom and control, achieving meaning, integration, social connection and self-realisation'.

The Hawthorne Studies led to a greater appreciation of the relationships between the social system, employee morale and productivity. These concepts are central to the development of human-centred manufacturing movement which began to emerge nearly fifty years later.

In Britain human-centred system concepts arose out of three complementary spheres. In the 1970s, the human-machine symbiosis model, pioneered at UMIST (Rosenbrock, 1989) and the Lucas Plan fostering the concept of socially useful production developed by workers at Lucas Aerospace (Cooley, 1987). The human-machine symbiosis model places human skill and creativity at the centre of technological and organisational innovation. The Lucas Plan proposed that production should be compatible with social needs and should be determined by use rather than just exchange value. The Plan had a significant impact on the British and international debates on alternative, socially compatible production and recognised that end-user knowledge and skill are essential to system effectiveness. During the late 1970s, a third influence emerged in the form of a social action research programme developed by the Social and Educational Applications of Knowledge Engineering (SEAKE) Centre during the late 1970s (Gill, 1989). Projects within this programme facilitated the development of participatory design methods and the human-centred concept of embracing a diversity of cultures, experiences and values during the process of technological design.

The British activities influenced the development of human-centred programmes in other European nations. The UTOPIA (in English, Training, Technology and Product from the Perspective of Skills and Democracy at Work) project was launched in 1981 (Utopia Report, 1981; Ehn et al., 1983) with aims similar to the Lucas Plan, utilising a design-by-doing approach to work design rooted in the Scandinavian democracy at work tradition. In West Germany, unions proposed concepts relating to the issue of shaping work and technology which underpinned the German humanisation of technology and work programme. The shaping concepts were extended by Bremen University during the mid-1980s. This work coupled with work on a human-centred turning cell at UMIST led to the development of the highly regarded and ambitious ESPRIT project 1217(1199) entitled 'Human-Centred Computer Integrated Manufacturing' (Corbett, 1988a,b; Clegg et al., 1989; Kidd, 1990a;

Bohnhoff et al., 1992). All these developments, collectively contribute towards the concept of human-centred or anthropocentric systems.

In the UK, human-centred concepts have, however, largely remained within the academic domain. German industry, however, with its large number of advanced, and often family owned, SMEs as well as the large number of advanced manufacturing technology users (Volkswagen, Daimler-Benz, Siemens and ABB) have embraced the challenges of designing human-centred work environments much earlier than other nations in Europe. For example, the VDI (responsible for setting German engineering standards) have drawn up a ten point checklist for implementing new production systems based on human-centred principles (Schmid et al, 1992).

The development of human-centred tools and concepts is being supported by an increasing number of research institutes, university research centres and funding bodies throughout Europe. These encompass for example, the Department of Trade and Industry through the MOPS (Manufacturing, Organisation, People and Systems) initiative in the UK and the European EUREKA-INTO (Integration of Technology and Organisation for Quality Production) initiative; the EPSRC (Engineering and Physical Sciences Research Council) programme in the UK; the European Community through the ESPRIT (European Strategic Programme for Research and Development in Information Technology) programme; the European Community MONITOR-FAST (Forecasting and Assessment in Science and Technology) programme on Anthropocentric Production Systems; the COMETT and DELTA initiatives; and the CAPRIN (Culture and Production International Research Network) network.

Examples of human-centred technology are ACiT, a proprietary software tool developed for cellular manufacturing systems (Ainger, 1990); The Helical Life Cycle Model to facilitate software project management applications (NATO ASI, 1993; CLASP, 1993; Ainger, 1994); three completed and fourteen ongoing projects within the INTO initiative (some of them are extensions of the MOPS work) on a wide range of subjects encompassing continuous improvement, teamworking, organisational change and supply chain management issues; Brödner (1991) describes two human-centred tools developed by the German Federal Manufacturing Technologies Programme based on firstly, a computer tool to facilitate the control of cellular manufacturing planning and scheduling activities and secondly, a generic numerical controlled programming tool for the shopfloor; finally, as part of the ESPRIT 1217 (1199) project (Wobbe, 1992b), a Danish team designed a 'sketchpad' tool to improve the

communication between shopfloor and design functions². This project is being extended by the CAPRIN network, sponsored by the FAST programme.

2.2.3.2 Principles of Human-Centred Systems

Human-centred organisational models aim at holistic, co-operative work structures with flat hierarchies and well qualified employees who have the opportunity and resources to learn and make 'decentralised' decisions. Human-centred system designs reflects this and includes many concepts such as personality promotion, skill based manufacturing and the complementary design of technology. The following human-centred concepts underlie the philosophy of the human-centred approach. They may be viewed as applicable to the factory, inter-departmental, working group and workplace levels (Wobbe, 1992) and are central for the holistic design and long term operation of cellular manufacturing systems:

- Human-centred concepts reject the technical-oriented or 'technocentric' approach which gives machines and technically mediated communications priority over people and social forms of collaboration. In addition, the paradigm concerns itself with balancing what is technically feasible and what is socially desirable. This relationship is dialectical in the sense that 'the technologically possible necessitates social purpose for it to become technology, and the translation of social purpose into technological artifacts is dependent upon what is technologically possible to construct' (Burns, 1986; Rauner et al., 1988).
- Developing unity and creative potential through diversity. An extension of this idea, is the rejection of the notion of a 'one best way or culture' and the 'sameness' of science and technology. Just as different cultures produce different languages, music and literature, so any society should develop appropriate forms of technology to meet its varying cultural and historical requirements (Jequier and Blanc, 1985; Darrow and Pam, 1985; Cooley, 1987; Clegg, 1988).
- Human-centred concepts foster the 'social shaping' of technology to combat social problems arising from 'inhumane' technology and its application to work. In addition, it advocates the design and development of completely open ended advanced technologies or tools (Ehn, 1988) which have the capacity to be used in a range of diverse application domains and accommodate corresponding social and organisational structures.
- Human-centred design advocates a design approach that transcends cultural, academic and professional boundaries. In addition, during the design process, it accommodates and

² Other human-centred ESPRIT projects include ESPRIT 385 entitled 'Human Factor Laboratories in Information Technologies' (Davis, 1987); ESPRIT 534 entitled 'Development of a Flexible Automated Assembly Cell and Associated Human Factors Study' (Corbett et al., 1987); ESPRIT 1030 entitled 'Human and Economic Factors in IT Uptake Processes' (Kidd, 1990a); and ESPRIT 5603 entitled 'Joint Technical and Organisational Design of CIM Systems for SMEs' (Kidd, 1992a). These projects sought to 'shape' and develop complementary technology in office and shopfloor environments.

fosters the integration of qualitative and quantitative concepts and three types of knowledge: propositional (theoretical), experiential and practical.

- Human-centred concepts regard people as both producers and consumers of knowledge. People have knowledge of a 'whole' production process and are aware of sources of variance and uncertainty. The human-centred approach has a view of knowledge which is holistic: absorbed information becomes knowledge and frequently used knowledge becomes wisdom. From this we encounter tacit knowledge (Cooley, 1987).

The following features summarise in broad terms the characteristics of human-centred systems from three perspectives. These characteristics build upon and fulfil in practical terms the human-centred philosophy outlined above.

1) Organisation

- a) Decentralised organisation based on relatively autonomous manufacturing units or cells. People work together in teams where possible on a defined product group with flexible task allocation.
- b) Access to all required information.
- c) Decentralisation of decision making authority to the shopfloor and autonomous units.
- d) The work environment must fulfil health and safety regulations.
- e) Organisational changes build upon previous organisational conditions so existing knowledge can easily be transferred and applied.

2) People

- a) Early, continuous and high levels of user involvement in system design and implementation.
- b) Accommodation of personal needs and preferences where technically and economically feasible and socially and politically desirable.
- c) High levels of social contact and communication through formal and informal mechanisms: teamworking and decision making activities.
- d) Encouraging suitable mechanisms and opportunities for personal development and self-improvement.
- e) High levels of autonomy and the authority to self-structure work.
- f) Fostering the retention and development of high and low level skills through comprehensive, continuous training and education programmes as well as through the opportunity to use a wide range of skills in the work itself.
- g) Training programmes reflecting existing levels of responsibility and skills requirements.

3) Technology

- a) Technology is designed to complement the abilities of people and so adopts the role of a tool to support people's skills rather than replacing them.
- b) Technology is designed to allow people to apply existing knowledge.

- c) The tool image is facilitated through flexible function allocations between people and computer; interactive, user-led dialogue; self-explanatory, consistent and robust software; and high levels of transparency.

At a conceptual level, the nature of human-centred design is illustrated by the Dual Design approach (refer to Figure 2-1; Bohnhoff et al., 1992). It proposes the appropriate and complementary development of both technical and social aspects of systems. Both the technology based and the working-process based design approaches should be used concurrently to obtain an optimum. The weaknesses of both approaches are compared and analysed involving the continuous exchange of ideas, as indicated by the arrows, to develop systems compatible with the requirements of both the technical and the human resources of a company (Bohnhoff, Brandt and Henning, 1992).

Technology, work organisation and skill profiles must be determined in parallel to fulfil system objectives (Brödner, 1988). New skill-based work methods require appropriately designed adaptive technologies or tools to complement the skills of people. To facilitate the long term use of decentralised decision-making structures involving autonomous workgroups, the system must support planning, scheduling and problem solving activities through appropriately designed interfaces and information support tools. In addition to the organisational aspects of the human-centred approach to work design is the 'shaping' of technology. Corbett (1985) outlines a set of criteria for designing human-centred technology or 'tools'. These are described in below and build upon the work by Rosenbrock (1981) at UMIST:

- *Complementarity*. People and machines should help each other to achieve an effect of which each alone is incapable.
- *Operator Control*. Efficient utilisation of human creativity and skill involves designing a

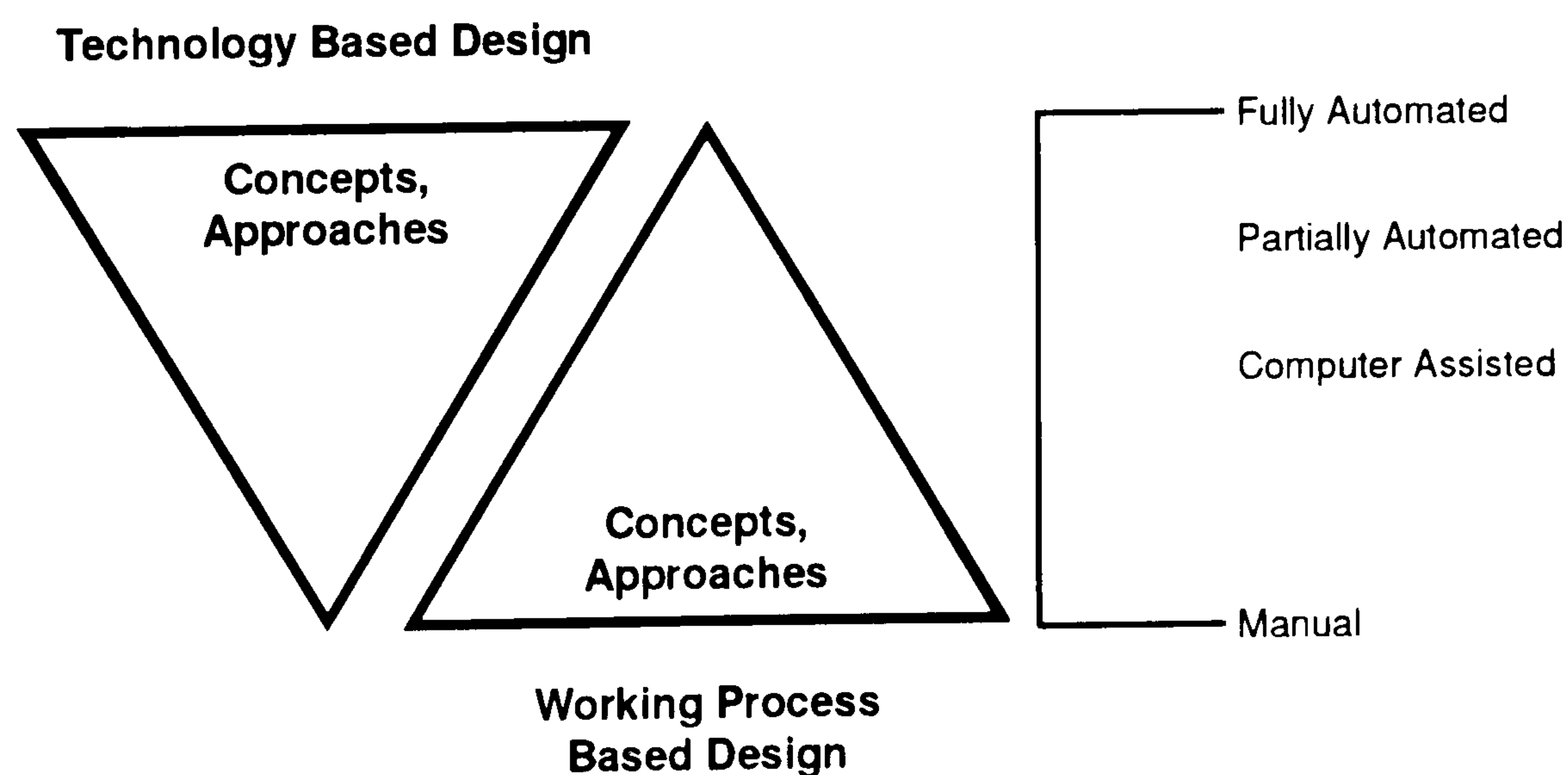


Figure 2-1 The Dual Design Approach to Human-Machine Systems

lathe that has operating choice-uncertainty built into it.

- *Interactivity*. Input and Output data should be negotiable and software should allow interaction between operator and the computer.
- *Transparency*. People must be able to 'see' the internal processes of the computer software to facilitate learning, control and fulfilment of responsibilities.
- *Compatibility*. People learn from operating equipment if they receive information compatible with their training and structural methods of learning using natural language, symbols and metaphors.
- *Accountability*. Software must be self-describing to facilitate awareness of what is going on and how decisions are reached.
- *Minimum Shock*. The system should not do anything that the people find unexpected in the light of their knowledge of the state of the system.
- *Error Reversibility*. The effects of all errors are observable and reversible.
- *Disturbance Control*. Tasks that contain choice-uncertainty should be under operator control with software support.
- *Fallibility*. People should never be put in a position of helplessly watching the computer carry out an incorrect, predictable operations.
- *Operating Flexibility*. The system should offer people the freedom to trade-off requirements and resource limits by shifting operating strategies without losing support.

Human-centred tools are often information technology based with adaptive user interfaces which are highly transparent for information, decision and control activities. Human-centred tools provide people with assistance in the management of complex situations by combining human skill (such as fast and adaptive decision making, creativity, tacit knowledge and experience) with computer capabilities (such as data storage, high processing speeds and rapid data retrieval). Human-centred technology itself does not guarantee or deliver human-centred work structures but are used to achieve their full potential. These forms of technology facilitate the development and acceptance of more 'democratic' forms of work organisation at the workplace, group, inter-departmental and factory levels (Wobbe, 1990).

2.2.3.3 Summary

The human-centred approach is built upon well established intellectual, practical and scientific traditions in Europe and throughout the world. Human-centred challenges are rooted in the mechanistic paradigm of science and technology (Gill, 1989). It is increasingly becoming

recognised as the 21st Century manufacturing paradigm throughout Europe for accommodating the concept of diversity for the development of culturally based technologies and work structures. The prevalence and importance of small to medium batch manufacturing supports the development of human-centred technology and forms of work organisation. This situation is experienced by a large proportion of European manufacturing industry. In addition, A FAST Report (cited Wobbe, 1992a) argues that 'since the European manufacturing base is largely composed of SMEs, and is characterised by highly skilled and flexible workforce, its future strength will depend upon the development of anthropocentric systems which build on skill, ingenuity and expertise of the working people'.

2.2.4 People Implementation Issues

The formation of cells using the methods outlined in Section 2.2.1 rely on technical criteria for matching families of parts with groups of machines. Formal group technology methods provide valuable assistance in facilitating the cell formation process. For such complex, practical 'problems' these methods should, however, be viewed merely as a way of providing guidelines for the designer. The design of cellular manufacturing systems is an iterative process that does not stop once the system is up and running. The design process benefits from the experience, knowledge and judgement of people who have an appreciation of the nature of the products and manufacturing processes of their organisation and of the industry in general.

The benefits of cellular manufacturing systems are strongly dependant upon organisational choice. The emergent technical and organisational properties of such systems can be open to abuse and mishandled. At one level, cellular manufacturing systems may be perceived as beneficial for the individual worker because they may facilitate long term participation and interest in the design of the manufacturing processes and working environment through greater autonomy and skills development.

From another perspective, however, cellular manufacturing may be viewed as a formalised way of persuading workers to internalise what were previously externally imposed controls. In other words, people in the cells are required to manage their own subordination and effectively take on more responsibilities as part of the transition to a cellular approach. Cellular manufacturing practices can create new forms of dependency between management and the shopfloor by encouraging the devolution of decision authority to self-regulating work groups or individuals on the shopfloor. Management cannot afford to lose the co-operation of their employees and so attempt to gain more control through the generation of commitment and co-operation. These forms of work organisation can be as manipulative and dehumanising as other systems of work. The transition from a traditional manufacturing approach to a cellular approach will impact upon a number of 'people' issues.

The way people work together, interact and understand the basic objectives and the purpose of cell production is critical for effective long term cell operation. Cell design is complex and

may be performed iteratively using formal group technology design methods as well as the experience and knowledge of people throughout an organisation. This iterative design process will often continue throughout the lifetime of a cellular manufacturing system because of the impact of the changing social, commercial and technological environments within which the cell system operates.

As well as clarifying which parts and which machines will form the physical cell on the shopfloor supervision, pay and training issues must be established to be compatible with cell production. In addition, it is essential to ensure the long term acceptance at all levels in an organisation. This initially involves identifying a champion for the system and establishing high level commitment to move forward and support the fundamental changes to working practices. The participation and full disclosure of information to all the people involved with the cell implementation must be sought to foster a motivated and knowledgeable workforce. In addition, it is essential to have highly-skilled people to cope with all disruptions that may affect production, to maintain control within the cells and to be able to move between cells as required.

2.2.4.1 Supervision

Internal cell fluctuations and disturbances are dealt with at their point of origin through the establishment of interdependent tasks and relatively self-contained cellular manufacturing systems. In these environments supervisors carry out interface or boundary regulation activities to guard against the uncontrollable transfer of disturbances from one cell to another. These factors, coupled with the increased complexity of manufacturing technology, require supervisors to adopt an holistic perspective and focus on boundary regulation activities. These activities are not directly related to cell production per se, but facilitates it by coping with issues beyond the physical cell boundary on the shopfloor and beyond the control of the people working in the cells. Boundary regulation activities encompass dealing with suppliers, customer needs, industrial disputes, capacity problems, inventory issues and system improvements.

2.2.4.2 Compensation

Cellular manufacturing methods enable industrial relations to overcome and move beyond the practical and symbolic importance of money towards the development of behaviours compatible with co-operation, initiative, creativity and problem solving. An organisation adopting cellular manufacturing methods must design their compensation or payment structure to support co-operation, flexibility and the change process.

Traditional piece-rate structures provide an obstacle for labour flexibility and the cultivation of commitment from employees. Flat-rate or time-rate structures are more conducive to cellular manufacturing systems. The transition between payment structures is complex and involves a change in well established practices and establishing long term commitment from employees

may take a considerable length of time and much effort. Flat-rate structures can be a source of demotivation. Feelings of inequity may be promoted if the differential in pay between high and low skilled people is perceived as insufficient by the more highly skilled. This differentiation is also a negative incentive for the less highly skilled people to attend training courses and develop their skill levels and may also foster ill-feeling through constraining opportunities to earn large salaries through overtime.

This payment system, however, facilitates the elimination of factional rivalries, promotes communication and information sharing as well as encouraging attention to the quality of work rather than merely to producing parts in large quantities.

2.2.4.3 Selection and Training

The design of cellular manufacturing systems requires making fundamental choices relating to downgrading or upgrading skill levels (Susman and Chase, 1986). The increase in automation has tended to polarise manufacturing skill level requirements resulting in highly skilled, fully autonomous workers at one extreme and low skilled 'machine operators' at the other. Many commentators, however, recommend a skills-upgrading policy compatible with the concepts of multi-skilling, retention of skills and autonomous individuals and work-groups. For example, Toyota's skills-upgrade programme comprises a comprehensive three stage job rotation initiative to facilitate the experience of using a multitude of skills where all people have the opportunity to perform all tasks in the cells (Huq, 1992).

The content of training and skills development programmes depend heavily on the nature of the production processes, the size of the plant and previous methods of production. The skills and knowledge requirements for working in cellular manufacturing systems are, however, difficult to assess. Personnel selection practices for cellular manufacturing systems should, however, choose people with high growth needs who will respond well to training programmes that provide workers with multiple skills as well as reward and compensation schemes that promote the learning of these skills (Wall et al, 1987; Voss, 1988; Ulich, 1990). This is, however, often difficult to achieve in practice with a workforce involved with a transition from a process to a product focused factory.

2.3 Conclusion

Human-centred concepts do not allude to some absolute state which must reflect totally the concepts described above. In addition, it is not the case that manufacturing systems will be ineffective and the people working in those systems unfulfilled unless all human-centred concepts are fully implemented. Instead, the human-centred approach seeks to build upon existing practices, knowledge and experiences to develop more effective and robust systems through improved use of people and technology. The realisation of sustainable human-centred forms of work organisation is complex. Much work is required to develop theory and useable

tools to overcome such vaguely understood issues of designing, implementing and operating sustainable human-centred systems.

The design of cellular manufacturing systems is a complex task involving the consideration of various group technology, human-centred and technology-led design methods. The process of implementing and sustaining human-centred strategies is demanding because they require, in many cases, fundamental change to well established working practices and organisational cultures (Clegg and Corbett, 1987; Clegg and Symon, 1989; Womack et al, 1990; Ainger and Newman, 1990; Banerjee, 1993; Bessant 1995). In practice, the realisation of human-centred concepts is culturally, politically and industrially sensitive.

In any organisation, given the financial, political, social and technological constraints, there is a range of cell configurations that may fulfil system requirements, corresponding to different manufacturing and business strategies. In manufacturing system design, research literature has tended to uphold a false dichotomy between organisational choice and technological determinism which, in practice, is rarely encountered. Often cellular manufacturing design strategies need to embrace a combination of human-centred and technology-led solutions.

Human-centred systems are conceived from the knowledge and skill of people and of the collaboration and responsibility of the different groups, teams and departments. At all levels, the principles of skill based work, collaboration, participation and decentralised decision making can be implemented and aided by appropriate technology. Central to human-centred forms of work organisation are cellular manufacturing systems which facilitate the development of robust, flexible and adaptive systems.

CHAPTER THREE

JOB DESIGN AND ALLOCATION OF FUNCTIONS

The design and analysis of jobs in manufacturing environments has been an area of sustained interest amongst industrial practitioners as well as organisational psychologists, sociologists and ergonomists. Traditionally, work in this field has focused on the characteristics of low-level, 'shopfloor' type jobs to identify and describe their effects upon the attitudes and behaviour of people. Job design methods and philosophies are at the core of the objectives and the methodology of this research.

This chapter discusses key job design theories in the context of current and more 'traditional' forms of work organisation and control. The division of labour or function allocation issue is the foundation for and is a fundamental outcome of job design. Function allocation, as an element of job design, has received much attention in a broad range of domains and is discussed in detail. The objectives and benefits of the research are described in light of the deficiencies outlined in existing job design practice and theory.

3.1 Job Design Methods

To fulfil manufacturing objectives, a wide range of system functions need to be allocated between people and between people and machines. The allocation of functions is fundamental to job design and embraces basic division of labour issues. The responsibility to carry out these functions also need to be allocated to individuals and workgroups. 'Job design' describes a process which details the nature and content of the functions and responsibilities and delineate how and why they are combined to form 'tasks' and 'roles' (Clegg, 1984; Parker and Wall, 1995). Tasks are affected by technology and are composed of actions requiring different skills and abilities. Roles are defined as the decision making and cognitive activities that encompass tasks and are influenced by forms of supervision and management control. The vast majority of job design studies focus on role-oriented changes, whilst leaving the task component largely unaltered (Kolodny and Kiggundu, 1980).

Much job design research as well as metrics for representing task and role characteristics are closely related to industrial practice. As a consequence, the development of current job design methods have tended to be relevant and contribute towards the development of solutions for existing and emerging business needs. Such needs embrace appropriate and new forms of work organisation and advanced manufacturing technologies encompassing group technology, cellular manufacturing, just-in-time and total quality management strategies.

There is always room for choice in the design of production systems. This choice is, however, constrained by the preconceptions, experience and values of system designers as well as 'external' financial, political and logistical pressures. These constraints affect the information processing, complexity and skill requirement characteristics of jobs as well as the degree of discretion afforded to people over the execution of system functions.

3.1.1 Allocation of Functions

Any system can be described in terms of the functions it performs. For a system to fulfil its objectives, these functions must be carried out by either people or machines. Allocation of functions is a fundamental concept within the classical division of labour issue (Chapanis, 1965). It includes the engineering approach for breaking a system down into its constituent parts and the control of systems in the process industry and man-machine interface design. The allocation of these functions to people or machines whether dynamically, temporarily or statically (depending on system requirements, the importance and criticality of the functions and the allocation process itself) can affect the operation and viability of a system as well as the people working in the system.

Functional descriptions should accompany system mission statements and the identification of a set of end-products. Viewing a system in terms of the functions it needs to perform, from a top-down perspective (identifying major functions first then breaking them down many times into sub-functions), provides a framework for discussing system details before the specific contextual details are determined. The process of function allocation is to ensure appropriate distribution of functions between people and machines to achieve a level of performance which neither could achieve alone (Corbett, 1985).

The allocation of functions stage is an important stage in the design of jobs which contributes to the successful operation of manufacturing systems (Brennan, 1984; Mital et al, 1994). It has been recognised that this stage is a crucial determinant of the success or failure of a system in the short and long term (Bamford, 1959). For example, Chapanis (1965) states that 'one of the first and most important problems in man-machine system design has to do with the allocation of functions between man and machines'. He also acknowledges their importance by stating 'the allocation of functions influence all of the later design thinking about the system'. Baily (1982) also supports this view and states that 'allocating functions is one of the most important activities designers ever perform'.

The primary focus of contemporary research effort in the area of cellular manufacturing has been biased towards how technology is used. A substantial amount of effort being directed towards the development of methods for grouping parts and machines¹ (Wemmerlöv and

¹ Over seventy new methods have been documented, and the International Journal of Production Research alone has reported fifty-one new methods since 1987. Unfortunately, only a minority of techniques such as Production Flow Analysis have been adopted, and have demonstrated their usefulness in industry.

Hyer, 1986). This affects which functions are automated, which are undertaken by people and the degree of functional flexibility and adaptivity. Few of these design processes reflect the true complexity and uncertainties inherent in small batch, cellular manufacturing systems. Case studies (Ravden et al, 1986; Majchrzak and Rahimi, 1988; Ulich, 1990; Koelsch, 1991; Banerjee, 1993) provide valuable insights into the technical and social impacts of cellular manufacturing and flexible manufacturing systems. The allocated functions between people and machines in cellular manufacturing systems is of particular importance to the following parties within an organisation:

- *Manufacturing Engineers, Supervisors and Cell Members.* They are concerned with the design and layout of the shopfloor as well as the general day to day running of the cellular manufacturing systems. To facilitate the fulfilment of system objectives, the following function allocation issues are of particular relevance during cell design: the identification of critical functions, function allocation viability and the allocation of responsibilities between people.

During cell operation, the allocation of functions affects the ability and opportunity of the cell members and supervisors to predict and rectify disruptions to production levels and component quality.

- *Senior and Operations Management.* At a strategic level, the allocation of functions between cell members and supervisors and between people and machines affects the flexibility, robustness and responsiveness of manufacturing systems. Redundancy of functions rather than the redundancy of parts, therefore, affects the ability of such systems to meet existing and emerging competitive requirements which in turn impacts upon fulfilling business objectives.
- *Training and Personnel Departments.* The allocation of functions shapes the content of company training programmes and personnel selection decisions by influencing the nature of work and skills requirements.

3.1.1.1 Significance and Definitions

The allocation of functions stage in the design of manufacturing systems is the most basic of system design decisions (Price, 1985) and is concerned with determining the functions to be performed by the different components within the system (Brennan, 1984). An investigation into the development of automatic programmable assembly systems, undertaken by a team of engineers and social scientists, revealed that 'task allocation as foremost in importance among eleven worker related research areas' (Westinghouse Research and Development Centre, 1980). These decisions are made either unconsciously (as is often the case) or as part of an allocation method with consideration of a number of criteria for functions that can be carried out to an equal extent by both people and machines. Allocated functions establish a boundary for systems development through job design and analysis, personnel selection, training requirements and man-machine interfaces.

Research literature tends not to treat the concepts of functions and tasks consistently. Some authors do not differentiate between the two concepts (for example: Brennan, 1984; Stammers and Hallam, 1985; Wei and Wieringa, 1994; Mital et al., 1994), whereas others are specific in their use of the term 'function' (for example: Price, 1985; Clegg et al., 1989; Grote, 1994). The concepts of functions and tasks are differentiated in this thesis:

- Functions are essentially analytical concepts (Price, 1985). They can be broken down into sub-functions and can be used to conceptualise a system without reference to people, machines and situational environment (Meister and Rabideau, 1965). DeGreene (1970) defines a function as 'a general means or action by which the system fulfils its requirements, whereas he defines a task from a behavioural perspective as 'a composite of related...activities performed by an individual, and directed towards accomplishing a specific amount of work within a specific work context'.

The nature of functions can be either information or material based. Information type functions such as 'plan workload' viewed as 'high-level' functions, whereas material functions like 'operate machine' are viewed as 'low-level' functions. In addition, functions may be treated as essential or auxiliary according to whether they are *necessary* to fulfil system goals or merely *accessory* (Price, 1985). Alternatives to the latter taxonomy include *basic* or *secondary* within the context of Value Engineering Analysis where 'a basic function is the prime reason for the existence of the product' (Demarle and Shillito, 1982); and *multiplicative* or *additive* within the context of man-machine systems for high risk aerospace environments (Price et al, 1965).

Functions allude to the basic *content* of the resultant activities performed by people and machines. They do not describe the *nature* of work itself or refer to social, technical or organisational components of the work environment.

- Functions are combined to form tasks and roles and based on contextual elements of the work environment to form jobs for people to fulfil. At this level, the emergent properties of combining functions are vast and relate to motivational, economic, logistical, commercial, legal and technological issues. These encompass concepts such as skills development, payment structures, industrial relations, customer satisfaction, health and safety issues, supervision and management styles and training issues.

The process of allocating functions does not determine job designs because of the room for strategic choice in systems design but it does, however, describe a boundary within which job design choices are made.

Contemporary allocation of functions processes reflect the differentiation between functions, tasks and roles. Decisions made during the allocation of functions design stage should take into account criteria relating to the design of jobs and should consider the effects of the work in economic, technical and social terms (Clegg et al., 1989). Contemporary processes by their very nature, therefore, distinguish between 'functional

and ‘task’ based decisions. The distinction is used in this thesis and reflects the design of the research methodology and research methods. For simplicity but to maintain the differentiation between the allocation of functions and later stages of job design, ‘task’ will denote both task and role components.

The following sections discuss the characteristics and motivations underlying ‘traditional’ and contemporary job design methods. The characteristics and relevance of allocation of functions methods to job design in various application domains are described.

3.2 Work Simplification

The process of work simplification, in engineering terms, is well understood. It involves the selection of job design options that provide the most technologically and structurally simple configurations to provide management with high levels of control. There are economic and psychological motives for adopting work simplification strategies. In economic terms, such strategies are often relatively inexpensive since people require minimal training, acquire few skills, are paid comparatively low wages and are relatively easy to replace. These strategies are also applicable for job designers who perceive that people neither want or respond to increased responsibility and autonomy. Such beliefs represent powerful motivators for the design of relatively simple and highly supervised jobs.

Some of the earliest accounts of the concept and benefits of work simplification are related by Smith (1776), Babbage (1835) and Gilbreth (1911) against the background of the first industrial revolution. Such concepts emphasise improved productivity through specialisation and the fragmentation of jobs (high division of labour) to facilitate short learning times, savings in training and the use of cheap labour. The widespread uptake of these concepts throughout most of the twentieth century has been strongly, if not solely, influenced by the writings and practical demonstrations of the ‘efficiency expert’ Frederick Winslow Taylor through the concept of scientific management (Taylor, 1947). He, in many ways, merely formalised what engineers had been practising since the start of the first industrial revolution.

In 1908, with the help of Taylor, Henry Ford applied work simplification methods to the mass production of the simplest car ever built, the Model-T. The use of moving assembly line methods made possible the development of new markets and had a profound impact upon the mobility of people and upon the structure of society as a whole. In 1924, the ten millionth car rolled off the production line in Detroit. By this time, the cycle of mass production feeding mass consumption leading to further production was well established in America.

Work simplification has been the dominant job design paradigm to meet the commercial and industrial conditions for the majority of this century (Braverman, 1974; Littler, 1985). A 1955 survey identified a list of fifteen criteria used by organisations to design jobs (Davis et al., 1955). The most important were minimising the time required to perform an operation, minimising skill requirements, achieving specialisation of skills and minimising training or

learning times. This trend is certainly widespread and in many cases suits the competitive requirements of low variety and medium to high production requirements. Buchanan and McCalman (1989), however, note that scientific management strategies are often unquestionably practised. All available and alternative strategic design choices are often not considered.

Recent work in the field of job design has tended to move away from merely focusing on performance and productivity issues in reaction to the perceived deficiencies in work simplification methods. Current job design strategies tend to take into account the physical and psychological well-being of people as well as their unique flexibilities and intellectual ability. Kidd (1988a) outlines a comprehensive case against scientific management principles. Such forms of work organisation are widely recognised within the context of current job design methods as deficient for current and emerging competitive requirements (Rosenbrock, 1977; Bainbridge, 1983; Cooley and Crampton, 1987; Slatter et al., 1989; Clegg et al. 1989; Bessant et al., 1992).

Early research in reaction to perceived deficiencies in work simplification focused on mental and physical health (Burnett, 1925; Wyatt and Ogden, 1924 (cited in Wall and Martin, 1987); Fraser, 1947; Kornhauser, 1965) and work attitudes (Walker and Guest, 1952). These early work failed to address issues of productivity, did not attempt to proactively redesign jobs and focused upon 'horizontal' division of labour issues. 'Vertical' issues embracing work-group autonomy and co-operative work structures were rarely considered (Wall and Martin, 1987).

The following sections describe recent job design strategies relevant to recent changes in technology and business requirements. These strategies encompass behavioural and socio-technical methods.

3.3 Behavioural Methods

The common objective of behavioural approaches is 'to design work in a way that achieves high work productivity without incurring the human costs that are associated with traditional approaches' (Hackman and Oldham, 1980).

3.3.1 Activation Theory

Activation theory is helpful in understanding how people react to highly routinised work and in planning for jobs that minimise the negative consequences of under-activating (i.e. repetitive and simple) work (Scott, 1976). To design jobs using this approach data are required on the magnitude and variation of sources of stimulation as well as the number of sensory channels (visual, auditory, olfactory, gustatory and tactile) that are affected by the task.

The theory has not received widespread application and suffers from three broad conceptual problems: people have different optimal levels of activation; due to familiarity with a given environment, people tend to adapt quickly to changes in the level of stimulation they experience; and the ideal level of activation for optimal task effectiveness varies between different kinds of work. Theory provides little guidance about how these issues should be dealt with in job (re)design.

3.3.2 Motivation Theories

Motivational models view people as learning, needing and perceiving animals. the most common of which are: Theory X, Theory Y (McGregor, 1960), Motivation and Hygiene Theory (Herzberg, 1959), Hierarchy of Needs (Maslow, 1954), Equity Theory (Adams, 1963), Existence Relatedness Growth (ERG) Theory (Alderfer, 1969), Reinforcement Theory (Steers and Porter, 1963), Social Learning Theory (Bandura, 1977), Goal Setting Theory (Latham and Locke, 1979) and Expectancy Theory (Vroom, 1964). A full discussion of these theories is beyond the scope of this thesis, suffice to say that virtually all the theories, however, purport to have universal applicability, although there is much evidence to suppose that these claims are unfounded. Each approach have their supporters and antagonists but tend to reveal only a particular aspect of human nature.

An insightful way of combining the various models is proposed by Mayes (1976). He proposes a contingency framework where different circumstances necessitate the application of different motivational models.

The various need theories (such as the Hierarchy of Needs, ERG and Motivation and Hygiene theories) acknowledge that although people differ in the strength of their needs, the same underlying set of needs, in varying combinations, can ultimately explain all behaviour. Likewise, cognitive models (such as the Reinforcement, Social Learning, Equity and Expectancy theories), although they may contain different criteria, suggest that the mechanisms leading to behaviour are about the same for most of us, once these differences have been taken into account.

Goal setting theory is the most universal of all the models since individual differences are seldom mentioned. It is essential, therefore, to understand the comparative strengths and weaknesses of the different models in different situations. The models can guide system designers towards the design of intrinsically motivating jobs.

The complexity of people and organisational environments as well as the requirement for political and social skills to implement theory in an overt, attractive form can, however, make model application difficult to achieve in practice.

3.3.3 Job Characteristics Methods

During the 1950s, job design research was dominated by issues relating to the horizontal division of labour and health issues (Walker and Guest, 1952). During the 1960s, however, vertical division of labour issues, encompassing the implications of restricted autonomy and responsibility, received much attention. From the USA, Herzberg's 'two factor' theory of motivation commanded considerable interest during this period and pioneered the concept of job enrichment. The factors giving rise to satisfaction are called motivators. Those giving rise to dissatisfaction are called hygiene factors. Motivators embrace achievement, recognition, work itself, responsibility and advancement issues.

The job characteristics approach focuses on objective characteristics of jobs and build into them elements that create conditions for high work motivation, satisfaction and performance. The approach recognises that people will respond differently to the same job. Consequently, these methods take into account characteristics of people as well as those of the work itself. Job characteristics are often specified at low levels of abstraction and so provide relatively tangible criteria for designing jobs. Like other behavioural approaches, job characteristics theory deals with aspects of jobs that can be changed to foster positive motivational incentives for people.

In the 1970s Herzberg's 'two factor' model was effectively displaced by the job characteristics model (JCM) developed by Hackman and Oldham (1976). This model built upon work in the area of job characteristics theory which had its roots in work by Turner and Lawrence (1965). This study examined relationships between people's opinions of their work and objective work elements. The JCM builds upon behavioural and socio-technical system approaches and draws heavily on job characteristics theory. The approach does not represent much of a departure in job design theory but rather condenses, in an explicit and understandable form, over fifteen years of research. The model deals with work for individuals and groups, emphasises the importance of collecting diagnostic data about a working environment and stresses the relationship between basic theory and practical methods of job (re)design.

The JCM specifies five 'core job characteristics' relating to worker attitudes and behaviour, encompassing skill variety, task identity, task significance, autonomy and feedback from the job (refer to Figure 3-1). Jobs with high levels of these characteristics especially autonomy and feedback are regarded to promote high levels of motivation, job satisfaction and reduce labour turnover and absenteeism. The strength of the job characteristics-outcome relationship relates to individual differences, especially 'growth need strength'.

The model has become a major influence in job design research. One reason for this may lie with the identification of a clear set of features and the provision of a diagnostic tool (the Job Diagnostic Survey, JDS) to measure these features (Hackman and Oldham, 1980). The tool itself, however, has been reduced in many cases to an approach concerned with the direct causal links between the five job characteristics and the outcome variables. Wall et al. (1987) suggest that the psychological states are an unnecessary elaboration. Often the three critical

psychological states are ignored (Orpen, 1979) or are treated as dependant variables (Kiggundu, 1981). Roberts and Glick (1981) provide a critical review of the model.

Recent criticisms have alluded to the need to develop this field of research to accommodate recent manufacturing advances. These include developments in manufacturing technology and forms of work organisation and control methods encompassing cellular manufacturing, just-in-time and total quality management. These manufacturing technologies embrace the concept of open systems (Bertalanffy, 1968; Flood and Jackson, 1991) and require an awareness of the external context in addition to forms of job design. The socio-technical approach to job design seeks to co-optimize the social and technological elements of a system with a view to cope with and absorb external fluctuations in the system's environment. This field of job design has moved the focus away from the individual to embrace workgroups and the external context of manufacturing systems. These concepts are discussed in the next section.

3.4 Socio-Technical Systems Theory

The concept of the socio-technical approach was developed by the London Tavistock Institute of Human Relations in the 1950s (Trist and Bamforth, 1948; 1951). Compared to a technically-oriented (i.e. scientific management; refer to Section 3.2) approach, socio-technical systems theory has a more positive concept of people. It considers the social and technical sub-systems of an organisation as being of equal importance and fosters their joint

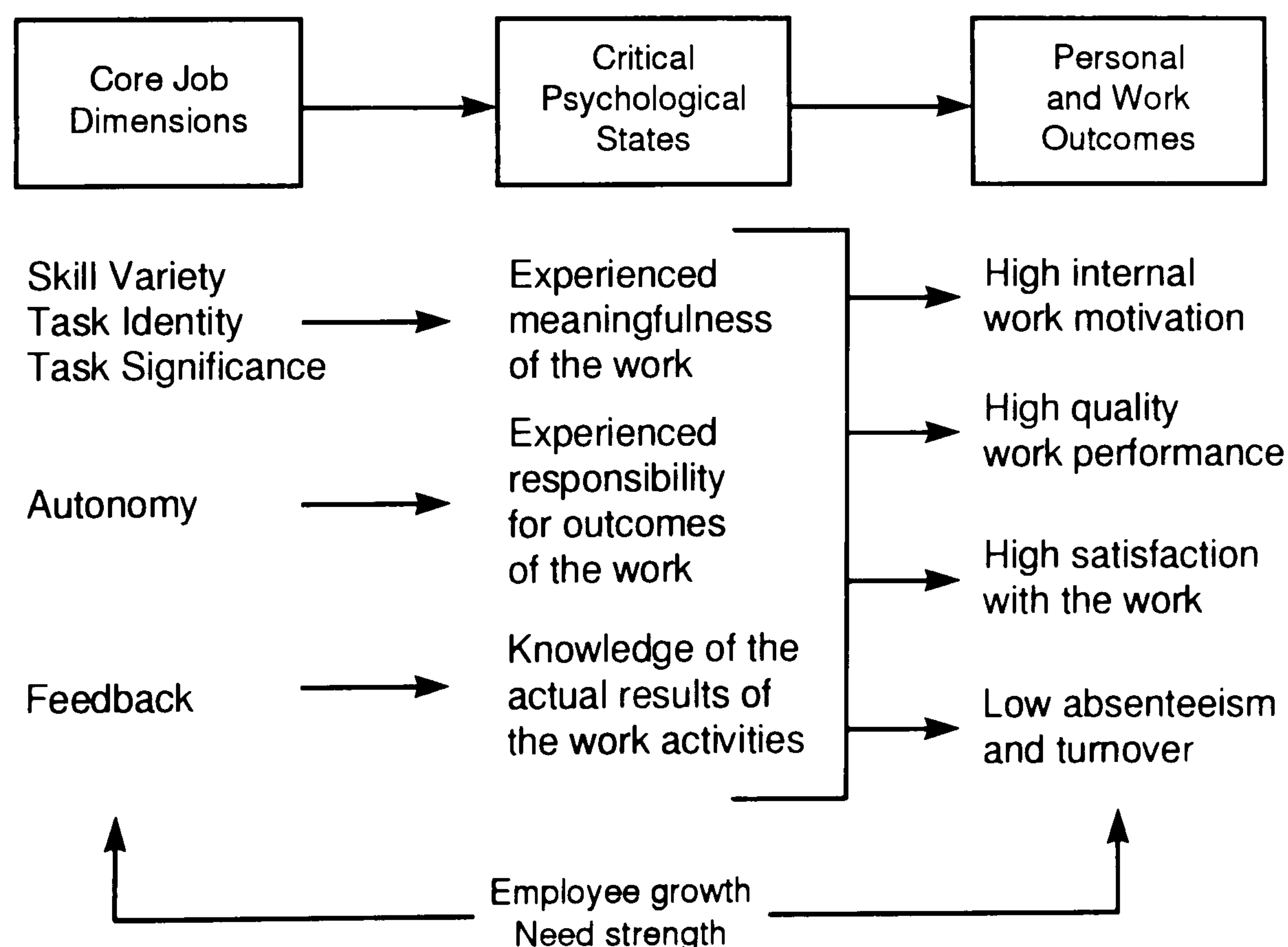


Figure 3-1 The Job Characteristics Model (JCM)

optimisation rather than optimising each sub-system independently to improve economic and social outcomes of work (Cummings and Molly, 1977). In addition, the approach emphasises forms of work organisation that promote co-operative working structures and autonomous workgroups.

Socio-technical theory was influenced and supported by work from many nations. These include work organisation studies in the Stockholm telecommunications exchange in Sweden (Westerlund, 1952, cited in Susman, 1976); the telecommunications industry in Holland (Beinum, 1963); the chemical industry in the USA (Davis, 1955); the Quality of Working Life programme in Norway (Davis and Cherns, 1975); and the textile industry in India (Rice, 1953). This work coupled with the innovative experiments in the Durham coal industry on 'composite working methods' (Trist and Bamforth, 1951) and the job design research in the USA, helped the socio-technical approach gain increased acceptance within academia and industry alike.

Open systems (Bertalanffy, 1968; Flood and Jackson, 1991) and cybernetic theory are integral to the socio-technical approach and support the need, in viable systems terms, for joint technical and social optimisation². Socio-technical systems are viewed as open, purposeful systems existing within an environment comprised of legal, commercial, social, political and technological components. The open system perspective facilitates understanding, from a holistic perspective, about 'what goes on in any given work organisation and what goes on in its environment - a fact that is dangerous to ignore when work systems are [redesigned]' (Davis and Trist, 1977, cited in Susman, 1976). This perspective influences the design of the adopted research methodology and data collection methods in this thesis.

During the 1960s and 1970s, the idea of the socio-technical approach became attractive as a means of increasing productivity without large capital investment. The 'experiments' of Volvo in Kalmar³ in the 1970s and Volvo in Uddevalla in the 1980s are well known examples of implementing socio-technical concepts to improve work satisfaction and productivity⁴. The Volvo experiences emphasised the attitudinal and performance benefits of autonomous workgroups (Trist and Bamforth, 1951; Burns and Stalker, 1961; Kemp et al., 1983).

² This view is embodied by the Law of Requisite Variety (Ashby, 1962). It states that for any system to remain under control (i.e. to be viable), the controller must be able to absorb the entire range of inputs that may affect the system. This is facilitated by joint-optimisation to cope with the range of possible inputs a system may experience. The range of inputs is often described in terms of uncertainties, variety, variance (Clegg, 1984) and turbulence.

³ The Volvo car factory at Kalmar, Sweden was set up two months after the much publicised General Motors failure of their highly automated Chevrolet plant at Lordstown, Ohio in 1972. The Volvo plant did not represent any major departures from the basic principles of mass-production, only from its practice. At Kalmar, they used semi-autonomous workgroups as the basic building block against the traditional one man, one shift, one station principle (Trist, 1978).

⁴ Additional studies have been carried out in Saab-Scania; Harman Industries in Bolivar, Tennessee; General Foods in Topeka, Kansas (Walton, 1977) during the 1970s and General Motors during the 1980s.

Volvo's experiments in work restructuring began in the late 1960s in existing truck and car plants near Gothenburg. This work set out to make auto work more attractive to reverse an upward trend in the labour turnover rate. Volvo claimed to have experienced lower labour turnover rates, more employee satisfaction, improved quality and fewer final adjustments. The Kalmar plant utilised the lessons from these earlier experiments. In designing the plant, management consulted employees, trade union officials, psychologists and sociologists. Volvo unions and management viewed Kalmar as a means for the 'deepening of social democracy'.

Inter-dependant tasks were combined and a group of workers given the responsibility for a complete function or component of the car. Functions previously performed by service units were assumed by the operating work-groups. The identification of a 'whole' task provided a rationale for learning all of the inter-related jobs. Each team had a shopfloor area permitting an average of six car bodies to be worked on simultaneously. The responsibilities of each group included scheduling, solving production problems, screening new employees and meeting outside suppliers. The distinction between the managed and the managers was de-emphasised. Kalmar did not establish any innovative reward systems probably because the unions and management wanted to conform with industry pay patterns.

These experiences were similar to those at Topeka. Kalmar, however, went further and introduced some new forms of production technology. To permit group assembly, Kalmar sought to redesign the product itself to facilitate the assembly of entire subsystems. In this respect, the Kalmar plant represents a major advance in system design since the Hawthorne Studies (refer to Section 2.2.3.1). Where Hawthorne sensitised us to the social system, Kalmar broke new ground in redesigning both the production technology and the internal construction of the product to accommodate the desired method of work organisation.

The experiments at Kalmar indicated a trend toward an openness about the purpose of work restructuring and a larger role for workers in deciding upon the appropriate method of work organisation.

Autonomous workgroups, however, did not receive widespread recognition in the USA until the 1970s reflecting the lack of specificity of the concept as well as the subsequent lack of research in the field (Cherns and Davis, 1975). Hackman (1977) suggested that autonomous workgroups may prove more influential than individual forms of job design because they embrace wider and more complete forms of work. Hackman (1983) subsequently extended the JCM to encompass the work-group.

Socio-technical theory has engendered a vast amount of research investigating the relationships between technology, organisational and social environments. For example, the relationships between organisational structure and technology (Hickson et al., 1969; Kynaston Reeves et al., 1970; Comstock and Scott, 1977; Mohr, 1971); classification of technology (Rice, 1958; Rackman and Woodward, 1970); organisational consonance (Woodward, 1960; Perrow, 1967; Mohr, 1971); and autonomous workgroups (Kolodny and Kiggundu, 1980; Wall and Clegg, 1981, Clegg et al., 1985).

Martin et al. (1990) provide some elaborations and emphasise the establishment of 'relatively independent and self-contained units of organisation [to] which holistic tasks are assigned'; the unity of product and organisation where the technical-organisational process must be designed in a way that the result can be traced back to the organisational unit; interdependent tasks to facilitate learning from the work itself; and the 'auto-regulation' of fluctuations, itself fostered by the former criterion. Emery (1980) provides a thorough review of the main features and nature of socio-technical systems. The above four criteria are central characteristics of cellular manufacturing strategies and objectives.

Although systems are comprised of social and technological sub-systems in equilibrium, practical field research has almost entirely focused on the social dimension. Pasmore et al. (1982) notes that only 23 of 134 socio-technical change experiments he reviewed involved any form of technical change, whilst 72 studies involved autonomous workgroups. The technical subsystem is often 'taken for granted' and equilibrium is achieved through adapting or 'repairing' the social sub-system. As Clegg (1984) says in the context of socio-technical job redesign, 'joint-optimisation is in practice, a myth'. In addition, Corbett (1990) acknowledged that although 'the socio-technical approach in many ways [has] changed the perception of the worker in a more positive direction, it did not really understand the importance of subjectively bounded knowledge in the work process'. Cherns (1976) provides a useful summary or 'checklist' of socio-technical principles. These have survived relatively intact to the present day but are criticised by Clegg and Symon (1989) due to their bias towards social and organisational rather than technological issues. Much work has been carried out conforming to these principles but has tended to leave the technical sub-system unchanged.

The socio-technical principles encompass (adapted from Cherns, 1976):

- *Compatibility.* The process of design must be compatible with its objectives. If systems are designed that are capable of self-modification and using the creative abilities of people, then those people must have the opportunity to participate in the design of the system in which they are expected to work.
- *Minimal Critical Specification.* During systems development, features that are essential to fulfil systems objectives must be identified but no more should be specified than is absolutely necessary. It is a mistake to specify more than is needed because by doing so could close options that could be left open (Rosenbrock, 1977). This applies to the task content as well as their allocation between people and machines. The elimination of these choices are referred to by Rosenbrock (1979) as the Luescher-Hills effect.
- *Socio-Technical Criterion.* This principle states that if variances in a system cannot be eliminated then they must be controlled as near to their point of origin as possible. The fewer variances that are allowed to influence the wider system, the fewer are the controls needed to deal with any disruptions. This promotes the modularisation of systems such as with cellular manufacturing methods and foster more complete jobs where people are

responsible for their own work and can achieve system goals given the resources and skills to do so.

- *Organism Versus Mechanism.* Redundancy of functions fosters the development of more robust systems capable of adapting to changing environmental demands. Such systems are organic in nature and supports the ability of functions to be performed in a number of different ways. Organic systems are flexible: roles are subject to re-definition, control and authority are exercised on a network basis and interaction is lateral rather than vertical.

Mechanistic systems may be depicted in terms of a redundancy of parts where people perform highly specialised functions and are unable to perform a 'large repertoire of performances'. They are definable by their precise definition of roles, hierarchical structure and vertical interaction between members of the hierarchy.

Burns and Stalker (1961) described the difficulties companies had with trying to maintain mechanistic systems of management in the face of rapidly changing environments and technologies, or those attempting to impose organic management ideas upon organisations with stable and traditional tasks. Woodward, in her studies of the effects of technology on structure and performance, indicated that small batch and process product companies benefited from a more organic form of structure, whilst large batch and mass production companies gained more from a mechanistic structure. To ensure success, it is important for companies to select a structure best suited to their production system (Woodward, 1965).

- *Boundary Location.* Where systems have a clear definable boundary, the more activities are controlled within the boundary by those working in the system, the more the role of the supervisors become focused on ensuring adequate resources for the people in the system to carry out their jobs. Such systems encompass cellular manufacturing environments. The people in the systems have the skills, responsibility and resources to work autonomously to fulfil system goals. Supervisors co-ordinate activities between cellular manufacturing systems and deal directly with suppliers and customers.
- *Information Flow.* Information systems should be designed to provide people with exactly the right type and amount of feedback to enable them to learn to control the variances which may arise.
- *Support Congruence.* The social system should reinforce behaviours which the system is designed to foster. Features that may reinforce or subdue required behaviours encompass pay and incentive structures, employee selection, conflict resolution, performance assessment, leave allocation and promotion policies. This was not the case at Volvo's Kalmar plant where pay was initially based on a time and method approach. This tended to stifle further work humanisation, despite the high levels of management commitment.
- *Design and Human Values.* Job design should provide a 'high quality of work' where jobs provide reasonable levels of demand, opportunities to learn from the work, a degree of

‘minimal’ personal decision making, social support and recognition in the workplace, the ability to relate ones work to ones social life and certain desirable prospects in performing the job well (Thorsrud, 1972).

- *Incompletion.* Design is an iterative process. As soon as a system is implemented, its consequences indicate the need for redesign through continuous improvement methods by interdisciplinary teams.

The behavioural, job characteristics and socio-technical methods provide a comprehensive and rich source of job design theory focusing from various perspectives on co-operative work structures, job enrichment strategies and autonomous workgroups. Because of this, these methods are appropriate for applying to small batch, high variety manufacturing environments such as cellular manufacturing systems (Wall and Martin, 1987; Brödner, 1988; Corbett, 1988b).

The allocation of functions or division of labour between people and machines is a fundamental outcome of all job design methods. This feature of all job designs has received much attention in many service, military and industrial domains. The following sections discuss the concept and its theories.

3.5 Allocation of Functions Methods

Methods for allocating functions have been dominated by four approaches:

- 1) Task analysis and simulation methods which are based on the assessment of workloads and whether people can sustain them.
- 2) Comparative frameworks or lists.
- 3) The ‘leftover’ design approach.
- 4) Complementary and Dynamic allocation methods.

Task analysis and simulation methods are support tools for the allocation process and may be used in combination with other methods. Comparative frameworks and ‘leftover’ design methods foster a closed systems approach. Closed system allocation of functions advocate one-off allocation without reference to the range of states a system may take during its operation. Allocations are, therefore, static and fixed. Complementary methods foster an open systems approach through adaptive or dynamic allocation methods which advocate many concepts from the socio-technical and human-centred paradigms.

Methods for allocating functions have been investigated and applied to many domains. Table F1.1 (Appendix F) is a comprehensive summary of the current state of work on the allocation

of functions in seven application domains. Table 3-1 categorises each domain into large and small scale environments.

Table 3-1 Matrix Outlining Function Allocation Domains

Large Scale
<ul style="list-style-type: none"> • Aerospace <i>Allocation Criteria:</i> psychological needs and workload; human reliability and capabilities; machine performance and capabilities; health and safety; and economic factors. <i>Allocation Methods:</i> comparative frameworks. Complementarity is discussed. • Process Control <i>Allocation Criteria:</i> human reliability and capabilities; machine performance and capabilities; health and safety; and criticality and importance. <i>Allocation Methods:</i> job and skills analysis. • Air Traffic Management <i>Allocation Criteria:</i> psychological needs and workload; human reliability and capabilities; criticality and importance; and responsibility. <i>Allocation Methods:</i> comparative frameworks. • Man-Machine Systems <i>Allocation Criteria:</i> A wide range of criteria but tending to focus on psychological needs and workload; human reliability and capabilities; machine performance and capabilities. A small number consider organisational and cultural issues; economic and market factors; criticality and importance; and responsibility. <i>Allocation Methods:</i> dynamic and adaptive; participative and complementarity.
Small Scale
<ul style="list-style-type: none"> • Human-Computer Systems <i>Allocation Criteria:</i> psychological needs and workload; human reliability and capabilities; machine performance and capabilities; information and knowledge needs. <i>Allocation Methods:</i> dynamic and adaptive and comparative frameworks. A few discuss complementarity. • Inspection and Surveillance Systems <i>Allocation Criteria:</i> psychological needs and workload; human reliability and capabilities; machine performance and capabilities; information and knowledge needs. <i>Allocation Methods:</i> comparative frameworks and dynamic and adaptive. • Human-Robotic Systems <i>Allocation Criteria:</i> psychological needs and workload; human reliability and capabilities; machine performance and capabilities; health and safety and economic factors. <i>Allocation Methods:</i> comparative frameworks and job and skills analysis.

The summary is in terms of the function allocation processes and criteria advocated and discussed by the authors. Overall, for all domains, the main allocation criteria are psychological needs and workload, human reliability and capabilities and machine performance and capabilities. Information and cultural issues are in addition advocated for human-computer systems, whilst the consideration of organisational and cultural issues are advocated in man-machine systems.

Comparative frameworks are advocated primarily in the human-robot system, process control, air-traffic control, aerospace and inspection and surveillance domains. Dynamic and adaptive allocation methods are advocated for human-computer systems to optimise workloads and minimise stress levels under a range of operating conditions. For man-machine systems, the majority of contemporary papers advocate dynamic and adaptive, participatory and complementary allocation methods. The widest range of allocation methods are advocated for man-machine systems which reflects the scope for organisational choice for job design in manufacturing system.

Cellular manufacturing systems advocate the use of human-centred (i.e. participative and complementary) function allocation methods to develop jobs able to cope with fluctuations and unforeseen events from within the manufacturing system and the wider environment (cf. open systems theory). This is advocated in this thesis and influences the development of a model to describe how function allocations and job designs are derived.

Task analysis and simulation methods are analytic in nature whereas comparative frameworks, the 'leftover' approach and complementary allocation methods are empirical. The latter methods do not require the collection of subjective data from people and so do not, therefore, require end workers to interact with the design. Allocation of functions methods are discussed in the following sections. Comparative frameworks and the 'leftover' approach are closely related and so are discussed together.

3.5.1 Task Analysis and Simulation Methods

A number of computer simulation and informational support tools have been developed for use in support of the allocation of functions process by estimating and describing workloads. These methods are widely used in the design of military, aerospace and process control systems and are viewed as being essential for facilitating the development of effective 'high-risk' systems. Workload assessment tools may be described under three headings: mathematical, task analysis and simulation methods.

Success in modelling workloads is primarily dependent upon the skills, experience and knowledge of the people who plan and carry out the work. It is these characteristics that make people invaluable in all decision making processes.

3.5.1.1 Mathematical Methods

An ambitious goal of the early workload researchers was the development of mathematical models for predicting operator and system performance. Such models would identify relevant variables and combine them so that workload-related effects on performance could be reliably estimated.

Three dominant methods emerge from this field of interest: manual control, information theory and queuing theory. Manual control models fall into two groups: classical control theory and optimal control models. The predictive properties of these models make them useful tools, although their mathematical complexity make them largely inaccessible for many practitioners. Information theory, based on the mathematical formulation of the transmission of information through an imperfect communication media, was popular in the 1960s for workload assessment (Senders, 1964). Finally, with queuing theory, the emphasis is on *when* tasks are performed rather than *how* they are performed (Senders and Posner, 1976). The method has extensively been applied to supervisory tasks where computers are viewed as mediators between people (the supervisors) and a physical process. The application domains encompass aircraft control, spacecraft, marine vessels as well as the control of chemical, electrical and nuclear power plants.

Associated work in this field encompasses a wide range of issues including adaptive aiding, multitask monitoring situations, attention allocation decisions, allocation of responsibilities in multitask human-computer environments as well as adaptive supervision and task allocation for human-computer interfaces. These application domains are comprehensively reviewed by Greenstein and Rouse (1976), Rouse (1977), Chu and Rouse (1979), Greenstein and Lam (1985), Shi-quan (1985), Millot et al. (1986), Millot and Kamoun (1988), Rencken and Durrant-Whyte (1989, 1993) and Reiger and Greenstein (1982). In all these cases, the need for extensive validation is required for establishing their usefulness in various process control, human-computer and military environments. The popularity of mathematical models have waned due to the development and refinement of computerised task analysis and simulation tools.

3.5.1.2 Task Analysis Methods

Task analysis methods are the most commonly used method for workload estimation during the preliminary stages of systems development⁵. The methods are firstly easy to conceptualise and understand and often do not require knowledge of advanced mathematical and simulation techniques. Task analysis provides useful information and insight into the nature of a proposed

⁵ The word 'task' is used in the following sections to be compatible with the associated research literature. The process of predicting workloads often occurs during the early stages of system development. Within this context, references to 'tasks' therefore allude to the concept of 'functions' as defined throughout this thesis.

system in general whether or not specific workload prediction are derived. Consequently, task analysis is useful for systems designers, ergonomists and engineers. In general, workload assessment methods begin with a mission scenario and requirements. These are systematically broken down (or decomposed) into tasks which are in turn broken down into sub-tasks. The resultant task elements are translated into real-world elements associated with the situation under consideration. Other methods are more detailed and group tasks into sensory channels or parts of the body - for example eyes, hands and feet. Other more detailed methods predict cognitive loads and use time stress as a major element in estimating workload.

Because of the large number of task analysis methods, a detailed analysis cannot be made here. Some of the more widely documented methods, however, include Hierarchical Task Analysis (HTA; Annett and Duncan, 1967) and the complementary Function Analysis System Technique (FAST; Blythway, 1971), Computer Aided Function Allocation Evaluation System (CAFES; Linton et al., 1977), the McCracken-Aldrich approach (McCracken and Aldrich, 1984), Time Based Analysis of Significant Co-ordinated Operations (TASCO; Roberts and Crites, 1985), Computerised Rapid Analysis of Workload (CRAWL; Bateman and Thompson, 1986), Workload Index (W/INDEX; North, 1986), Yourdon Modelling (Yourdon, 1986), timeline analysis (Stone et al., 1987), Structured Systems Analysis Design Method (SSADM; Downs et al., 1988), Human Factors in Information Technology (HUFIT; Taylor 1990), CATALYST (Rouse et al., 1992) and the Manpower and Personnel Integration tool (MANPRINT; Goom, 1993).

Many of the above methods were initially developed for military applications. Within a manufacturing context, however, only the Yourdon Modelling, SSADM and HTA methods are commonly used in practice (Older and Clegg, 1995). Many of the methods, CAFES for example, have not been successful and have remained within the academic domain. One reason for this may lie with the database development costs that are needed to cope with enormous data requirements. In addition, the majority of these methods require high levels of skill and experience for the precise and systematic capture and analysis of data.

3.5.1.3 Simulation Methods

Simulation methods are characterised as elaborate task analysis methods which utilise and generate the statistical nature of the task elements. Meister (1985) provide a useful review of simulation methods and application domains. Accurate descriptions of people, the system and the system environment are important prerequisites for a representative simulation model. In addition, simulations can compare differences across a number of system configurations and operational settings.

Because of the large number of simulation methods a detailed analysis cannot be made here. Some of the more widely documented methods, however, include Human Effectiveness Function Allocation Methodology (HEFAM; Connolly and Willis, 1960), Human Operator Simulator (HOS; Wherry, 1969), Systems Analysis of Integrated Networks of Tasks (SAINT; Wortman et al., 1975; and MicroSAINT; Laughery et al., 1986), Model Human Process

(MHP; Card et al., 1983), Simulation for Workload Assessment and Manning (SIMWAM; Kirkpatrick et al. 1984), Siegel-Wolf Network Models (Meister, 1985), Sequiturs Workload Analysis Systems (SWAS; Holley and Parks, 1987) and Human-Machine Allocation Network-based Environment (HUMANE; Madni, 1988).

Simulation methods represent the behaviour of people statistically and produce measures of effectiveness for human-system performance. Task analysis, on the other hand, generate performance characteristics as a function of fixed time increments for a given context. Running a computerised task analysis a number of times would yield the same results. Running a simulation model a number of times, however, may not yield the same results due to statistical modification of task times and performance accuracies. Computer simulation models, combined with task analysis methods are the most thorough of the analytical techniques for estimating workloads. Validation, however, as with all analytic methods, remains a major issue facing computer simulation methods.

3.5.2 Comparative Frameworks

Comparative frameworks or lists are used to allocate functions between people and machines according to often deep rooted perceptions of what 'men are better at, machines are better at', or in shorthand MABA-MABA (Mital et al, 1994). The first notable example was developed by Fitts (1951) for 'the development of an optimal air-navigation and traffic-control system' (refer to Table 3-2). Subsequent lists have informally become known as Fitts Lists. Here the abilities and limitations of people and machines are compared for identifying function allocations. Functions are applied according to, for example, performance data, physical characteristics, information handling capabilities, computational abilities and perceptual requirements. These principles were first embodied in discussion papers by Craik (1947) where he recommends that we describe human functions in mathematical terms comparable with those in describing mechanical functions.

Many writers have criticised this approach, most notably Jordan (1963) who writes 'to the extent that man becomes comparable to a machine we do not really need him any more since he can be replaced by a machine'. The functions that cannot be automated for, say, technical, economic or reliability reasons are often leftover for people to perform. This reflects the work simplification approach to job design. In highly automated systems, this can result in people adopting the role of passive observer which makes it 'difficult...to develop mental models and strategies and to maintain an up-to-date knowledge of the state [of the system]' (Edwards and Lees, 1974). Such an approach has potentially negative implications for people where work becomes unchallenging and monotonous which can lead to poor performance (Clegg et al., 1989).

The design philosophy behind this approach reflects a 'leftover' allocation method and does not take into account the psychological needs of people (Bailey, 1982).

Table 3-2 The Original Fitts List

<p>Humans appear to surpass present-day machines with respect to the following:</p> <ol style="list-style-type: none"> 1) Ability to detect small amounts of visual or acoustic energy 2) Ability to perceive patterns of light or sound 3) Ability to improvise and use flexible procedures 4) Ability to store very large amounts of information for long period and to recall relevant facts at the appropriate time 5) Ability to reason inductively 6) Ability to exercise judgement
<p>Present-day machines appear to surpass humans with respect to the following:</p> <ol style="list-style-type: none"> 1) Ability to respond quickly to control signals and to apply great force smoothly and precisely 2) Ability to perform repetitive, routine tasks 3) Ability to store information briefly and then to erase it completely 4) Ability to reason deductively, including computational ability 5) Ability to handle highly complex operations, i.e. to do many different things at once

The lack of clear allocation criteria for functions that can be carried out to an equal extent by both people and machines often lead to short term solutions (Price, 1985; Mital et al., 1994). Although Price (1985) views comparative frameworks as valuable heuristic aids to design, Kantowitz and Sorkin (1987) note the absence of usable heuristics as well as difficulties in using the lists other than as a source of reference for the first steps in function allocation. Despite the criticisms, Fitts List are, however, very popular amongst practitioners because they can be applied to many environments and are preferred than having no guidance at all (Kantowitz and Sorkin, 1987).

Other more elaborate lists have been developed within the contexts of process control systems (Edwards and Lees, 1974; Edwards, 1979; Swain and Guttman, 1980; Sheridan, 1988), inspection systems (Mertes and Jenny, 1974; Bhatt and Sun, 1991; Hou, 1993), human-computer interaction (Whitfield, 1967; Barfield and Salvendy, 1984), human-machine-robotic systems (Meister and Rabideau, 1965; Nof et al., 1980; Swain, 1980; Kamali et al., 1982; Pulliam and Price, 1983; Ghosh and Helander, 1986; Price and Tabachnik, 1968; Mital et al., 1991; Genaidy and Gupta, 1992; Mital et al., 1994), process control (Edwards, 1979) and flexible manufacturing systems (Mital et al., 1991). Such lists which claim to specify the relative merits of people and machines are likely to become rapidly out of date as new technologies are introduced to manufacturing.

The original Fitts List has had little impact upon engineering because it was too general, it focused on separate rather than shared allocations, was qualitative and provided no guidelines or heuristics for establishing trade-offs between different allocation criteria. The frameworks also provide no consideration of the cumulative psychological effects of the allocations upon

people. In addition, comparative frameworks receive a great deal of criticism because they ignore important situational factors, encompassing social, economic, political, and psychological issues (Chapanis, 1965; Nickerson et al. 1981; Greenstein and Lam, 1985).

Although the underlying concepts of the comparative approach are viewed by many as being methodologically flawed (Jordan, 1963; Chapanis, 1965a; Corkindale, 1967; Greenstein et al., 1985; Reiger et al., 1982; Kantowitz and Sorkin, 1987; Clegg et al., 1989; Mital et al., 1994), the approach itself does not necessarily advocate a technocentric view of complex systems. For example, in the foreword of the 1951 report by Fitts, Viteles states that the report is written ‘...from the viewpoint of human engineering, which is concerned primarily with the formulation of plans governing the design of machines for efficient human use, and with the effective integration of men and machines...’. He advocates research into ‘problems on morale and motivation...; on the elimination of excessive fatigue and monotony, and on other human problems which arise in the work situation’. It is not the underlying philosophical objectives of the work which are deficient but rather the recommended framework for function allocation embodied in the Fitts List which resulted from his report. Fitts himself conceded that using the lists as the sole determinant for allocating functions was to lose sight of the basic nature of a system containing humans and machines. The use of the comparative approach may, however, promote the ‘leftover’ approach for function allocation.

3.5.2.1 Human-Robotic Systems

Robots are sharing manufacturing work environments with people at an ever increasing rate. They have proven their usefulness in many industrial environments, in particular the automobile industry (Nof et al., 1980). A significant range of performance differences exist between people and robots. Robots can rapidly perform, for example, painting and welding operations and can handle heavy and fragile parts. People on the other hand outperform robots in many assembly type operations as well as with more cognitive activities such as planning, creativity, sensory, predictive and improvement functions. Robots are, however, becoming more flexible, accurate and ‘intelligent’. Consequently, the decision of whether people or robots should undertake particular functions is becoming increasingly more complex and important.

An approach adopting static comparisons between robots and people, similar to the Fitts List approach, make it difficult to analyse their dynamic interaction. A job and skills analysis approach developed by Nof et al. (1980) ‘suffered from a lack of specificity’ and produced outputs which were difficult to translate into allocation decisions (Ghosh and Helander, 1986). The latter propose a ‘systems’ approach combining task analysis and comparative lists to focus specifically on assembly tasks. Kamali et al. (1982) propose a framework and methodology for function allocation between people, robots and automation. The methodology focuses attention onto the influence of automation and robots on people. The proposed allocation approach is (more or less) unique within the context of allocating functions in human-robotic

systems in that it makes a concerted effort to consider the psychological needs and well being of people.

The following tools are widely used for comparing the capabilities and performance characteristics of people and robots to facilitate the allocation of functions process: Robot Time and Motion (RTM) charts (Paul and Nof, 1979), ROBOT Maynard Operation Sequence Technique (ROBOT MOST) tool (Wygant, 1986; Wygant and Donaghey, 1987), Job and Skills Analysis (JSA) charts as well as Robot Man Charts (RMC; Nof et al., 1980). These methods facilitate a fine grained analysis of manufacturing human-robotic systems. All the approaches, in one form or another, detail the mechanical, sensory and computational components of people which facilitates a comparison with the characteristics of robots. Although many authors advocate the development of coherent jobs and the needs of people, specific details tend not to be elaborated on (except Kamali et al., 1982). In comparing the abilities of robots and people, the latter are reduced to mechanical components. In doing so, these methods fail to take an holistic perspective in view of the life of manufacturing and assembly systems within typically dynamic industrial environments.

In general it is recommended to allocate functions according to a number of criteria encompassing unit production costs, product quality, production timing, health and safety, ergonomic, reliability, design for manufacturability and improvement issues as well as considering the impact on the people in the system (Nof et al., 1980; Ghosh and Helander, 1986; Mital et al., 1994). The results from many of the methods are, however, difficult to interpret into function allocation decisions. In addition, methods depend greatly on information that may not be available during the early stages of system development and tend to consume large amounts of time and effort. Other more human-oriented approaches, based on job and skills analysis, have been developed for producing 'complete', meaningful jobs. These methods were applied to the Volvo plant at Uddevalla, Sweden (Ehn, 1988).

3.5.3 Complementary and Dynamic Allocation Methods

Complementary allocation of functions methods strongly advocate the socio-technical and human-centred view of man-machine systems. As with the comparative or Fitts Lists methods, the nature of complementary approaches are empirical (rather than analytical) allocation methods.

The complementary⁶ approach for allocating functions ignores concepts of comparability between people and machines. Although Whitfield (1967) views the difference between comparable and complementary function allocation as a purely semantic one, the importance

⁶ Other terms for the approach encompass 'synergistic relationship' (Hormann, 1971), 'synergistic approach' (Majchrzak, 1988), 'man-computer symbiosis' (Licklider, 1960), 'symbiotic man-robot relation' (Engelberger, 1974) and the 'SIMBIOSIS-model' (Parsons and Kearsley, 1982). In addition, Salvendy (1988) and Corbett (1990) refer to 'hybrid automation'.

of the approach has been recognised for about thirty years (Price, 1968; Chapanis, 1965; Jordan, 1963). It builds on the notion that people and machines have complementary abilities in performing individual functions, and that their combined abilities should be utilised to achieve optimal system control, maintenance and operation.

An underlying message that accompanies all Fitts Lists is the notion that people 'are flexible but cannot be depended upon to perform in a consistent manner whereas machines can be depended upon to perform consistently but they have no flexibility whatsoever' (Jordan, 1963). Rather than thinking about comparing people and machines for determining which is better for getting a task done, the complementary approach moves the design process towards viewing machines as tools for people to use rather than as elements of a system to which people are comparable if not subordinate. Within this framework, systems designers are forced to think about a task that can be done by men and machines.

Complementary allocation advocates the close integration of functions and job design criteria. The allocation of functions is evaluated against the foreseeable nature of the job and alongside physical, technological, legal, political, organisational and social constraints. The approach is essential when allocating responsibilities in complex systems (Jordan, 1963; Price, 1985). Grote (1994) extends the concept to encompass socio-technical analysis and criteria to facilitate the allocation process. For legal reasons, machines cannot be given responsibility to carry out tasks. People must be assigned clear responsibilities to ensure individual tasks are completed satisfactorily for legal, task criticality and reliability reasons. Stakeholder participation in the complementary allocation process is widely advocated and is central to a project known as KOMPASS (in English, Complementary Analysis and Design of Production Tasks in socio-technical systems; Weik, 1993; Grote, 1994; Weik et al., 1995). The project focuses on developing guidelines for the complementary design of batch production systems. Much contemporary research has focused on complementary allocation methods falling into two broad categories:

In small scale work environments where the emphasis for contemporary allocation is in 'humanising' work in a way more intrinsically motivating for the people on the shopfloor. This includes computer integrated manufacturing and human-computer application domains. In the former case, an approach for complementary allocation of functions was proposed as part of Project ESPRIT 534 (Ravden et al., 1987; Clegg et al., 1993). The tool ensures that human factors are considered throughout the design process by 'looking ahead' at the characteristics and the potential impact of the work on people and machines. In the latter case, Greenstein and Lam (1985) propose an allocation strategy incorporating dynamic allocation in the overall function allocation process. The approach shares many of the characteristics of more contemporary function allocation strategies including iteration and a wide range of social and operational related criteria.

Large scale environments including aerospace (Price and Tabachnik, 1968) and air traffic control (Debernard et al., 1992) systems emphasising flexibility as well as adaptive and dynamic allocation.

A number of generic complementary methods have been developed. For example, Shoval et al. (1993) propose an adaptive method focusing in parallel optimal task allocation and information transfer; Chapanis (1965a) proposes a general approach for function allocation which emphasises many of the characteristics of more contemporary methods including the effects of cumulative workload, trade-offs, task criticality, responsibility, reliability as well as social, political and economic criteria (cf. Clegg et al., 1989); and finally, Price (1985) proposes an allocation of functions strategy for man-machine systems. The method takes a hypothetical-deductive approach (cf. Price and Tabachnik, 1968) and uses MABA-MABA lists as heuristic aids. This method although systematic lacks a comprehensive range of allocation criteria. A range of allocation methods are represented graphically in Appendix F by Chapanis, 1965; Price, 1968; Gosh and Helander, 1983; Greenstein and Lam, 1985; Price, 1985; Ravden et al., 1987; Clegg et al., 1989; Clegg et al., 1993; Hin, Lou and Drury, 1993 and Clegg, 1994.

An important extension of complementary methods encompass the concept of dynamic function allocation between people and machines according to which party has resources available. Dynamic allocation is particularly applicable in highly computerised environments where people and machines are both capable of carrying out functions. It allows people and machines to change during system operation the extent to which they are involved in carrying out a particular function. Little work, however, has been undertaken in studying the dynamic allocation of functions between people. The responsibility for decision making and for carrying out particular functions is dependant on wide organisational choice and may be shared between individuals or within groups. In manufacturing systems, function allocation between people (for example, operators and supervisors) is performed informally based on the state of the shopfloor, industrial relations, experience, skill levels and established working practices. Work needs to be done to assess whether formal methods for dynamic allocation between people are beneficial to such low-risk environments.

A dynamic allocation approach to design, therefore, fosters situation specific rather than situation independent systems. Allocations are allowed to change during system operation. This approach develops more robust and fault-tolerant systems, by designing for a redundancy of functions rather than a redundancy of parts, and fosters flexibility and makes better use of system resources. There is widespread consensus that human-computer relationships should be complementary (Rouse, 1975; Millot and Kamoun, 1988). Dynamic allocation has encouraged a shift from correctly anticipating user needs to evaluating system behaviour and the performance of people (Kantowitz and Sorkin, 1987)⁷.

⁷ The concept of dynamic allocation is multi-faceted and as such is treated differently in the literature. For example, Goom (1994) describes a dynamic allocation method where machines are allocated functions by default but people are allowed to override allocations where necessary. Gramopadhye et al. (1992) refer to adaptive allocation to describe situations of high workload where machines are used only when people need assistance. Greenstein and Lam (1985) refer to adaptive allocation to describe a mixed-initiated approach where function (re)allocation is initiated by either people or machine.

Complementarity may be realised in many forms encompassing the dynamic allocation of responsibilities (Licklider, 1960; Jordan, 1963; Chu and Rouse, 1979; Rouse, 1977, 1979, 1981; Shi-quan, 1985; Greenstein et al., 1986) and the design of computer interfaces to foster adaptive aiding (Steeb et al., 1979; Greenstein and Lam, 1985; Millot and Willaeyts, 1985; Greenstein et al., 1986; Morris and Rouse, 1988; Rencken and Durrant-Whyte, 1993). Decisions relating to the conditions underlying machine initiated allocations, however, still need to be established based on models of human behaviour.

Dynamic allocation of function methods help minimise variability in workload levels by eliminating situations of cognitive and physical over and under-loading. It also allows people to develop their knowledge and overall understanding of system states (Greenstein and Lam, 1985). In general, the nature of these forms of systems, therefore, reflects an holistic (open systems) approach for absorbing uncertainties from the non-deterministic social, technological, commercial and organisational system components.

3.6 Discussion and Summary

The following discussion summarises the current status of job design theory and methods. The discussion embraces traditional and more recent forms of job design as well as the fundamental job design issue of allocating functions between people and machines. Finally, an outline of research requirements is presented.

3.6.1 Summary of Current Status

Work simplification has been the dominant job design paradigm for the majority of this century (Braverman, 1974; Littler, 1985).

Taylor formalised this approach through the concept of scientific management (Taylor, 1947). Scientific management promotes the demarcation between the management activities of planning and control and the 'craft' activities of workers. It fosters a form of work organisation where management are responsible for: designing jobs and for developing more efficient work methods through training and control as well as regulating work methods and determining how and when tasks needed to be done. Underlying these concepts are three important dichotomies: the separation of means and ends, the separation of theory and practice and the separation of doing and knowing (Gill, 1990).

Early research in reaction to perceived deficiencies in work simplification focused upon 'horizontal' division of labour issues whilst 'vertical' issues embracing work-group autonomy and co-operative work structures were rarely considered (Wall and Martin, 1987). Contemporary work, however, has sought to embrace these 'vertical' issues by developing methods and theory applicable to current competitive and business requirements as well as recent changes in technology. They embrace behavioural and socio-technical system job design

methods which aim to support the use of advanced manufacturing technologies as well as more flexible and 'democratic' forms of work organisation and control. The following discussion summarises the current state of these job design methods.

● Behavioural Methods

- Activation Theory

The theory has not received widespread application. The theory provides little guidance about how to overcome the following job (re)design problems: people have different optimal levels of activation, people tend to adapt quickly to changes in stimulation due to familiarity with an environment and the ideal level of activation for optimal task effectiveness varies between different kinds of work.

The number of conceptual and measurement problems make application of the approach difficult and offers little guidance about how jobs should be structured to elicit positive working behaviour. The theory may, however, be used as a valuable heuristic for identifying characteristics of jobs that have extreme sources of under or over activation.

- Motivation Theories

Basic to any explanation of why people behave in a particular way within a working environment is a theory of motivation. In general, motivation theories describe models of behaviour in terms of the need to satisfy a multitude of psychological, social and physical needs through some form of incentive to direct the energies of people towards fulfilling system objectives.

Incentives may be either extrinsic or intrinsic. Extrinsic rewards form part of the working environment, are externally mediated and are awarded by others. They can best be thought of satisfying the 'lower order' or basic needs of people. Intrinsic rewards are internally mediated and arise from carrying out a job itself. They may be thought of as satisfying the 'higher order' needs of people such as self-esteem, recognition, achievement, responsibility and self-actualisation.

Motivation theories seek to develop models of intrinsically motivating work because of their potential to sustain levels of motivation through fundamental changes in the beliefs and behaviours of people. This concept underpins recent job design methods which seek to design jobs that are, in themselves, sources of intrinsic motivation.

The complexity of people and organisational environments as well as the requirement for political and social skills to implement theory in an overt, attractive form can make model application difficult to achieve in practice.

- Job Characteristics Theory

The job characteristics approach focuses on objective characteristics of jobs and build into them elements that create conditions for high work motivation, satisfaction and

performance. Job characteristics are often specified at low levels of abstraction and so provide relatively tangible criteria for designing jobs.

The model has become a major influence in job design research because of the identification of a clear set of features and the provision of a diagnostic tool (the Job Diagnostic Survey, JDS) to measure these features (Hackman and Oldham, 1980). The theory does not directly deal with negative features of a job, as does activation theory, and focuses on people working alone, rather than in groups. Job characteristics theory is fundamentally, therefore, a theory of individual motivation.

● **Socio-Technical Systems Theory**

Criticisms have alluded to the need to develop methods of job design to embrace recent developments in manufacturing technology and forms of work organisation and control (e.g. cellular manufacturing, just-in-time and total quality management). These manufacturing technologies require an awareness of the external context in addition to forms of job design (cf. open systems theory).

The socio-technical approach to job design moves the focus away from the individual to embrace work-groups and the external manufacturing context with a view to cope with and absorb external fluctuations in the system's environment. In theory, this is achieved by co-optimising the social and technological elements of a system.

The socio-technical approach has, however, several conceptual weaknesses. Although systems are viewed as comprising social and technological sub-systems in some form of equilibrium, empirically based research has almost entirely focused on the social dimension (Pasmore et al., 1983). Mumford (1972) criticises much socio-technical research in that it largely does 'not address directly the question of the design of technology or consider the possibility of technical options'.

Although the approach may have a number of conceptual limitations, Ehn (1988) notes that 'many of the tools that have been developed are extremely useful in analysing work organisation and production technology. [The] job required and group autonomy criteria are...a challenge to design for democracy at work'.

The most basic outcome of these job design methods is the allocation of functions between people and machines. Function allocation methods and theories deal with more fundamental, low-level issues than the behavioural and socio-technical job design methods. It is, therefore, a separate but complementary field of job design and is recognised as a crucial stage in determining the success or failure of a system (Bamford, 1959; Brennan, 1984; Mital et al., 1994). Chapanis (1965a) acknowledges its importance by stating 'the allocation of functions influence all of the later design thinking about the system'. Allocation of functions is a fundamental concept within the classical division of labour issue (Chapanis, 1965a). The allocation of functions, whether dynamically, temporarily or statically, can affect the operation of a system and the well-being of the people working in the system.

Function allocation decisions are made either unconsciously (as is often the case) or as part of an allocation method with consideration of a number of criteria. These decisions help to establish a boundary for systems development through job design and analysis, personnel selection, training requirements and man-machine interfaces. The following discussion summarises the current state of function allocation methods and theory.

Fitts Lists are still the most commonly used method. This is despite their characteristics of comparing people and machines, lack of explicit allocation criteria for functions that can be carried out to an equal extent by both people and machines and lack of trade-off and cumulative workload considerations (Price, 1985; Mital et al., 1994). Their prevalence may be due to their apparent intuitiveness and ease of use. Their application tends to reflect 'traditional' system design methods popular in the West, where interdisciplinary participation in design and implementation is often lacking.

There have, however, been several developments in dynamic allocation of functions methods which have, unfortunately, tended to occur in the literature rather than in practice. This work has focused specifically on human-computer interaction. With the exception of Stammers and Hallam (1985), methods for dynamically allocating functions and responsibilities have not been addressed in detail.

Contemporary function allocation methods have tended to move beyond comparing the abilities of people and machines and views them instead as complementary elements of a system. In this case, the allocation of functions is treated as part of a whole design process (Clegg et al., 1989; Ip et al., 1990; Weik, 1994; Grote, 1994) and machines are viewed as tools for optimally utilising the skills of people (cf. human-centred manufacturing methods).

Recent advances in complementary allocation methods have tended to build upon and fine tune previous sets of function allocation criteria. Chapanis in the 1960s recommended the consideration of complementarity, trade-offs and task criticality issues. Since then, few significant advances have been made. The majority of methods require a degree of previous training for selecting appropriate allocation methods, alternative allocation scenarios and for determining trade-offs.

In human-centred manufacturing systems design, function allocation has embraced complementary methods. They seek to embrace more 'real world' (i.e. system dependent) issues by integrating more closely the criteria for allocating functions with the characteristics of the manufacturing environment itself.

These function allocation methods have evolved into a process of detailing people's roles, responsibilities, tasks and work methods - rather than merely allocating basic functions between people and machines. Complementary allocation methods have, therefore, blurred the scope and purpose of the function allocation process. The trend in complementary function allocation methods is to integrate function allocation decisions with higher level job design and socio-technical criteria. This tends to make more unclear the allocation process by virtue of

the vast number of environmental factors by which allocation decisions and trade-offs are made. Consequently, function allocation becomes less identifiable as a separate design stage in job design.

In addition, many system methods, group technology for example, do not address allocation of functions explicitly (Kidd, 1992; Fuld, 1994). If function allocation issues are considered then often it is only after major design and procurement decisions have been made. In addition, consciously allocating functions between people and machines requires a rigid and very formal design strategy. Chapanis (1965) recommends that function allocation commences with a complete specification and analysis of system functions. This is, however, unrealistic in practice because of engineering uncertainties as well as the creative and iterative nature of job and system design. Such processes, therefore, often do not permit the explicit consideration of function allocation issues and instead just happens as part of the overall design process.

3.6.2 Outline of Research Requirements

Cellular manufacturing has been recognised as an essential structural component of world class manufacturing and is a widely adopted form of management organisation and control. The original intention for using cells was to rationalise material flow, promote line simplification and control material handling.

Cells are widely recognised to foster improvements in process responsiveness and flexibilities and product quality through a focus on the methods of production and more co-operative work structures. Many cells are run by a small teams of people. Traditional manufacturing system designs consider cell design primarily in terms of methods for grouping parts and machines. Often the social and motivational components of job design were not formally considered.

The review of job design methods and theories identifies a more 'humanistic' trend towards the design of more intrinsically motivating work to fulfil system objectives. There is also a wider acceptance of the need to extend the design view to embrace not only the individual but also work-groups and whole systems. These issues are embraced by human-centred (and socio-technical) design methods which adopt an open systems perspective to consider not only the technical infrastructures but also the influence of the social context and system environment (i.e. organisational boundary aspects).

The development and practice of job design in cells is an area with little formal process. This work attempts to provide a model to identify the factors and their inter-relationships relevant for human-centred job (re)design in cells. The model adopts an open systems perspective and is comprised of three levels to reflect the close relationship between contemporary function allocation, behavioural and socio-technical job design issues and methods.

The model may be re-used to build-up a series of comparable snap-shots to formally record changes in job design and to facilitate learning about the process and benefits of change.

Consequently, the model can act as a foundation for continuous job design and also as a focus for discussion and debate about the jobs that people do in the Cells: how they relate to policy and how they are obtained.

CHAPTER FOUR

MODEL DEVELOPMENT

The purpose of the chapter is to describe the development of the job design model and the field research methodology used to carry out data collection to validate the model.

To facilitate this, firstly, the systems approach underlying the design of the model and research methodology is outlined. Secondly, an outline of the research methodology is described along with a discussion of the company taking part in the research. Four manufacturing cell case studies and their selection process are described. This provides a context for the succeeding sections on data collection and model development.

Thirdly, the pilot study and main research period are described in more detail. The 'features' emerging from these periods are described and the method for describing their inter-relationships is outlined. Finally, the process of model validation and possible applications for using the model are discussed.

4.1 Model Structure

A systems approach was adopted for conducting the research and for model development. This section describes the concept of a system in general terms and demonstrates how the proposed model conforms with this perspective.

A system is a concept for structuring our thinking about problem situations (Flood and Jackson, 1991; refer to Figure 4-1). It's development arose to explain biological phenomena and as a response to the failure of mechanistic, reductionist thinking.

A system is a richly interactive group of elements and relationships within a boundary with the environment. Inside the system, inputs are transformed into outputs. Systems are characterised by feedback and regulatory loops. The behaviour of an element feeds back through relationships, and maybe via other elements, so the elements in the system are controlled. Elements may be given attributes such as size, colour or number. Relationships may be given attributes such as intensity, flow or strength.

An open system has a boundary which is permeable to inputs and outputs. For example, organisms are open systems with energy and materials entering and leaving them. The cellular manufacturing environments studied during the research are viewed as open systems.

In systems thinking, open systems have emergent properties peculiar to themselves and are meaningless to the individual parts that make up that system: the whole may be viewed as *greater* than the sum of its parts. In mechanistic thinking, a system is *equal* to the sum of the parts.

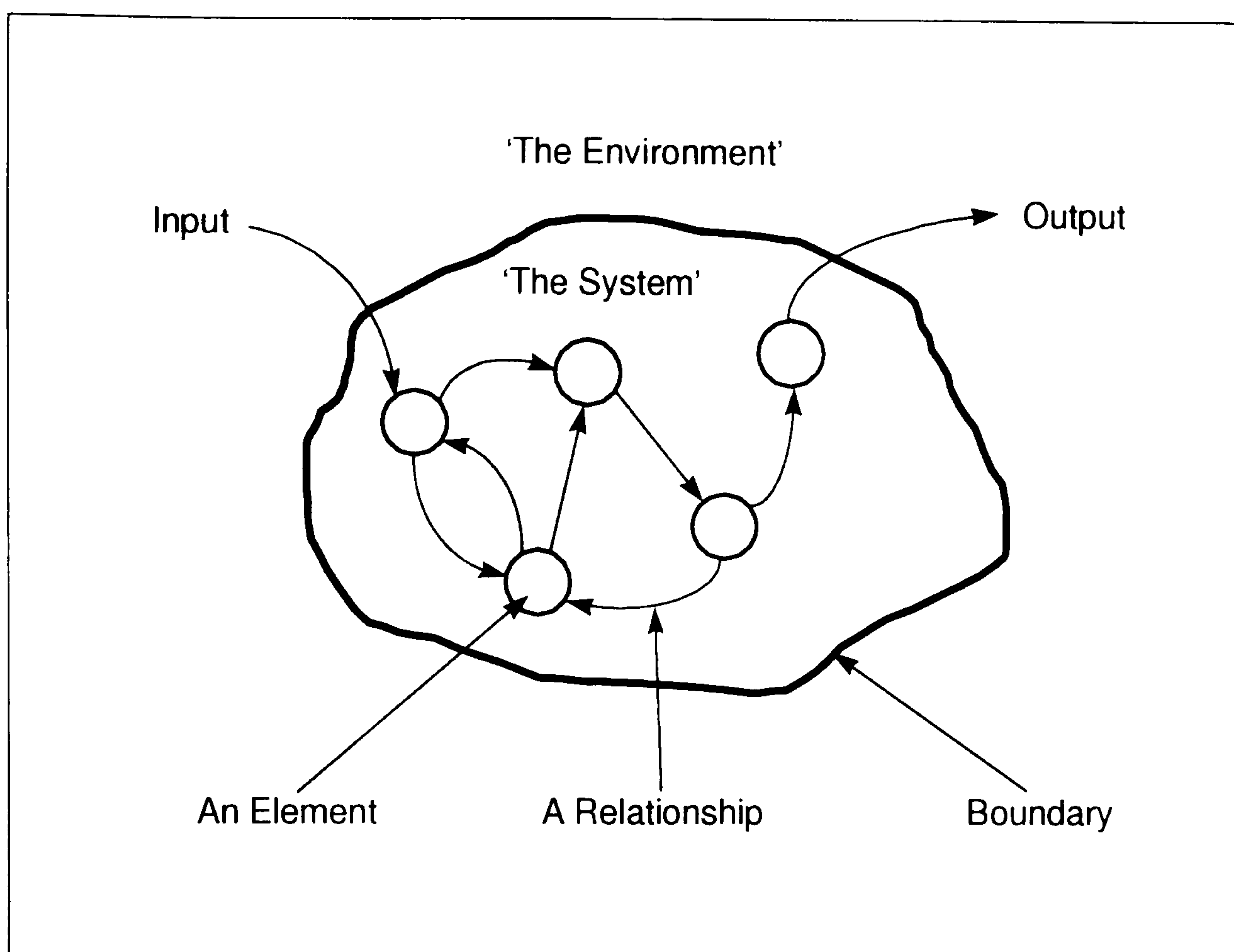


Figure 4-1 General Systems Diagram

Homeostasis is the ability of a system to dynamically maintain itself (i.e. self-regulate) by transforming in a changing environment. Open systems exhibit control in homeostasis by communicating information from the environment and between elements. It is the ability to achieve homeostasis that ensures the viability of a manufacturing cell. This is achieved in these environments through the combined abilities of people and machines to cope with and absorb sources of variance.

The cellular manufacturing environments were viewed as open systems (refer to Figure 4-2):

- The 'environment' embraces issues outside the boundary of a manufacturing system. These involve company practices, manufacturing methods, management structures, suppliers and customers.
- The 'system' encompasses the physical manufacturing cell on the shopfloor as well as work organisation issues.
- The 'elements' describe the individual machines and people in the system. The 'elements' themselves exist and interact at many levels.

To embrace the open system and human-centred approaches to job design, it was proposed that three levels of analysis were identified in the model (adapted from Ulich, 1994; Weik, in press; Grote et al, in press). The multi-level nature of the 'system' is represented by the

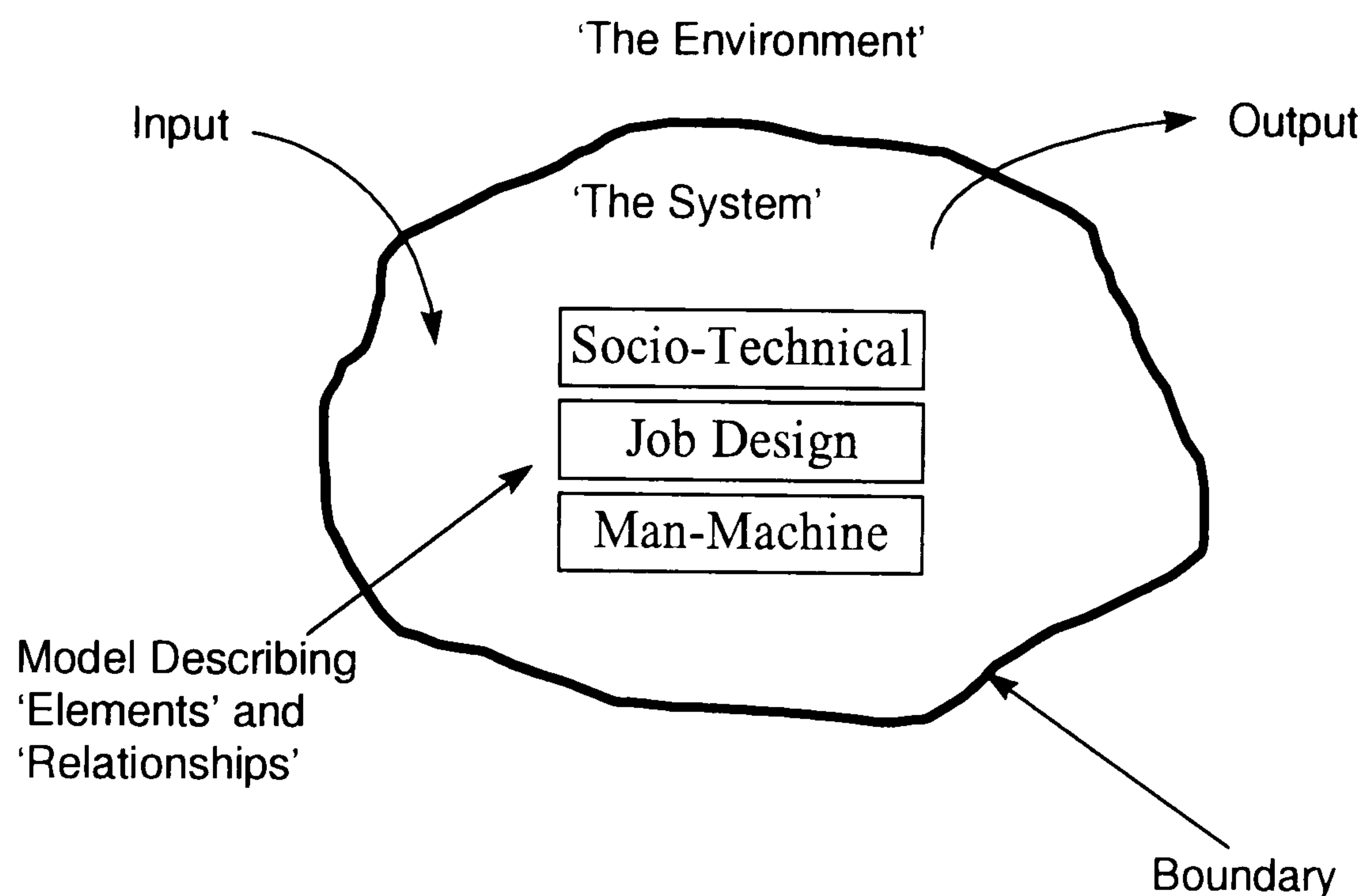


Figure 4-2 Combining the Research Methodology and Open Systems Theory

proposed model and is used to structure the research methodology. Issues described at these levels are viewed as not independent and are interrelated at each level and between levels:

- 1) *Man-Machine*. This level is concerned with issues affecting the allocation of functions between 'elements'. In general, features describing these issues were selected from complementary function allocation methods and theories.
- 2) *Job Design*. This level is concerned with social organisation and work structure factors affecting the 'relationships' between 'elements'. The selection of features describing these issues was influenced by behavioural models of job design embracing the job characteristics model and models of motivation.
- 3) *Socio-Technical*. This level is concerned with issues affecting work organisation methods to cope with and absorb 'environment' and 'system' variances to achieve homeostasis. Features describing these issues were selected from socio-technical systems theory and practice. A socio-technical perspective was adopted for the following reasons:
 - a) Because of the 'complex' and 'unitary' characteristics of cellular environments (Flood and Jackson, 1991). These systems comprise of 'many elements in close inter-relationship, exhibit probabilistic behaviour which is difficult to predict, are open to the environment and include purposeful parts.' An organic metaphor or 'open systems' view usefully describes these systems where the human elements have needs to be met should the system be effective and flourish.

This perspective is compatible with and characteristic of cellular manufacturing environments. The system breaks-down when the views of the human elements are neglected, conflict and coercion are ignored and when it is reactive (purposive) rather than proactive (purposeful) to the environment.

- b) Contemporary work on allocation of functions, in particular carried out by Susman (1976), Clegg (1989), Martin et al (1990), Ulich (1990; 1994), Weik (1993), Grote (1994), Weik et al (1995; in press) and Grote (in press) extend the concept of allocation of functions to encompass systems design from the perspective of both the technological and social environments.

From this perspective, function allocation is an intrinsic component of the 'whole' job design process. This approach adopts a human-centred and open system perspective by moving the focus of job design beyond that of the individual and the work-group to embrace, in system terms, the 'system' or Cell as the unit of analysis (Clegg, 1984; Alder, 1986; Cooley, 1987; Blumberg, 1988; Corbett, 1989; Martin, 1990; Schmid et al, 1992; Kidd, 1992a,c; Parker et al, 1995).

The field research methodology was designed to select and finalise key features to describe issues affecting job design at each level of analysis. These three levels help structure the research methodology and the design of the data collection methods. The research sought to describe quantitatively and qualitatively features at each level for different cellular environments and describe the relationships between features and levels to facilitate model development and validation.

In system terms, the model describes the impact of factors in the manufacturing 'environment' upon the 'elements' and their 'relationships'. Four manufacturing cells are studied in the field research. The data collected from the research describing this impact is structured by the model. The following section provides an overview of the research methodology to achieve the above objectives.

4.2 Overview of Research Methodology

The adopted field research methodology involved a two week pilot study and a main research period of fifteen months. The longitudinal study approach facilitated the collection of a full and representative set of data by interview and observation and helped foster a detailed understanding of cell design, operation and management issues.

The pilot study had two key objectives. Firstly, from a methodological viewpoint, to help identify the features that will comprise the model for study during the main research period, to select a range of Cells for analysis and identify suitable research methods for carrying out the study. Four Cells were selected for analysis. A multiple-case study approach was adopted to

suit the ‘manufacturing island’ characteristic of the Cells and reflects the exploratory nature of the research.

Secondly, from a practical viewpoint, the pilot study provided a period of orientation and acclimatisation to the people, procedures, politics and the physical environment of the company.

Data gathering collection methods were designed from pilot findings and finalised during the initial stages of the main research period. Appendix A complements and supports the specific choice of methods through a review of the methodological and ‘scientific’ issues relating to research strategy and methods in general.

The objectives of the main research period were to finalise the design of the model and data collection methods, collect data to populate the model for the four case studies and validate the model relationships from qualitative data.

A range of features were short-listed from pilot study findings and from a review of exemplary work in the fields of function allocation, job design, socio-technical systems and human-centred systems theory. The features were finalised after the initial analysis of the first case study. All research participants were involved with validating the individual features for each case study.

The inter-relationships between the features were initially proposed from an analysis of the research findings and later enhanced and approved by the participants. This further validation process helped confirm the participants’ understanding of the specific features, the model in general and the main factors influencing the state of job design in the Cells.

The field research was carried out in a British manufacturing company. The company was selected because of its successful use of cellular manufacturing methods, the wide range of machine and assembly cells available for study and the high levels of experience and enthusiasm for change. In total, two divisional managers, nine works managers, two chief manufacturing engineers, five supervisors and ten setters and operators played a full part in the research. The company is described below.

4.3 The Company

The company in which the investigations were undertaken manufactures braking system components for heavy goods vehicles and employs 800 people. It is organised into four autonomous Divisions. In the past, the company has seen an increase in the demand for its products because of the increase in heavy goods traffic. In the late 1980s, however, intense competition saturated the market and was found that customers were buying fewer products and were making them last longer. As a consequence of this and from the constraint of having a static product range, the company found itself needing to compete for orders on the bases of

product quality, lead time and delivery performance. To remain competitive, the company adopted a cellular manufacturing approach with the goal of becoming world leaders in their industry.

The first manufacturing cell was implemented in 1990 as one of the first steps in changing to a just-in-time manufacturing approach. There are currently many machining and assembly cells of different ages and complexity throughout the company. The company experienced many benefits from adopting cellular manufacturing concepts. Many of these cells have undergone further evolution as a result of the changing business environment.

Over the past five years change has been a normal and expected aspect of life in the company. Recently, the company began a focus on step change, as opposed to incremental change, to facilitate a more rapid move towards world class performance and to build their business by being more flexible and responsive. Changes in shopfloor manufacturing techniques have been supported by changes in organisational and social structures. The company places great emphasis on tackling the 'softer' issues which encompass organisational restructuring, modifications in management practices and the replacement of piece-work to a flat-rate pay structure.

The importance of skills development and education is seen as essential for maintaining long term competitiveness. Cell members are encouraged to develop their craft, teamworking and inter-personal skills through high-profile, company-wide workshops and training programmes. In addition, long term courses improve their awareness and understanding of just-in-time, total quality and continuous improvement concepts. These programmes are regarded as continuous rather than one-off events and emphasise the importance of quality, lead-time and set-up reduction, a customer focus and the elimination of all sources of waste.

The company did not consciously allocate functions in the design of their manufacturing cells. The transition from a functional layout to a cellular approach was primarily constrained by financial, logistical and technological factors. All cells were effectively designed, therefore, on hard engineering principles. The allocation of functions between people 'just happened' as a consequence of these as well as other organisational changes.

The company considers the engineering issues of cell design and operation to have been largely overcome and have expressed a need for furthering their understanding of the social problems which, until now, have not been fully addressed. It is believed that understanding the 'softer' aspects of cell design and operation will help to minimise the risks associated with further cell redesigns and implementations.

4.4 Pilot Study

A two week pilot study was carried out during November 1993. Between February and November research objectives, requirements and time scales were discussed. The pilot study

was characteristic of a 'pilot test' as described by Yin (page 165, 1989) where the research is largely exploratory. It was used to define the content and type of data to be collected and identify appropriate collection procedures and protocols to be followed in the main research period.

The pilot study was conducted within a very broad framework as befits a preliminary exploratory study and reflects a structured investigative approach where the findings from the study were genuinely uncertain.

The framework is described by questionnaires and semi-structured interviews which were based on the following aspects of manufacturing cell operation and design: the skill levels of the cell members, the age of the cells, cell loading, size of part family, number and types of machine and cycle times. These aspects provided a basis for initial cell selection.

The pilot study was comprised of four phases. Each phase is described in detail in Appendix C. Due to the unpredictable and disruptive nature of the shopfloor environment, they often varied in length and were frequently carried out in parallel. The four phases are:

A) Orientation

Objectives were:

- a) Identify and detail the company's manufacturing strategy, working and shift patterns, mechanisms for communication as well as training and education practices.
- b) Identify procedures for gaining access to the shopfloor and the cell members.
- c) Identify document data sources - cell design details, production rates, machine utilisation figures, minutes from cell meetings.
- d) Learn how to get around the company, identify restricted areas and where all the departments are located.

B) Cell selection

Objective was:

Identify and negotiate access to a number of manufacturing cells based on a predefined sampling strategy.

C) Initial data collection

Objectives were:

- a) Determine suitable locations for interviews away from the shopfloor.
- b) Become familiar with the abilities and demographics of the people working in the Cells.
- c) Develop a basic understanding of 'what goes on in the cells'.

D) Follow-up interviews

Objectives were:

- a) Build upon the previous data collection activities and obtain opinion and factual details on issues relating to the original cell selection criteria.
- b) Build upon and complement data already gathered from earlier activities to help with the identification of features for analysis during the main research period.

4.4.1 Cell Selection

The objective of the sampling strategy was to gain access to a representative and wide range of cases to obtain a rich set of results and a degree of analytical generalisability. The primary features influencing cell selection were the age of the cells, the skill levels of the cell members and the number and types of machine. Cell selection was carried out to select a range of cells that were broadly dissimilar in these respects and within the following practical constraints:

- a) The amount of disruption experienced by a cell due to a cell redesign, machine breakdowns and industrial disputes.
- b) Inconvenience to cell members and supervisors.
- c) The personal perspectives of the supervisors where they thought a group of people would be particularly responsive and enthusiastic to take part in the research.

Because the supervisors were responsible for cell production and had an intimate knowledge of the shopfloor, the supervisors identified a range of cells from these criteria. In addition, all supervisors expressed interest in the work which matched their efforts in selecting cells as close as possible to the needs of the research. Individual cells were selected through dialogue with the supervisors. This whole process reflected a purposive and heterogeneous sampling strategy. The former relies on the judgement of the researcher as to typicality and interest and the latter involves a deliberate attempt to select cases exhibiting widely varying characteristics.

In total, four Cells were selected, two each from different divisions of the company. During the pilot study, three cells were selected. Two Cells in Division V were selected using the sampling strategy described above. The Cells exhibited the most favourable characteristics amongst those cells 'available' at the time and were typical of the cell population in the company. In this report, these are denoted as Cells C and D. In Division C the above sampling processes was used for Cell A. Cell B was chosen at the beginning of the main research period.

Table 4-1 outlines key features of the four Cells. Layouts of the four Cells are shown in Figure 4-3. For all Cells, the function allocation process was a 'one-off' implicit allocation. A policy of adopting a human-centred approach to job design was implemented whenever possible. In each Division, the Cells share the same supervisors. All production, set-up and changeover tasks are predefined and are clearly displayed in the Cells. The cell members visually and physically inspect 100% of work in all Cells.

Cells A and B are both three years old and well established. The cell members are highly skilled in both and are responsible for all aspects of production, part quality and the state of the Cell. Cell A manufactures only one part with two variations for an international customer. The cell members fully manufacture the parts and box them for shipping. Cell B manufactures two parts with four variations each for a downstream assembly cell on the shopfloor.

In Cell A, the Primary Machine is the critical machine, it has a cycle time of about a minute and performs the majority of cutting operations. The Cell can operate with either one or two cell members. Intra-cell job rotation is determined by the cell members.

The four mills in Cell B are critical for production and line balancing requirements. As with Cell A, it can operate with either one or two cell members. When two people are working in the Cell, the Cell is divided into two sub-cells. Sub-cell job rotation is determined by the cell members. The cell members in Cells C and D are generally less skilled than in Cells A and B. The customers for both Cells are assembly cells in a nearby assembly shop. Interaction by the cell members with these cells is small. During the research period, however, an assembly cell was relocated next to Cell D to improve material flow and process visibility.

Table 4-1 Key Features of Cells A to D

Cell Feature	Cell A	Cell B	Cell C	Cell D
Age	3 years	3 years	14 months	2 years
Number and Types of Machines	Primary Machine (multi-functional), washer, drill, deburrer, surface measurement equipment	3 mills, NC Mill, 2 washers, chamfer machine, vibro, gauge station, bolt rig	2 Fanuc NCs, Takisawa NC lathe, de-burring booth, Pre-Com gauge station	2 Fanuc NCs, 2 Takisawa NC lathe, washer, de-burring booth, Pre-Com gauge station
Times for First Offs	6 minutes	10 minutes	3 minutes	3 minutes
Number of People	One or two people. Job rotation between six people on day and night shifts	One or two people. Job rotation between six people on day and night shifts	One person. Job rotation between four people fortnightly and on day and night shifts	One or two people. Job rotation between four people fortnightly and on day and night shifts
Size of Part Family	One part with two variations	Two parts with four variations	One part with four variations	Two parts with four variations
Cell Loading	High and constant Cell in arrears	High and constant Cell in arrears	High and constant	High and fluctuating
Skill Levels	Highly skilled. Half have completed apprenticeships	Highly skilled. Half have completed apprenticeships	Machine operators	Machine operator & setter-operators

This was, however, unsuccessful for cleanliness and cultural reasons. The machine and assembly shop working cultures were found to be incompatible.

Cell C is relatively young and not well established. Because of the tight line balancing requirements, the cell members need to work much harder than in other cells in Division V. The Fanucs need to be operated in parallel to ensure that enough work is produced so the lathe is kept running.

Cell D was developed as a cell for manufacturing overspill and late work from other cells. It has evolved over the past two years and has taken many forms. Recently all machines, tooling

and jigs were dedicated to manufacture a family of parts. Line balancing in the Cell is not tight. Under ‘normal’ operating conditions, only one cell member is required to work in the Cell. When additional output is needed, two cell members are typically required to jointly operate all machines. During periods of heavy loading, however, the Cell is still used for its original fire-fighting duties.

The four Cells are typical of the size and manning characteristics of the cells studied in the US cellular manufacturing study (Wemmerlöv and Hyer, 1989; refer to Section 2.1.1.2). All Cells reflect the 87% of companies who’s cell members can ‘perform a variety of tasks and move between different workstations’. Only Cells A and B, however, reflect the 39% of companies who claimed their cell members could move between different cells. The system design approach adopted by The Company, involving full participation of all stakeholders, concurs with the recommendations of this as well as the Ingersoll study.

4.4.2 Summary of Pilot Study

The nature of the pilot study was exploratory and facilitated the selection of features for developing the model, the design of the research methods for use during the main research period and the development of a sampling strategy for data collection. Four Cells differing in respect of their age, the skill levels of the cell members and the number and types of machine were selected for analysis.

The two formal research methods used in the pilot study were semi-structured interviews and

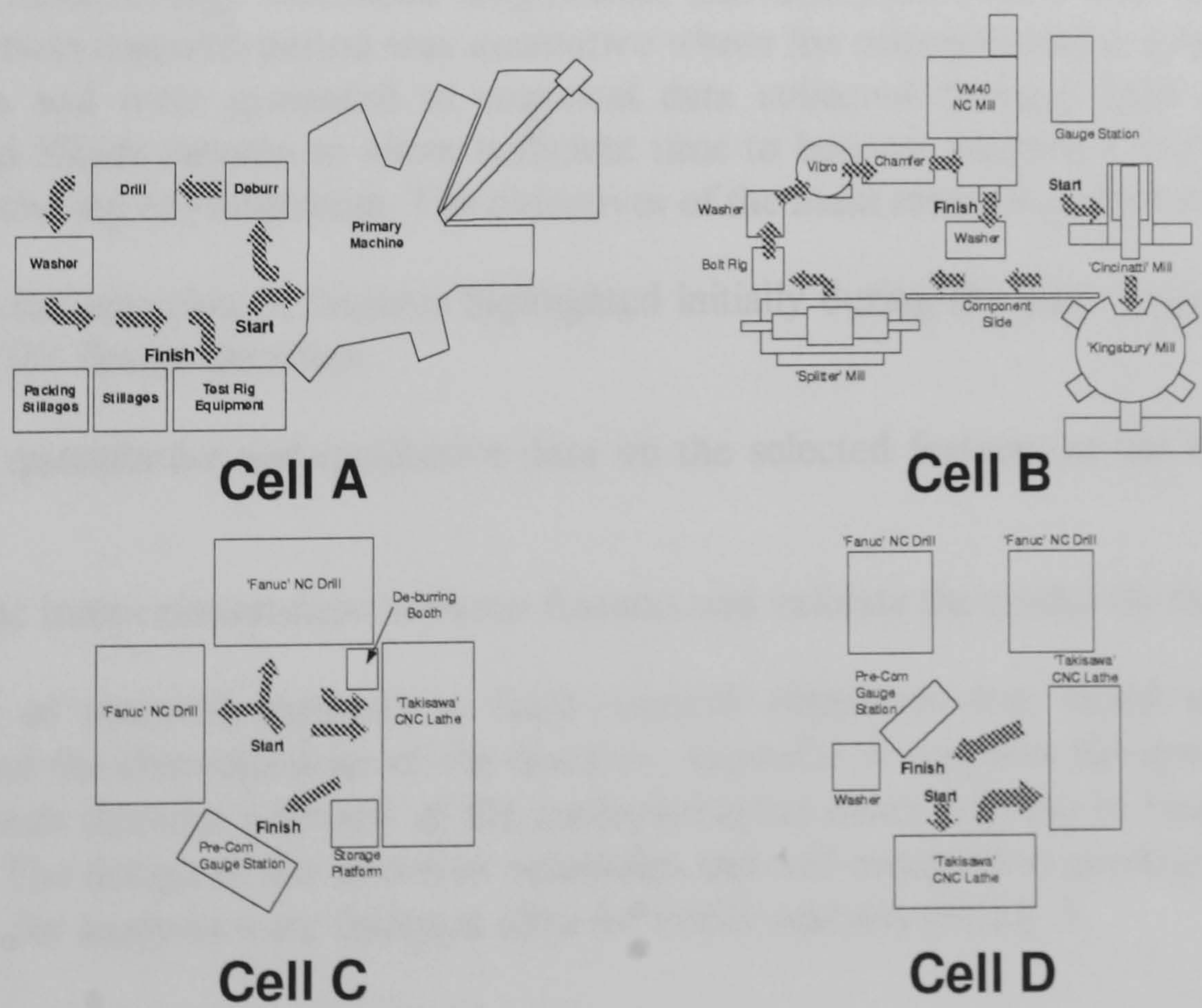


Figure 4-3 The Four Case Studies, Cells A, B, C and D

self-completion questionnaires. All cell members and supervisors were involved in the research. The semi-structured interviews provided a flexible method to collect a rich body of data on the nature of work in the cells as well as the attitudes of the cell members towards their jobs. The questionnaires proved a useful way of rapid data collection on these issues. The two methods were complementary and painted a rich and detailed picture of cell activity.

Apart from the methodological difficulties with categorising and ‘making sense’ of the data, the main practical difficulty involved making the cell members comfortable with taking part in the research. This was overcome with time through social contact during and after work and a genuine interest in their work. Findings from the pilot study research are summarised in Appendix C.

4.5 Development of Model

The model brings together exemplary work in the field of complementary function allocation, behavioural job design methods and socio-technical systems theory. This section provides an overview of the main research period and describes the features that were finalised at the beginning of this period.

4.5.1 Overview of the Main Research Period

The research methodology embraced longitudinal and multiple-method data collection. The nature of the main research period was qualitative where the concepts and constructs emerged from the data and were grounded in empirical data collected through field research. The research lasted fifteen months to allow sufficient time to become immersed in the complexity of the manufacturing environments. The objectives of the main research period were threefold:

- 1) To finalise the selection of features highlighted initially during the pilot study and from an analysis of job design literature.
- 2) To collect quantitative and qualitative data on the selected features at the three levels of analysis.
- 3) Describe the inter-relationships between features and validate the model for the our Cells.

The selection of research methods to fulfil research objectives was based on pilot study experiences and the characteristics of the features. Appendix A supports the specific choice of research methods through a review of the methodological issues relating to research strategy and methods. The design of the interview schedules and self-completion questionnaires as well as the features for analysis were finalised after the initial analysis of Cell A.

Semi-structured interview, shop-floor observation and self-completion questionnaire methods were used to collect data on features at the three levels of analysis. These methods are well established and are widely used and documented. A description of the sampling strategy, research methods and data analysis are presented in Appendices A to D. The multiple-method approach embraced both quantitative and qualitative data collection methods to develop a rich, detailed and representative model of the four case studies. Quantitative methods provided 'situational settings' for qualitative data collection methods and which facilitated data analysis. The use of quantitative and qualitative data facilitated the triangulation of data to acquire a rich and representative picture of the technological and social settings.

During the research period, a rapport was developed with respondents which aided the collection of representative and reliable data. This facilitated the opportunities for and the number of informal conversations, chance meetings and serendipitous encounters with key individuals. These were invaluable as sources of data and is a characteristic of case study and field research. Although data collected from these sources were often un-quantifiable, they helped develop a deeper understanding of the company and of specific individuals and working practices.

Data analysis was facilitated by comparing the various sources and types of data. To facilitate validation, the data was inspected by all cell members and supervisors throughout the research period. A further validation process was conducted with these parties to identify the inter-relationships between the individual features in the model. These validation processes helped the 'would-be' users of the model (i.e. the cell members and supervisors) understand the nature of the model and its uses. In addition, this helped them understand the nature of the job designs in the four Cells.

4.5.2 Model Features

The model is used principally as a template to facilitate and provide a structured approach to job redesign by formally describing the impact of the manufacturing environment upon function allocation, work organisation and socio-technical elements of job design in cell systems. Like the job characteristics model (refer to Section 3.3.3), the model emphasises positive characteristics of jobs which complements the application of human-centred methods and theories to job design in manufacturing environments (refer to Section 2.2.3.2).

Criteria for the complementary allocation of functions were compiled and a set chosen from pilot study findings and from a review of exemplary work in the fields of function allocation, job design and human-centred systems theory. These criteria were not viewed as being conceptually and practically at the same 'level' nor as independent. They embrace both function allocation and job design decision criteria.

On completion of the analysis of Cell A during the main research period, a short-list of features for the man-machine and job design levels was chosen based on existing instruments such as KOMPASS (Weik, 1993; Grote, 1994; Weik et al., 1995; refer to Section 3.2.2.3), the

Job Diagnostic Survey tool (Hackman and Oldham, 1980; refer to Section 3.1.2.3) and criteria proposed by Corbett (1985), Greenstein and Lam (1985). Alder (1986), Brödner (1988, 1990a), Corbett et al (1988), Clegg et al (1989), Kraiss (1989) Corbett et al (1990), Bohnhoff et al (1992), Dunckel et al (1993) and Ulich (1994).

The socio-technical level of analysis encompasses issues relating to the ability of the system to achieve homeostasis within its environment by co-optimising its technological and social sub-systems. This ability alludes to Ashby's law of Requisite Variety (1956) where the controlling system must generate at least as much variety (a measure of complexity) as the controlled system if that system is to be autonomous and achieve full, long-term independence.

The controlled system represents the four manufacturing cells which must absorb the complexity of the 'environment' (refer to Figure 4-2) to achieve homeostasis. In this context, the focus is on redundancy of functions to deal with all forms of disruption rather than the redundancy of parts.

The model forms the basis of the main research methodology and the design of the research methods. Collected data are summarised in the next chapter and described in detail in Appendices D and E. The features at the three levels of analysis are described below:

4.5.2.1 Man-Machine Level Features

At a man-machine level, function allocations are described in fundamental terms by what individual people do and what individual machines do. At this level there is no concept of a system or the integration of machines and people to describe manufacturing processes (refer to Section 3.2.1).

Man-machine features include adaptive allocation of functions, decision authority and competence, technical coupling, machine transparency and nature of operator loading (adapted from Corbett, 1985; Greenstein and Lam, 1985; Alder, 1986; Corbett et al, 1988; Clegg et al, 1989; Kraiss, 1989; Corbett et al, 1989; Bohnhoff et al, 1992). Each feature is broken-down into dimensions to describe their individual characteristics.

A) Adaptive Allocation of Functions (AAF)

a) Definition

Adaptive functions refer to functions that are allocated dynamically between people and machines. Dynamically allocated functions are those carried out by either people or machines according to the state of the Cells, the need to avoid overloading and under-loading people, functional criticality, health and safety issues and the decision making capabilities of people and machines (Greenstein and Lam, 1985).

In addition, it highlights the requirement and the degree to which people can manually override production and modify production settings. The allocation of adaptive

interactive functions is mediated by the design and functionality of the man-machine interface.

b) Data Collection

Data on adaptive allocation of functions was collected through semi-structured interviews and questionnaires as well as walk-and-talk-throughs and periods of observation on the shopfloor.

A functional analyses of the Cells was carried out using the hierarchical task analysis (HTA) technique to formally describe which functions and under what circumstances these functions are carried out by the cell members. HTA findings were discussed with the cell members to finalise their content. The functional analyses are summarised in Tables G1.1 to G1.8. Tables G1.1 and G1.2 correspond to Figures G1.1 to G1.10 (refer to Appendix G).

c) Feature Dimensions

- i) Opportunities to manually override automated functions,
- ii) The ability to automate manual functions.

B) Decision Authority and Competence (DAC)

a) Definition

Decision authority refers to the decision making capabilities of machines and their ability to facilitate decision making processes in the Cells. Competence relates to the ability of the cell members to act upon decisions made by themselves, supervisors and machines. The latter is mediated by the skill levels of the cell members and the resources available to them. The feature indicates the technological sophistication of the technology employed and highlights the decision making characteristics of machine operation in general (Corbett, 1985; Corbett et al, 1988; Kraiss, 1989).

b) Data Collection

Data on decision authority and competence was collected through semi-structured interviews and questionnaires with all cell members and supervisors as well as walk-and-talk-throughs and periods of observation on the shopfloor.

c) Feature Dimensions

- i) Opportunities for the cell members to make decisions during machine operation,
- ii) The ability of machines to make decisions,
- iii) The competence of the cell members to act upon their decisions.

C) Technical Coupling (TC)

a) Definition

The degree of technical coupling in a system may be viewed as the extent to which the physical and cognitive activities of the cell members are technologically mediated. These

are affected by issues relating to machine design, line balancing requirements and cell loads (Corbett et al, 1988; Kraiss, 1989; Corbett et al, 1989).

b) Data Collection

Data on technical coupling was collected through semi-structured interviews and questionnaires with all cell members and supervisors and periods of observation on the shopfloor.

The critical incident technique provided descriptions of the way the machines and equipment affected the activities of the cell members through the description of effective and ineffective actions (refer to Appendix A).

Throughout the research period, technical coupling in the Cells remained largely static because the machines, manufactured components, cycle times and production sequences remained largely unchanged. In addition, cell loads remained typically high in all Cells.

c) Feature Dimensions

- i) Technical constraints upon movement in a Cell,
- ii) The degree to which machines and equipment pre-define work methods,
- iii) The degree to which workflow patterns are rigidity prescribed.

D) Machine Transparency (MTR)

a) Definition

Machine transparency refers to the ability of the cell members to form a clear picture of an individual machine process. It is primarily affected by machine design which influences the exchange characteristics of data and sensory cues between people and machines (Alder, 1986; Clegg et al, 1989; Bohnhoff et al, 1992; refer to Section 2.2.3.2).

High levels of transparency enables cell members to predict and identify system failures and to learn about and develop an understanding of a system or individual process.

b) Data Collection

Data on transparency was collected through semi-structured interviews and questionnaires with all cell members.

c) Feature Dimensions

- i) Transparency of machine processes,
- ii) The ability of the cell members to prevent machine failures.

E) Nature of Operator Loading (NOL)

a) Definition

The nature of operator loading describes the composition of work in terms of the proportion of physical and cognitive tasks required by the cell members to fulfil manufacturing objectives. It identifies the degree to which the cell members may be over or under loading themselves mentally and physically (Greenstein and Lam, 1985; refer to Section 2.2.3).

b) Data Collection

The nature of operator loading was evaluated through semi-structured interviews and questionnaires with all cell members and supervisors, walk and talk throughs as well as periods of observation on the shopfloor.

Throughout the research period, the nature of operator loading changed little in Cells A, B and C. In Cell D, cognitive loads increased proportionally for two cell members on completion of training courses.

c) Feature Dimensions

- i) Proportion and content of physical functions,
- ii) Proportion and content of cognitive functions.

4.5.2.2 Job Design Level Features

The job design level encompasses issues relating to work organisation, the identification and description of technological and social sub-systems and the translation of the functions into tasks.

At this level, individual functions (which are, by their nature, abstract concepts unrelated to any specific real-world context) are amalgamated to create jobs with reference to manufacturing methods, physical space, skills requirements, experienced responsibilities, quality issues and production requirements (Clegg, 1984; Price, 1985; Clegg et al, 1989).

Job design features include cell transparency, interaction and communication needs, experienced responsibility, process feedback, task flexibility and maintenance and use of skills (adapted from Hackman and Oldham, 1980; Clegg, 1984; Alder, 1986; Hacker, 1986; Brödner, 1988, 1990a; Corbett et al, 1990; Bohnhoff et al, 1992; Dunckel et al, 1993; Ulich, 1994). Each feature is broken-down into dimensions to describe their individual characteristics.

A) Cell Transparency (CTR)

a) Definition

Cell transparency refers to the ability of the cell members to form a clear picture of a 'whole' production system at any given time. This embraces not only low level technological issues but more high level organisational and commercial issues as well.

Cell transparency is influenced by levels of machine transparency; the skill levels and experience of the cell members and the quality and use of communication mechanisms between Cells, the shopfloor and management (Alder, 1986; Clegg et al. 1989; Bohnhoff et al, 1992; refer to Section 2.2.3.2).

b) Data Collection

Data on transparency was collected from semi-structured interviews and questionnaires with all cell members and supervisors.

c) Feature Dimensions

- i) General awareness of the state of a whole system.

B) Process Feedback (PF)

a) Definition

Process feedback from the work itself and from others help cell members evaluate their own performance, implement corrective measures, learn from the working environment and propose system improvements. The feature highlights the content and use of feedback and information sharing mechanisms. Effective process feedback helps sustain Cell performance in the long term by facilitating the elimination and prediction of system variances (Hackman and Oldham, 1980; Clegg, 1984; Hacker, 1986; Brödner, 1988, 1990a; Corbett et al, 1990; Dunckel et al, 1993; Ulich, 1994).

b) Data Collection

The content and forms of feedback were evaluated through semi-structured interviews and questionnaires cell members and supervisors and by periods of observation on the shopfloor.

The characteristics of machine feedback changed little throughout the research. In Division C, however, formal mechanisms for providing feedback between cell members, supervisors and management improved during the research period.

c) Feature Dimensions

- i) Levels of feedback from the work itself,
- ii) Levels of feedback from 'agents' (i.e. people using, supervising and managing the system).

C) Skills Use and Retention (SUR)

a) Definition

The regular use of a broad range of physical and cognitive skills facilitates learning from the work itself, allows one to retain their skills and provides opportunities for personal development. This feature is central to describing the nature of work in the Cells and reflects the relevance and effectiveness of the company training programme.

Highly skilled cell members are invaluable to the company because they are flexible and allow supervisors to deal with 'boundary' activities to rapidly rectify disruptions when they occur. Multi-skilling allows them to effectively fulfil and be allocated all necessary task and role functions (Hackman and Oldham, 1980; Clegg, 1984; Hacker, 1986; Brödner, 1988, 1990a; Ulich, 1994).

b) Data Collection

The maintenance and use of skills was studied through semi-structured interviews and questionnaires with all cell members and changed little throughout the research. The responses from earlier interviews also proved invaluable.

c) Feature Dimensions

- i) Opportunities to use high-level skills,
- ii) Ability to retain high-level skills,
- iii) The variety of skills used.

D) Task Flexibility (TF)

a) Definition

Task flexibility has three dimensions: job rotation, enlargement and enrichment dimensions. These dimensions refer to elements of job design which seek to extend the scope and variety of work through movement between different jobs as well as the horizontal and vertical integration of tasks. The feature describes key characteristics of work related to management style as well as the effectiveness of the company human-centred manufacturing policy (Hackman and Oldham, 1980; Clegg, 1984; Brödner, 1988, 1990a; Corbett et al, 1990).

b) Data Collection

Task flexibility was studied through semi-structured interviews and questionnaires with all cell members and supervisors. In general, the policies and content of the three task flexibility dimensions varied little during the research period.

c) Feature Dimensions

- i) Opportunities for job enlargement activities,
- ii) Opportunities for job rotation activities,
- iii) Opportunities for job enrichment activities.

E) Interaction and Requirements (IR)

a) Definition

Interaction and communication needs refers to the manufacturing requirement for various parties to discuss and resolve production, organisational and commercial issues. It highlights the state of industrial relations, management style and the degree of responsibility allocated to the cell members (Hackman and Oldham, 1980; Clegg 1984;

Hacker, 1986; Brödner, 1988, 1990a; Corbett et al, 1990; Dunckel et al. 1993; Ulich, 1994).

b) Data Collection

Data on interaction and communication needs were collected through semi-structured interviews and questionnaires with all cell members and supervisors and by observing activities in the Cells. Interaction and communication needs varied throughout the research period and depended on the type and severity of Cell disruptions.

c) Feature Dimensions

- i) Opportunities for dealing with and interacting with others.

F) Experienced Responsibilities (ER)

a) Definition

The amount of responsibility allocated to the cell members is dependant upon strategic choices made by management. These choices reflect the skill levels of the cell members, the complexity of the working environment, industrial relations and the allocation of functions. They impact upon supervisory style, workplace flexibility, the autonomy of the cell members and is a potential source of intrinsic motivation (Hackman and Oldham, 1980; Clegg, 1984; Alder, 1986; Brödner, 1988, 1990a; Corbett et al, 1990; Ulich, 1994).

b) Data Collection

Experienced responsibilities were studied through semi-structured interviews and questionnaires with all cell members and supervisors as well as by periods of observation on the shopfloor. The experienced responsibilities of the cell members remained largely static throughout the research period.

c) Feature Dimensions

- i) Levels and content of experienced responsibilities.

4.5.2.3 Socio-Technical Level Features

Socio-technical features were selected from exemplary work in the field of socio-technical systems analysis and include independence of system, task inter-dependence and sources of variety and boundary regulation activities (refer to Section 3.1.3; adapted from Cherns, 1976; Susman, 1976; Emery, 1978; Hackman, 1983; Alder, 1986; Brödner, 1988, 1990a; Ulich, 1994).

A) Independence of System

a) Definition

The regulation of disturbances at their point of origin is essential for the independence of the Cells and ensures disturbances are not transferred in an unpredictable way from one cell to another. The ability of the Cells to self-regulate in the long term is dependent upon the ability of the cell members and supervisors to eliminate, predict and rectify organisational, technical and commercial disruptions. This feature highlights the effectiveness and use of mechanisms to achieve the latter as well as outlining the influence of key variances (Cherns, 1976; Susman, 1976; Emery, 1978; Hackman, 1983; Brödner, 1988, 1990a; Ulich, 1994).

b) Data Collection

The independence of the Cells was studied by periods of observation on the shopfloor, attending cell meetings, semi-structured interviews with all supervisors and walk-and-talk-throughs in the Cells. The responses from other features were invaluable for describing this socio-technical feature.

The ability of the Cells to self-regulate and methods for pre-empting disruptions remained largely unchanged during the research period.

B) Task Inter-Dependence and Sources of Variance*a) Definition*

Task inter-dependence refers to the synergy established between people using various procedures and technologies to undertake a set of related tasks. Tasks are dependent upon each other in terms of the flow of work, quality and information. It refers to the degree to which tasks are oriented towards a common manufacturing objective, the ability to identify critical tasks and inter-dependencies and the degree to which the consequences of carrying out tasks is easily understandable and predictable (Cherns, 1976; Susman, 1976; Emery, 1978; Hackman, 1983; Alder, 1986; Brödner, 1988, 1990a; Ulich, 1994).

High levels of task inter-dependence creates a need for collaboration between cell members, often setting a pattern of consultative interaction that can also include the supervisors. Clear task inter-dependencies improves the ability of the cell members to regulate, co-ordinate and cope with Cell disturbances before they affect neighbouring operations or cells.

b) Data Collection

Task inter-dependence and sources of variance were studied through semi-structured interviews with all cell members and supervisors, from periods of observation on the shopfloor as well as walk-and-talk-throughs in the Cells.

Because the work methods and machines used in the Cells varied little throughout the research period, task inter-dependencies remained unchanged. Sources of variety and the timing of disruptions, however, varied and were unpredictable.

C) Boundary Regulation

a) *Definition*

Boundary regulation refers to the activities of the supervisors in dealing with Cell matters not directly associated with production on the shopfloor. These encompass Cell and shopfloor improvements, assembly shop requirements, health and safety, training, capacity problems, absenteeism, industrial disputes, long term production planning and dealing with suppliers and customers.

The feature describes the ability of the Cells to operate independently in the long term as well as highlighting the influence of management style, industrial relations and other sources of variance on this independence (Cherns, 1976; Susman, 1976; Emery, 1978; Hackman, 1983; Alder, 1986; Brödner, 1988, 1990a; Ulich, 1994; refer to Section 2.3.1).

b) *Data Collection*

Boundary regulation was studied by interviewing the supervisors and by observing activities in the Cells. Supervisory style changed little throughout the research period.

4.6 Cell Job Design Model

The Cell Job Design Model is graphically depicted in Figure 4-4. The features at each level of analysis are detailed. This view is the analysis view of the open system model in Figure 4-2. The features are descriptions of the factors in the manufacturing environment that build-up the relationships between people and machine elements of the manufacturing systems.

The socio-technical features guide the analysis to focus on the overall operation of the manufacturing cell. The job design features focus the analysis on the organisation of work for the cell members. The man-machine features focus the analysis on the allocation of functions between the people and machines and between people.

Once the man-machine level strategy is realised in physical machines, the cost of replacing machines normally limits the scope of change in the other levels of analysis. The relationship between the job design and the socio-technical levels determines how much the cell workers focus on the 'tasks' and the 'management' functions in the cell.

The features are not independent and are interrelated. They can have a facilitating or a constraining effect on each other. The strength of these relationships characterise the manufacturing cell and its underlying design, operation and management philosophy.

The Figure illustrates the way the model is used in different job redesign scenarios. For example, for job redesign requirements embracing the influence and scope of function allocation changes and strategies, the users of the model analyse the features at the

man-machine and job design levels. Likewise, for Cell operation and boundary regulation issues the users analyse the features at the job design and socio-technical levels.

The inter-relationships between features and dimensions are determined quantitatively from an analysis of the research data and qualitative from the experience and knowledge of the users (refer to Tables 4-2 and 4-3). This was carried out with input from the research participants and helped to validate the selection of features and the structure of the levels. Each dimension of the features in a column is taken in turn. For example, where a man-machine level dimensions is considered to constrain a job design dimension, a 'C' (large constraint) or 'c' (small constraint) is entered into the corresponding location on the grid. Likewise for man-machine level dimensions considered to facilitate job design dimensions, an 'F' (large facilitator) or 'f' (small facilitator) is entered.

The model does not identify direct cause-and-effect relationships between *individual* dimensions because the dimensions themselves are inter-related and are not independent. Instead, the model helps the users identify possible relationships between *ranges* of dimensions and levels of analysis and/or ranges of other dimensions. This improves the visibility of the job redesign process by making the users aware of the potential 'knock-on' effects of changing single aspects of the working environment. This demonstrates the true complexity of the job redesign process.

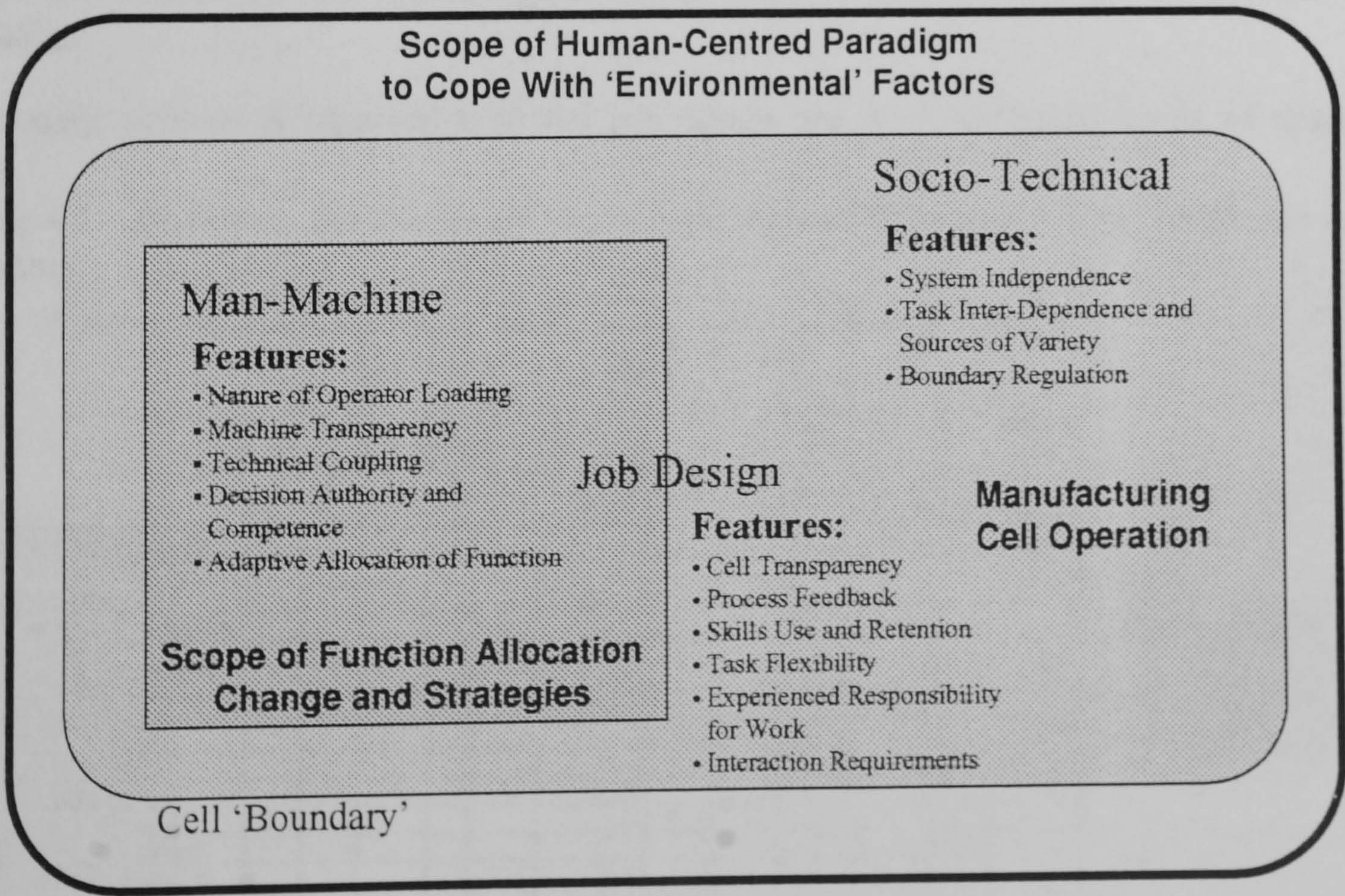


Figure 4-4 Overview of the Model

From this qualitative data validation and learning process, the net impact of issues described by the man-machine features at the job design level (vertical sum) and the net impact of these upon the individual job design features (horizontal sum) are quantified (refer to the Key in Table 4-2). An example for each ‘sum’ is given below:

- 1) Most man-machine features are considered a constraining factor to ‘feedback from the work itself’. If the man-machine interface is like a ‘black box’, opportunities for feedback are minimised. In this case, however, the cognitive dimension of the ‘nature of operator loading’ (NOL) is viewed as a facilitator. There is, therefore, a mixture of constraining and facilitating influences upon each job design feature. Because of this, the qualitative and quantitative descriptions of the individual man-machine dimensions are reviewed collectively to build-up a single picture of the full impact upon each or group of job design level feature. It is perceived that overall, man-machine features strongly constrain ‘feedback from the work itself’ (-3.5).
- 2) The physical ‘nature of operator loading’ (NOL) dimension strongly constrains the way jobs are designed. In this case, all skill dimensions are strongly constrained with an overall perceived net impact of -4.5.

Particularly large (≥ 3) or small (≤ -3) values highlight the dominant influences upon job design. These limits were determined from the experience of completing these Tables during the research period. The process helps clarify and eliminate uncertainties and ambiguities in describing the relationship between function allocation and job design issues. In addition, it helps to validate the content and applicability of the model to facilitate the process of job redesign.

The same process is repeated with the job design and socio-technical levels of analysis to

Table 4-2 Describing The Impact Of Function Allocation Dimensions At The Job Design Level of Analysis

Man-Machine Level		NOL		MTR		TC			DAC			AAF		Net Impact Upon JD Feature
		Physical	Cognitive	Transparency or Machine Processes	Failure Prevention	Constraint Upon Movement In Cell	Pre-Defined Task Methods	Workflow Rigidity	Decisions Made by Cell Members	Decision Making Ability of Machines	Competence to Act Upon Decisions	Opportunity for Manual Override	Automation of Manual Tasks	
Job Design Level	CTR	General Awareness	c		c	C	c		f		f	C	f	-2
	PF	Feedback from the Work Itself	C	f	C	C				c		c		-3.5
		Feedback from Agents												
	SUR	Skills Use	C	f										
		Skills Retention	C	f										
		Skills Variety	C	f										
	TF	Job Enlargement	f											
		Job Enrichment		c										
		Job Rotation												
	IR	Level of Interaction												
		Dealing With Others												
	ER	Experienced Responsibility for Work	c											
		Net Effect of MM Feature	-4.5	+1.5										

KEY

Code	Meaning	Score
C	Large Constraint	-1
c	Small Constraint	-0.5
F	Large Facilitator	+1
f	Small Facilitator	+0.5

describe the influence of job design on the ability of a cell to self-regulate (refer to Table 4-3). Particularly large (≥ 2) or small (≤ -2) values highlight the dominant influences upon socio-technical system issues. The values are '2' instead of '3' because the number of socio-technical features are fewer than with the man-machine / job design matrix. These limits were determined empirically from the analysis of collected data during the main research period. As before, this process helps clarify and eliminate uncertainties and ambiguities in describing the relationship between features at the job design and socio-technical levels.

The result of the analysis in the four Cells are presented in Chapter Five.

4.7 Model Validation Methodology

The data collection and analysis activities yielded detailed and representative models of job design for the four Cells (refer to Appendices D and E). The model validation process involved two phases:

- 1) During the main research stage the qualitative and quantitative data was validated with input from all supervisors and cell members. The characteristics of the model and the individual features were described early in the research with all parties.

Once data had been gathered for all cell members in a Cell, formal meetings were arranged to discuss the validity of the features a level at a time and on separate occasions. This was done to avoid the participants becoming confused with other level features and helped them focus their efforts on validating related features at the same level of analysis. For each Cell, therefore, three formal meetings were held with all cell members and supervisors. During these meeting, the data was presented to the participants in a reduced form. Additional informal discussions were arranged with the cell members and supervisors when required.

These meetings yielded meaningful discussions about the nature of job design in general and the features at the three levels of analysis in particular. Based on these validation meetings, data representativeness and accuracy was confirmed and enhanced according recommendations from the participants.

- 2) The second validation phase involved the identification of possible inter-relationships between features at adjacent levels of analysis. At least one formal meetings was held for the cell members and supervisors in each Cell.

Table 4-2 and Table 4-3 help the research participants adopt a systematic approach towards the analysis and verification of the inter-relationships between features. They help them consider and formally describe the impact of low-level function allocation issues upon the state of work organisation at the job design level of analysis.

Table 4-3 Describing The Impact Of Job Design Dimensions At The Socio-Technical Level of Analysis

Job Design Level	CTR	PF		SUR			TF			IR		ER
Socio-Technical Level	General Awareness	Feedback from the Work Itself	Feedback from Agents	Skills Use	Skills Retention	Skills Variety	Job Enlargement	Job Enrichment	Job Rotation	Level of Interaction	Dealing With Others	Experienced Respon-sibility for Work
System Independence												
Task Interdependence and Sources of Variance												
Boundary Regulation												
Net Impact Upon STS Feature												

Feature relationships between adjacent levels are identified through inspection of the qualitative and quantitative data for each feature. This is facilitated by identifying the dominant features at each level of analysis. The nature of the process is one of consensus and debate about their relationships. The scores allocated to the relationships are indicators of the strength and type of impact. They allude to the nature of relationships and do not try to measure them accurately or imply a cause-and-effect relationship because to do so would attempt to simplify the complexity of the manufacturing environment.

The scores are summed to indicate a net impact between features. These score indicate dominant relationships and upon review were modified and discussed further. The process is an iterative one and often lasted for more than two hours. For practical reasons, each meeting was spread across a number of days.

4.8 Summary

From the main research period, the features at the three levels of analysis were fully described in qualitative and quantitative terms. The research sought to produce a single representative model describing the content and inter-relationships between features at different levels of analysis. For each Cell, model accuracy and representativeness was confirmed by all cell members and supervisors. All features are relevant to the design of jobs in Cell environments and were understood by the research participants. These validation activities were carried out throughout the fifteen month main research period and supports the selection of features at each level of analysis.

The model is used to structure the process of implementing job design changes based on business need and/or production objectives. The content and multiple-level characteristic of the model fosters the allocation of functions from a human-centred perspective and describes issues affecting job design in the four Cells from the three perspectives.

The model helps to integrate work organisation and socio-technical issues with more low-level function allocation considerations. It facilitates the systematic description of the inter-relationships between features at adjacent levels and highlights the key issues for consideration during job redesign. In addition, the model facilitates learning about how job designs are derived from low and high-level perspectives.

Collected data are described in the following chapter.

CHAPTER FIVE

MODEL VALIDATION

Chapter four describes the development of the Cell Job Design Model with the different factors that influence the design of jobs in cellular manufacturing systems. The validity of these factors were ensured during the review meetings in the field research. This chapter takes the validation further by using the qualitative and quantitative data generated from the collected data for the four Cell studies and establishing the cell specific inter-relationships between features. Each inter-relationship set describes the characteristics of the cell job design.

For Cell A, the features and their perceived inter-relationships are summarised in quantitative and qualitative terms. This description illustrates the low-level detail available to the users of the model. The presentation of Cells B, C and D are less detailed to facilitate the flow of the thesis. The data generated from the main research period was vast. Detailed findings of all four Cells are presented in Appendices C and D.

A comparison of the Cells is presented to demonstrate the sensitivity and value of the model in describing jobs in different cell systems.

5.1 Validation of Model Using Cell A

The following sections describe the qualitative and quantitative data for Cell A which was used to validate the model. The data describe the features and their inter-relationships at the three levels of analysis. Quantitative measures are taken from the main research questionnaire (Questionnaire Three; refer to Appendix E). Job Diagnostics Survey measures are included to complement these measures (JDS, Questionnaire One). For clarity, all JDS measures are suffixed with “JDS”.

5.1.1 Man-Machine Level of Analysis, Cell A

The features at the man-machine level of analysis are discussed and is complemented by Table G1.1, Appendix G. They describe the state of function allocation in Cell A.

1. Adaptive Allocation of Functions (AAF)

Opportunity for Manual Override	1.1
Automation of Manual Tasks	1.0
Satisfaction	3.3

The allocation of interactive functions between supervisors and cell members is static. All interactive functions are allocated to and rotated between the cell members. Opportunities to manually override the automated functions is small (1.1) because of the design and functionality of the man-machine interface. The scope for automating manual (interactive) functions is very small (1.0). The cell members are only slightly satisfied with this situation (3.3) because of constraints to physical movement around the Cell as well as the emphasis on the use and allocation of interactive functions.

There is wide scope and flexibility for strategic choice in adaptively allocating enabler and role functions between cell members and supervisors. Enabler functions such as housekeeping, storage and quality assurance functions are statically allocated to the cell members. The supervisors undertook many of the daily production planning and Cell improvement functions when cell loads were high. Re-allocation of these functions are carried out informally according to changing circumstances.

2. Decision Authority and Competence (DAC)

Decisions Made by Cell Members	4.6
Decisions Making Ability of Machines	1.0
Competence to Act Upon Decisions	5.0
Satisfaction	4.3

The range of decisions made by the cell members as well as their competence to act upon them is high (4.6 and 5.0 respectively). All but the most severe machine and component problems are rapidly dealt with by the cell members. The cell members are therefore highly autonomous under 'normal' operating condition (4.2 JDS). The level of satisfaction with this situation is good (4.3). In contrast, machines have few (if any) decision making abilities (1.0) which fosters the allocation of role and enabler functions to people.

Cell members carry out a wide number of enabler functions. These involve making daily production planning, machine resetting and calibration, tool and coolant replacement and intra-Cell job rotation decisions. Cell members also decide when to set offsets to compensate for tool wear, whether to discard or rework out-of-tolerance parts and liaise with other parties to settle potential uncertainties.

Role functions involve making continuous improvement, maintenance and long term production planning decisions. These decisions are made jointly between the supervisors and cell members.

3. Technical Coupling (TC)

Constraints Upon Movement in Cell	3.8
Pre-Defined Task Methods	5.4
Workflow Rigidity	5.6
Satisfaction	3.9

All task methods are predetermined (5.4) and are clearly defined. The level of workflow rigidity (5.6) is high because of the pre-defined task methods and tight line balancing requirements. These as well as the design of the Primary Machine strongly influence the

movement of cell members around the Cell (3.8). The Primary Machine has a short cycle time (around one minute) and requires it to be continuously ‘fed’ with work. The main cutting operations are performed by the Primary Machine and is critical for maintaining production. Production levels reflect the utilisation of this machine and it rigidly pre-determines the flow, pace and timing of work in the Cell.

The level of satisfaction with this situation is quite high (3.9). The TC scores reflect a static allocation of task functions between people and machines.

The level of technical coupling is symptomatic of these features and limit opportunities for the cell members to undertake and effectively carry out role functions. The intended effects of allocating role functions to the cell members, reflecting their high levels of skill and experience, are often not realised.

4. Machine Transparency (MTR)	Transparency of Machine Processes	1.8
	Failure Prevention	2.0
	Satisfaction	3.6

The transparency of machine processes (1.8) and the ability to prevent machine failures (2.0) is poor. This, as well as high cell loads and tight line balancing requirements, constrain the ability of the cell members to carry out many enabler and role functions to help them closely follow and evaluate the state of the machines. This constrains their ability to predict, identify and rectify machine failures or propose machine improvements.

Process transparency is low for the Primary Machine - cell members are unable to predict and identify machine failures. This is because there is no facility to intervene in the cutting processes; poor informational feedback on machine status, tool-wear and material condition; and poor visibility of the manufacturing operations because of safety guards and spraying coolant.

Transparency and control over the deburring and washing operations is good. These operations are fully understood and involve significant amounts of manual interaction. Transparency is poor for the QA operations in because of their ‘black box’ and highly technical nature. Overall, the level of satisfaction with this situation is quite good (3.6) because the cell members have a good general awareness of Cell operations (4.0). The latter is discussed at the job design level.

5. Nature of Operator Loading (NOL)	Physical	4.2
	Cognitive	3.5
	Satisfaction	2.8

Under ‘normal’ operating conditions, cell members carry out few cognitive (role) functions (3.5) and many physical (task) functions (4.2). This is described by the above features. Task functions are carried out for between 60% and 85% of the total working time. The level of satisfaction with this situation is very poor (2.8). The allocation of role functions is open to

wide strategic choice. The maturity of the Cell and high skill levels facilitate the allocation of a wide range of role functions between the supervisors and cell members. The interactive nature of the allocated functions for machine operation characterises the general nature of work in the Cells.

5.1.1.1 Features at the Man-Machine Level, Cell A

Table 5-1 outlines the dominant features at the man-machine level. These features are those with especially large (≥ 4.0) or small (≤ 2.0) values. Collectively, they describe the nature of function allocation in Cell A. Figure 5-1 summarises graphically the features and provides a method to compare features between Cells and/or between job redesigns. All features were validated by the cell members.

The inability of the machines to facilitate decision making is reflected in the low DAC score and ensures all role and enabler functions are allocated to people. The low AAF scores highlight the static nature of this allocation.

Table 5-1 Dominant Man-Machine Dimensions

Feature	Dimension	Score
Adaptive Allocation of Functions (AAF)	Opportunity for Manual Override	1.1
	Automation of Manual Tasks	1.0
Decision Authority and Competence (DAC)	Decisions Made by Cell Members	4.6
	Competence to Act Upon Decisions	5.0
	Decision Making Ability of Machines	1.0
Technical Coupling (TC)	Pre-Defined Work Methods	5.4
	Workflow Rigidity	5.6
Machine Transparency (MTR)	Transparency of Machine Processes	1.8
	Failure Prevention	2.0
Nature of Operator Loading (NOL)	Physical	4.2

Poor MTR constrains the ability of the cell members to understand the state of the Primary Machine as well as their ability to fulfil role functions.

The high TC scores support the latter by outlining the extent to which the physical and cognitive activities of the cell members are prescribed by the equipment used. These scores stress the static nature of function allocations between people and machines and emphasise the need for the cell members to carry out mostly interactive functions. This is supported by the high NOL score.

The cell members are only slightly satisfied with the nature of operator loading (2.8) and the adaptive nature of function allocations (3.3) but are more satisfied with levels of transparency (3.6) and technical coupling (3.9).

They are, however, satisfied with the levels of decision authority and with their competence to carry out decisions (4.3). The contrast between the high DAC satisfaction score and the combined NOL and AAF scores highlights the mismatch between the intended human-centred systems design policy and the job design reality in the Cell.

The physical, un-adaptive and technologically mediated nature of work conflicts with the capabilities of the cell members and minimises opportunities to carry out role functions. This reflects the overall medium level of satisfaction with the outcome of the function allocations between people and machines (3.6).

5.1.2 Job Design Level of Analysis, Cell A

The features at the job design level of analysis are discussed and is complemented by Table G1.2, Appendix G. They describe the state of work organisation in Cell A.

1. Cell Transparency (CTR)	General Awareness	4.0
	Satisfaction	3.6

In general, cell transparency is high (4.0) and is facilitated by highly skilled (polyvalent) cell members with high levels of responsibility (see ER below) and good communication

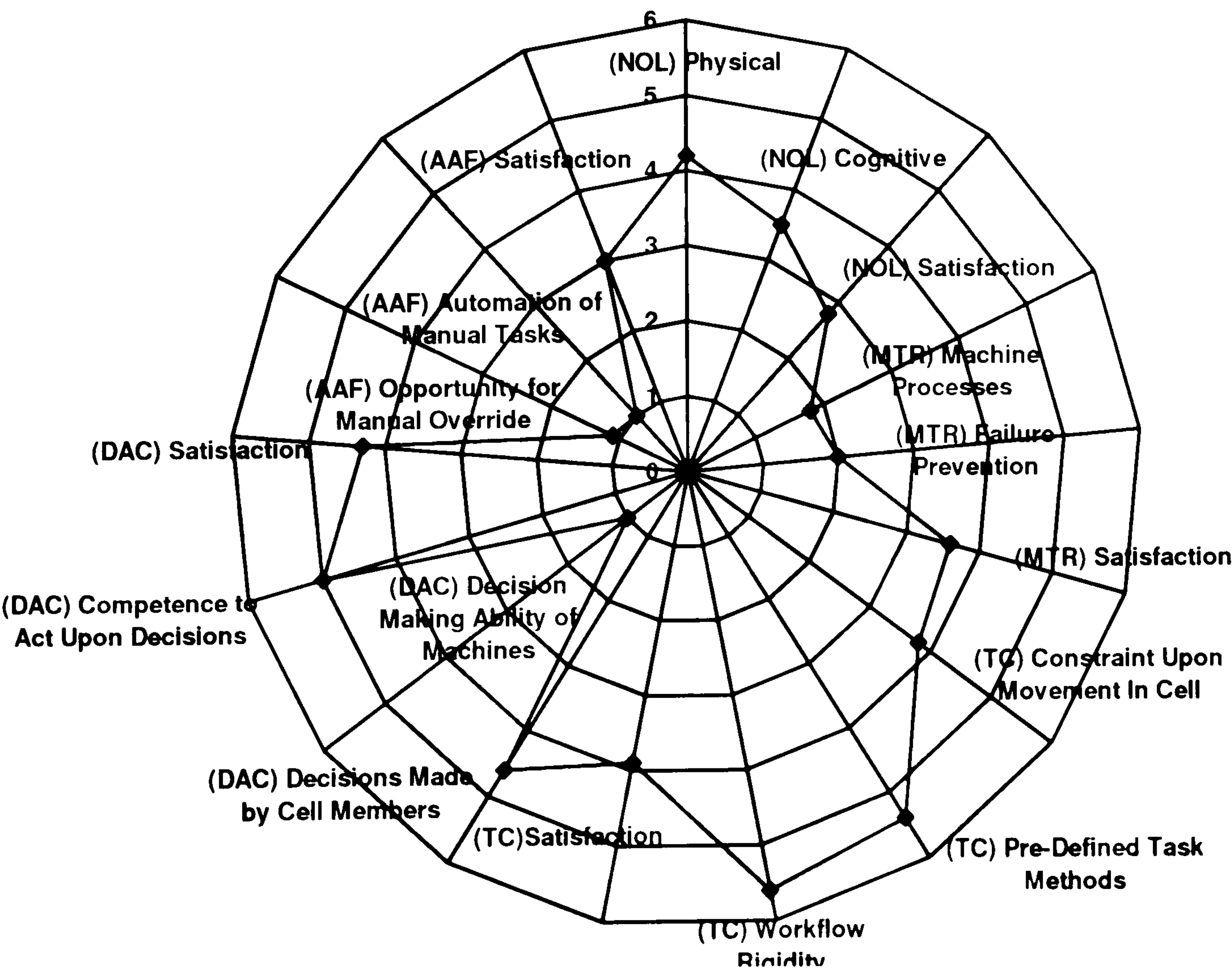


Figure 5-1 Delta Plot Showing Research Findings for Man-Machine Level Features - Cell A

methods (described in PF below). The former reflects the adaptive allocation of enabler and role functions between cell members and supervisors. This enhances the understanding and awareness of shopfloor issues affecting long term Cell viability. Overall, the level of satisfaction with this situation is quite high (3.6).

2. Process Feedback (PF)

Feedback from the Work Itself - JDS	3.4
Feedback from Agents - JDS	3.1

Process feedback from the Primary Machine is poor (reflected by low MTR scores). The cell members can forecast the progress of an operation by experience and from audible cues. The Primary Machine provides corrective feedback through a system called MARPOSS to compensate for tool wear. This facilitates tool replacement but does not provide information on the status of cutting operations. In general, feedback from the work itself on the performance of the cell members not good (3.4 JDS) and is basically in the form of the number and quality of finished components.

Feedback to the cell members from ‘agents’ is poor (3.1 JDS) but is compensated by a broad range of feedback methods developed and used collectively by the supervisors and cell members. They include Cell meetings, quarterly Divisional meetings, notice-boards and flip charts. Cell meetings are often scheduled by the cell members when the need arises to discuss cell improvements and manufacturing problems. Quarterly Divisional meetings are held to present and answer questions on the performance of each Division and the company as a whole. Notice-boards are used to display component details, operating procedures and customer queries and complaints. Flip charts in the Cells help cell members rapidly record production problems and solutions to improve problem solving, continuous improvement and inter-shift communications.

These feedback methods facilitate good cell transparency and, when time is available, the effective execution of role functions.

3. Skills Use and Retention (SUR)

Skills Use	2.4
Skills Retention	1.6
Skills Variety - JDS	3.6
Satisfaction	1.8

The cell members are highly skilled - half have completed four year craft apprenticeships. Under ‘normal’ operating conditions, low level skills involving interactive functions are typically carried out for between 60% to 85% of the total working time. There are few opportunities for the cell members to use and practice their full range of skills (2.4 and 1.6 respectively). This complements the medium Skills Variety score (3.6 JDS).

Role functions are carried out more during periods of disruption, at improvement meetings and for general problem solving on the shopfloor. This is reflected in the high DAC scores. The discretionary use of high level skills is constrained by high cell loads (the priority to meet production targets), machine design and the tight line balancing characteristics of the

Cell. This is reflected in the high TC and NOL scores and very low MTR and AAF scores. The level of satisfaction with this situation is correspondingly very low (1.8).

4. Task Flexibility (TF)

Job Enlargement	4.7
Job Enrichment	3.6
Job Rotation	5.3
Satisfaction	4.6

The cell members rotate (re-allocate) all task and role functions between themselves (5.3). Under ‘normal’ operating conditions, inter-cell job rotation on a fortnightly basis is typical. Job enlargement is fostered by the allocation of all task functions to the cell members (4.7) to foster autonomy (4.2 JDS) and minimise casual labour. This reflects the high NOL score and the combined TC and AAF scores (refer to Section 5.1.1.2).

Job enrichment is fostered by high levels of skill (polyvalence) and the adaptive allocation of role functions. Constraints upon opportunities to carry out role functions and experience high levels of autonomy are outlined above. This reflects the medium job enrichment score (3.6). Overall, the cell members are satisfied with this situation (4.6).

5. Interaction Requirements (IR)

Level of Interaction	5.0
Dealing With Others - JDS	4.0
Satisfaction	4.8

High cell loads require two people to work in the Cell. One cell member concentrates on ‘feeding’ the Primary Machine with work, whilst the other performs the deburring, washing and QA operations. Tasks are co-ordinated in general by the formal standardisation of task (Refer to PF above) and on a daily basis through informal verbal communication in the Cell. The level of interaction between cell members and supervisors is high (5.0) which corresponds to the good Dealing With Others JDS score (4.0).

Daily planning activities are carried out between the cell members and supervisors and may typically last up to twenty minutes. Production planning is carried out often between a number of supervisors and the cell members when disruptions occur because of potential disturbances to the rest of the shopfloor. Both parties also plan rectification activities to solve shopfloor problems. The level of satisfaction with this situation is high (4.8).

6. Experienced Responsibilities (ER)

Experienced Responsibility for Work - JDS	4.6
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The cell members have to fulfil many responsibilities (4.6 JDS). They are solely responsible for part quality, pulling work from stores, maintaining the workplace and housekeeping, setting dates for and organising Cell meetings, determining intra-cell job rotation, front line maintenance as well as maintaining, setting and operating the machines. The responsibility of the cell members to assure part quality is constrained by the design of the Primary Machine. The responsibility for daily and more long term production planning and proposing and implementing improvements is shared between the cell members and

supervisors depending on cell loads and the state of the whole shopfloor in Division C.

These levels of responsibility allow the cell members to work with much autonomy (4.2 JDS) releasing the supervisors to deal with boundary regulation activities. The responsibility for fulfilling the role functions allocated to the cell members reflects the amount of trust and good industrial relations between the supervisors and cell members.

5.1.2.1 Features at the Job Designs, Cell A

Table 5-2 outlines the dominant features at the job design level. These features are those with especially large (≥ 4.0) or small (≤ 2.0) values. Collectively, they describe the nature of work organisation in Cell A. Figure 5-2 summarises graphically the features and provides a method to compare features between Cells and/or between job redesigns. All features were validated by the cell members.

The ability to develop a clear picture and understand the state of the whole Cell is good (4.2) and is reflected in the high CTR, ER and IR scores. This helps the cell members fulfil their daily production and long term Cell development responsibilities. The fulfilment of these responsibilities, however, is constrained by the priority to maintain production levels as well as by issues highlighted by the high TC scores.

Table 5-2 Dominant Job Design Level Dimensions

Feature	Dimension	Score
Cell Transparency (CTR)	General Awareness	4.0
Skills Use and Retention (SUR)	Skills Retention	1.6
Task Flexibility (TF)	Job Enlargement	4.7
	Job Rotation	5.3
Interaction Requirements (IR)	Level of Interaction	5.0
Experienced Responsibilities (ER)	Experienced Responsibility for Work	4.6

The potential for de-skilling are high (i.e. skills retention is very low, 1.6) which is fostered by issues leading to the low AAF and MTR scores and high TC and NOL scores. High TF scores in light of function allocations highlight an increase in the time spent on carrying out interactive functions rather than increasing levels of decision making and autonomy (c.f. the medium job enrichment score).

Division C is experiencing much difficulty in overcoming the mismatch between implementing new forms of work organisation, the abilities and aspirations of the cell members and the nature of work. This is a major hurdle to nurturing enthusiasm and support on the shopfloor for change.

5.1.3 Feature Relationships Between the Man-Machine and Job Design Levels

The features at the man-machine and job design levels were validated by the cell members and supervisors. The second validation phase involved the identification of possible inter-relationships between features at these levels of analysis. Two formal meetings were held for the cell members and supervisors to identify their inter-relationships based the previous

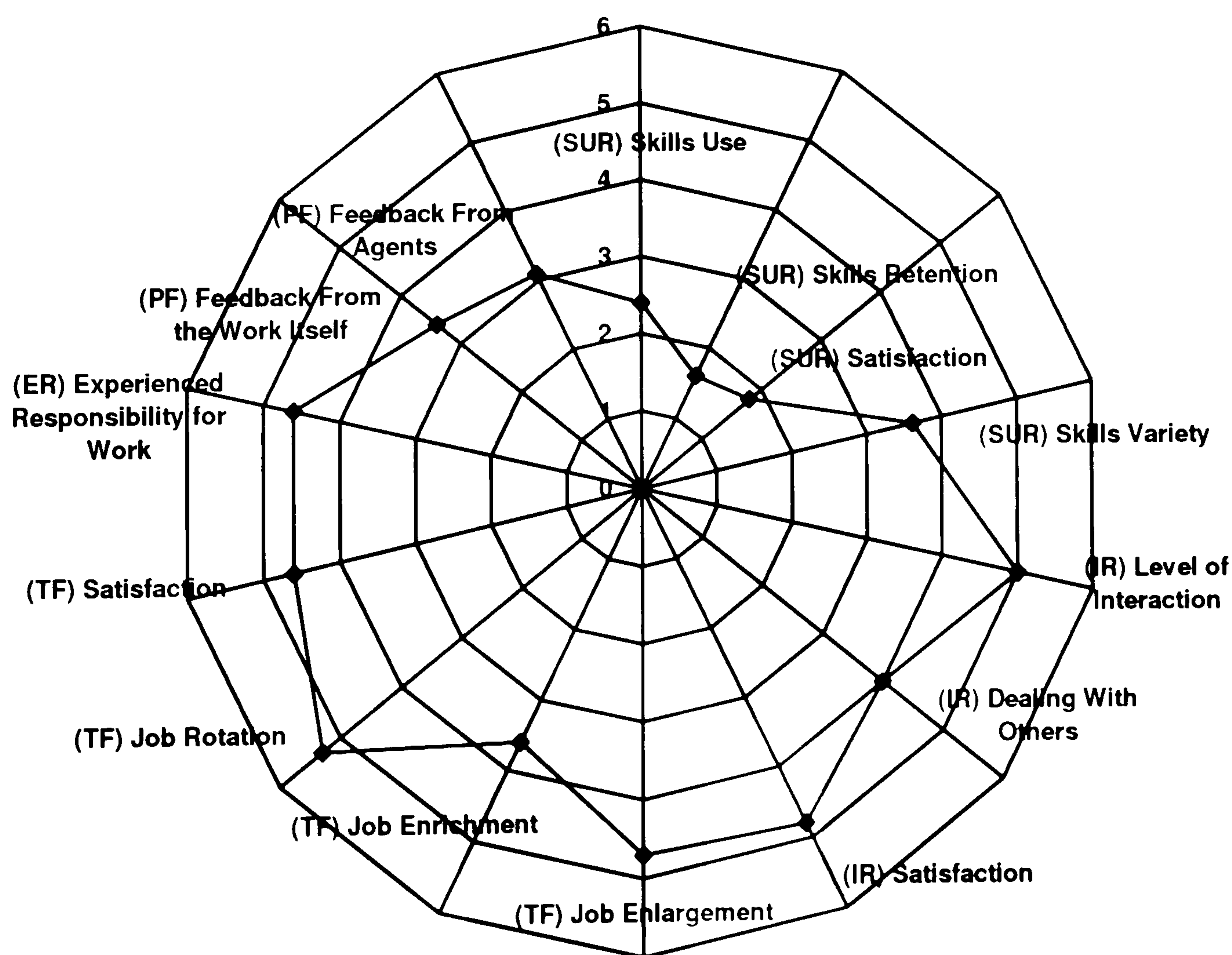


Figure 5-2 Delta Plot Showing Research Findings for Job Design Level Features - Cell A

validation process and an inspection of the collected data.

Table 5-3 identifies the dominant relationships between the man-machine and job design levels of analysis. The net impact of the man-machine dimensions at the job design level (vertical sum) as well as the net impact of these upon the individual job design dimensions (horizontal sum) are calculated (refer to Section 4.6). The relationships in Table 5-3 were initially developed from the research findings and then verified from discussions with all supervisors and cell members. From this validation process the key findings include:

- 1) The dominant function allocation dimensions influencing overall job design include (refer to the shaded columns in Table 5-3):

a) Physical (NOL),
b) Transparency of Machine Processes (MTR),
c) Failure Prevention (MTR),
d) Decisions Made by Cell Members (DAC),
e) Competence to Act Upon Decisions (DAC),
f) Opportunity for Manual Override (AAF).
- 2) The job design dimensions most affected by function allocation issues are measured by the number of man-machine dimensions constraining or facilitating them. These dimensions include:

a) General Awareness (CTR),
b) Feedback from the Work Itself (PF),
c) Skills Use (SUR),
d) Skills Retention (SUR),
e) Skills Variety (SUR),

Table 5-3 Matrix Summarising the Impact of Function Allocation Features Upon Work Organisation Issues in Cell A

Job Design Level

Man-Machine Level

		NOL		MTR		TC			DAC			AAF		Net Impact Upon JD Feature
		Physical	Cognitive	Transparency of Machine Processes	Failure Prevention	Constraint Upon Movement In Cell	Pre-Defined Task Methods	Workflow Rigidity	Decisions Made by Cell Members	Decision Making Ability of Machines	Competence to Act Upon Decisions	Opportunity for Manual Override	Automation of Manual Tasks	
CTR	General Awareness	c		c	C	c			f		f	C	f	-2.0
PF	Feedback from the Work Itself	C	f	C	C					c		c		-3.5
	Feedback from Agents													0
SUR	Skills Use	C	f	c	c		c		F		F	C	f	-0.5
	Skills Retention	C	f				C		f		F	C		-1.0
	Skills Variety	C	f			c	c	c	f		f	C		-2.0
TF	Job Enlargement	f					f	f					f	+2.0
	Job Enrichment		c	C	C				f		f	C	c	-3.0
	Job Rotation								f		f			+1.0
IR	Level of Interaction					C		c						-1.5
	Dealing With Others					c		c	f		f			0
ER	Experienced Responsibility for Work	c		c	c				F		F	c		0
Net Impact of MM Feature		-4.5	+1.5	-3.5	-4.0	-2.5	-1.5	-1.0	+5.0	-0.5	+5.5	-6.0	+1.0	

KEY

Code	Meaning	Score
C	Large Constraint	-1
c	Small Constraint	-0.5
F	Large Facilitator	+1
f	Small Facilitator	+0.5

- f) Job Enlargement (TF),
- g) Job Enrichment (TF),
- h) Experienced Responsibility for Work (ER).

From a validation process with the cell members and supervisors, it was perceived (and agreed) that 'general awareness' (-2), 'feedback from the work itself' (-3.5), 'skills variety' (-2) and 'job enrichment' (-3) were the most constrained, whilst 'job enlargement' (+2) the most facilitated by man-machine level dimensions.

- 3) In light of 2, the dimensions largely un-influenced by function allocation issues are:
- a) Feedback From Agents (PF),
 - b) Job Rotation (TF),
 - c) Level of Interaction (IR).

These job design dimensions tend to be primarily determined through manufacturing policy and issues described by other job design features.

The analysis of the content and inter-relationships between features at the man-machine and job design levels lays the ground-work for using the model.

5.1.4 Socio-Technical Level of Analysis, Cell A

The features at the socio-technical level of analysis describe the ability of the Cell to minimise and cope with production variances.

1. Independence of System

The preventative maintenance activities and communication mechanisms are key to minimising production variances. The company maintenance programme facilitates this by maintaining machines and pre-empting mechanical failures.

Continuous improvement activities help minimise sources of production uncertainty. The polyvalence of the cell members enable them to take part in front line maintenance activities. All but the most severe machine, material and product variances are dealt with by the cell members.

Cell meetings are good mechanisms for strategic planning, cell improvement and problem solving activities. Long term maintenance through continuous improvement activities and being able to predict internal cell disruptions are, however, constrained by machine design, commercial pressures and the nature of work itself.

When disruptions occur, the supervisors and cell members plan rectifying activities. Notice-boards and flip-charts, as well as cell meetings, foster the communication of Cell problems between the cell members, supervisors and shifts. Solutions are implemented by a combination of the supervisors, cell members and mechanical engineers and often affect

working procedures. Under 'normal' operating conditions the supervisors proactively implement improvements.

The need for the cell members to carry out largely interactive functions (under 'normal' operating conditions) does not foster the maintenance of high level skills (1.6) as well as enthusiasm and interest in the work itself. These issues constrain the ability of the cell members to predict internal cell disruptions. Poor machine feedback (3.4), high technical coupling (5.4) and low machine transparency (2.0) provide few opportunities for the cell members to learn from the work itself and predict when production disruptions will occur.

2. Task Inter-Dependence and Sources of Variety

The tasks are sequentially related by a single flow-line 'pull' system where downstream tasks are dependant upon all preceding tasks. Task are inter-dependent in terms of material flow and part quality. There is no flow of information between machines. Because of high technical coupling and un-adaptive task allocations, all machine operations are critical and highly inter-dependent. To minimise the transfer of errors between machine operations the flow of materials is controlled by the cell members rigidly adhering to standardised work procedures.

The Primary Machine is the main source of internal mechanical disruption and is the critical operation. The machine is very complex and is prone to breaking down two to four times a year. The cause of a breakdown is often difficult to identify and ultimately to repair because of its complexity and age - it broke down twice during the research period, in each case for about ten working days. This reduces the autonomy of the cell members since engineers and technicians are often needed to fix the machine.

Organisational disruptions include feelings of inequity fostered by changes in the payment structure, the requirement to attend Total Quality refresher courses, 'juggling' people around the shopfloor by the supervisors according to production priorities. The rationale behind how these issues relate to Cell production was always formally or informally communicated with the cell members.

Poor supplier performance is the main source of external variance. Castings occasionally suffered from porosity and could not be used and delayed work for up to five days.

3. Boundary Regulation

Under 'normal' operating conditions, the boundary regulation activities of the supervisors typically encompass the organisational issues described above. Supervisors distance themselves as much as possible from direct Cell production because of the high level of confidence in the abilities of the cell members as well as the well established and proven nature of operating procedures.

The supervisors primarily liaise with the cell members when disruptions interfere with the execution of task and role functions. When this happens, the two parties meet informally on

the shopfloor or formally in Cell meetings to exchange production, supplier and customer information and to plan activities to rectify the immediate problem. They evaluate whether the problem may be resolved by the cell members or with external help. If the breakdown cannot be resolved using front line maintenance skills, mechanical engineers and technicians rectify the problem. This, however, may take time because the required people may need to be subcontracted into the company. Under these conditions, the supervisors relocate the cell members into other cells.

The supervisors communicate directly with the suppliers to minimise unexpected or late deliveries as well as faulty components.

5.1.5 Features Relationships Between the Job Design and Socio-Technical Level, Cell A

The features at the socio-technical level was validated by the cell members and supervisors. A single formal meeting was held for the cell members and supervisors to identify the inter-relationships between the job design and socio-technical levels based on earlier validation processes and an inspection of the collected data.

Table 5-4 describes the relationships between features at the job design and socio-technical levels of analysis. The matrix helps build-up a picture of how work organisation issues affect the ability of the Cell to cope with and absorb production variances. Especially large (≥ 2) or small (≤ -2) values highlight the dominant influences upon socio-technical system issues. Dominant work organisation issues influencing the ability of the Cell to self-regulate include:

- a) General Awareness (CTR),
- b) Skills Use (SUR),
- c) Skills Retention (SUR),
- d) Skills variety (SUR),
- e) Job Enrichment (TF),
- f) Level of Interaction (IR),
- g) Experienced Responsibility for Work (ER).

These dominant job design features impact upon all socio-technical level features. From the analysis of the findings, it was viewed that Cell self-regulation is strongly facilitated by 'general awareness' (+3.0), 'level of interaction' (+3.0) and 'experienced responsibility for work' (+3.0). From the research, these job design features also strongly facilitate work organisation issues at the job design level.

This analysis completes the model validation for Cell A. All the features have been described quantitatively and qualitatively and their relationships between adjacent levels of analysis highlighted. In this form, the model describes the state of job design in Cell A at three levels and can be used to structure the process of job redesign.

Table 5-4 Matrix Summarising the Impact Job Design Features Upon The Ability of Cell A to Self-Regulate

Job Design Level	CTR	PF		SUR			TF			IR		ER
	General Awareness	Feedback from the Work Itself	Feedback from Agents	Skills Use	Skills Retention	Skills Variety	Job Enlargement	Job Enrichment	Job Rotation	Level of Interaction	Dealing With Others	Experienced Responsibility for Work
System Independence	F	c	c	C	C	C	f	C	f	F	F	F
Task Interdependence and Sources of Variance	F			C	C	C	f	C	f	F	f	F
Boundary Regulation	F			c			f		f	F		F
Net Impact Upon STS Feature	+3.0	-0.5	-0.5	-2.5	-2.0	-2.0	+1.5	-2.0	1.5	+3.0	+1.5	+3.0

At both stages, the quantitative analysis of the data is complemented by an analysis of the qualitative data and from the experience of the model users. The limits for identifying the key dimensions at either stage are determined from the analysis of the findings and the model validation processes with the research participants.

The key dimensions at each level as well as the key inter-relationships between adjacent levels are identified to build-up a picture, for the model users, of the primary issues affecting the design of jobs. Consequently, these issues at three levels of analysis require particular attention when the model is used to structure the process of job redesign.

Figure 5-3 Graph Comparing the Features at the Main Machine Level for Cells A and B

5.2 Model Comparisons, Cells B, C and D

The following sections summarise the finding from the research for Cells B, C and D. As with Cell A, quantitative measures are taken from the main research questionnaire and the Job Diagnostics Survey. Only quantitative data is shown to facilitate the presentation of findings. The full findings are described in Appendix D.

5.2.1 Quantitative Summary of Features

The collected data are representative of the state of job design at the three levels of analysis and are supported by the qualitative data presented in detail in Appendix D. Table 5-5 provides a quantitative summary of the features at the man-machine and job design levels of analysis for Cells B, C and D. Figure 5-3 and Figure 5-4 provide a visual comparison of the three Cells of man-machine and job design features respectively. Particularly large (≥ 4.0) or small (≤ 2.0) values highlight the dominant features at each level.

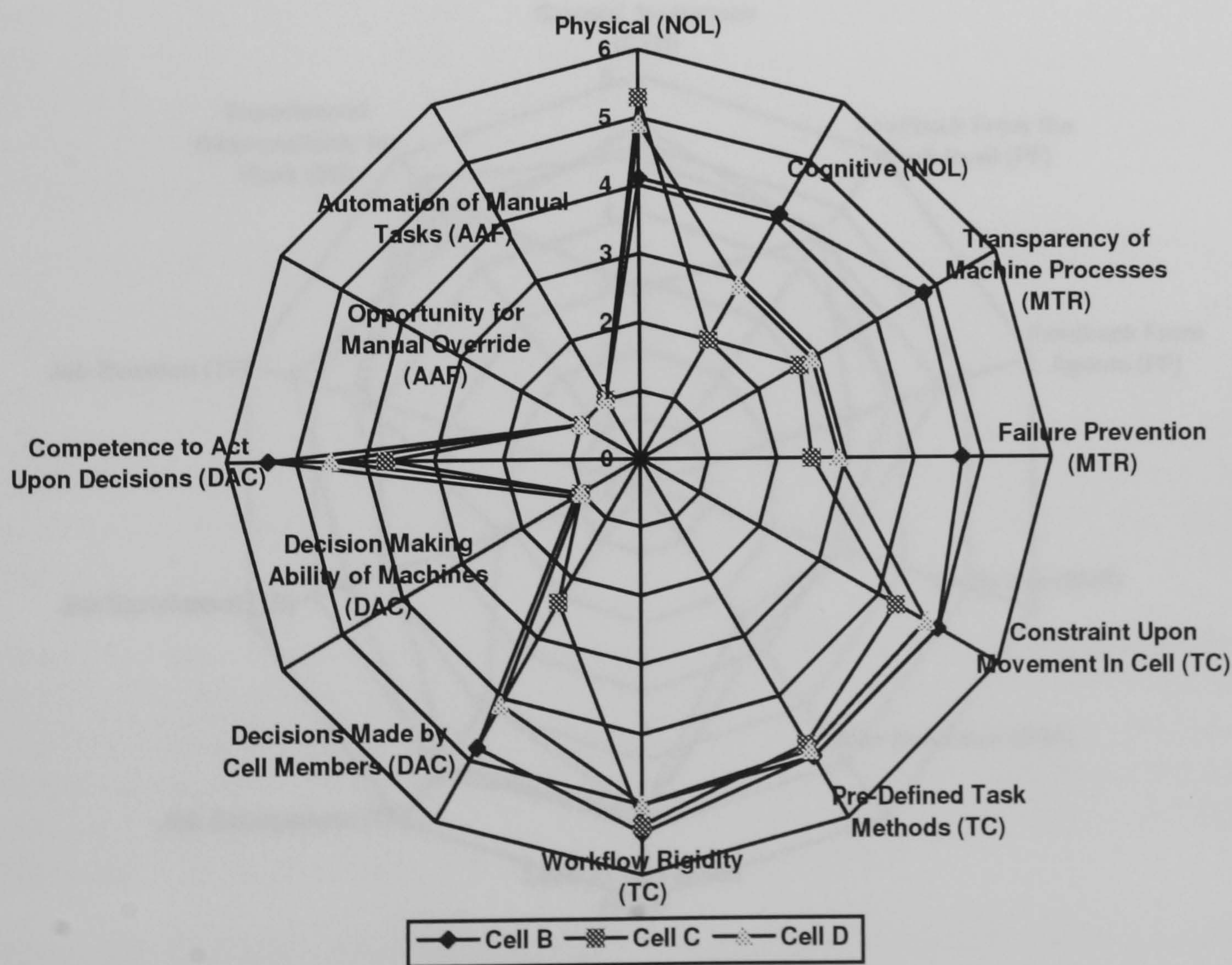


Figure 5-3 Graph Comparing the Features at the Man-Machine Level for Cells B, C and D

Table 5-6 and Table 5-7 summarise for Cell B the relationships between the man-machine and job design, and the job design and socio-technical levels respectively. These relationships were initially derived from the collected data and validated by the cell members and supervisors.

Likewise, Table 5-8 and Table 5-9 summarise the same for Cell C, and Table 5-11 and Table 5-10 for Cell D. The shaded columns in each Table represent the dominant relationships between adjacent levels which are of primary importance to the users of the model. Particularly large (≥ 2) or small (≤ -2) values highlight the dominant influences between adjacent levels of analysis. These limits for identifying the key dimensions are determined from the analysis of the collected data.

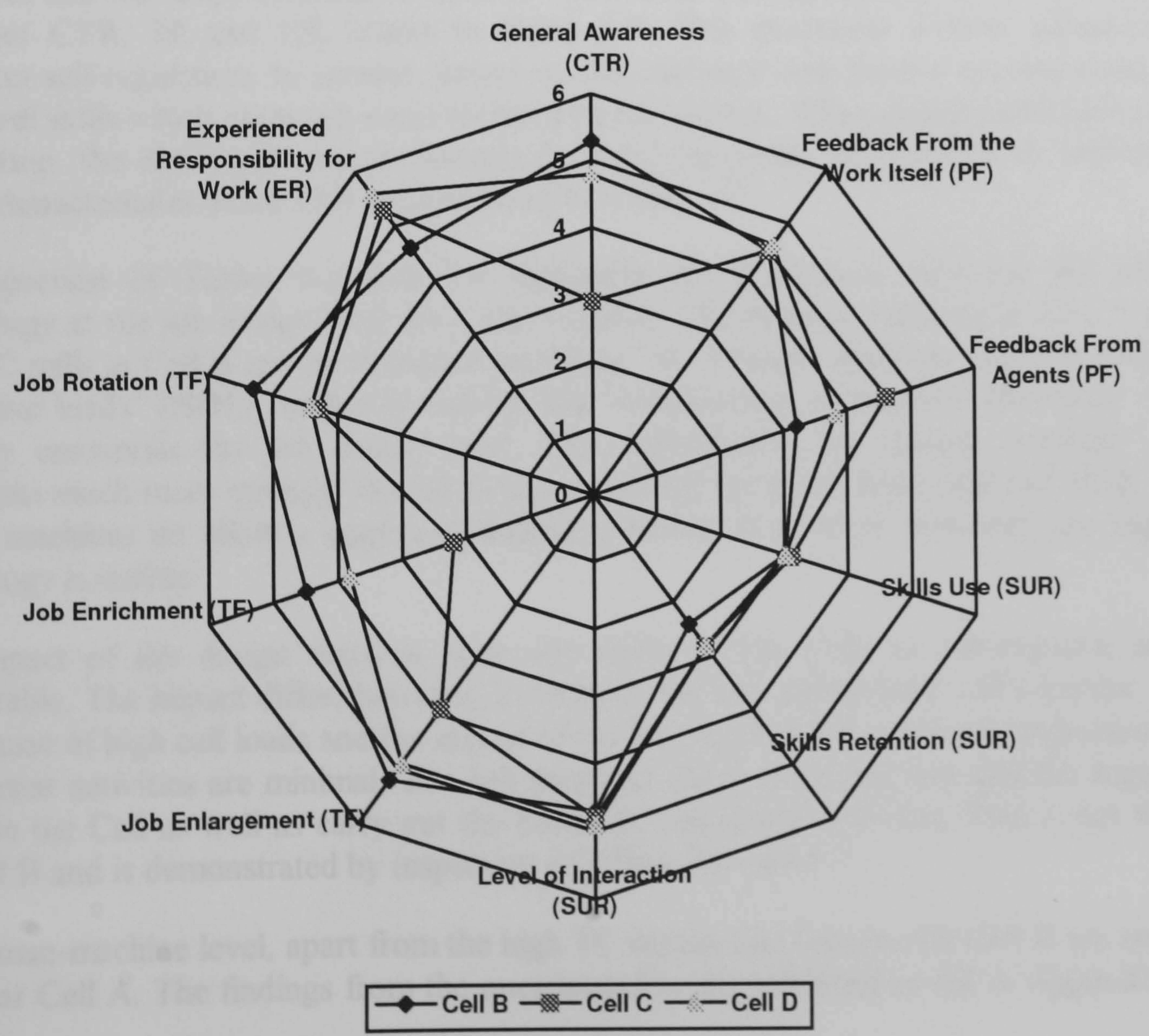


Figure 5-4 Graph Comparing the Features at the Job Design Level for Cells B, C and D

5.2.2 Discussion of Quantitative Data, Cell B

Cell B is three years old. The management structures are well established and there exists a high level of trust between the cell members and supervisors. This trust was facilitated by involving the cell members in designing the Cell and is fostered by their high levels of competence and skill in its operation. The company promoted human-centred manufacturing methods by seeking to foster the widespread adoption of high scoring IR, SUR, TF and ER job design features. Their realisation is, however, not always feasible.

The impact of the many NC machines upon these features is significant as reflected by the TC, MTR and AAF scores in Table 5-6. The Cell experiences consistently high cell loads and typically short machine cycle times (refer to Table 4-1). Basic machine operating activities are carried out for between 50% to 80% of the total working time. Because of this, the cell members experience high physical and cognitive loads and their activities are in general technologically mediated. These machines limit the use of high-level skills and require the cell members to continuously 'feed' machines with work. These are manifested by the dominant constraining man-machine features in Table 5-6.

The high skill levels of the cell members, their good knowledge of the manufacturing processes and the scope afforded to them to work with minimal supervision is reflected in the dominant CTR, IR and ER scores in Table 5-7. This promotes worker autonomy and facilitates self-regulation. In context, however, this contrasts with the low use and retention of high-level skills which constrain socio-technical level features. When opportunities arise during production, the above job design features facilitate the ability of the Cell to self-regulate. These characteristics of the Cell are described by Table 5-7.

An inspection of Tables 5-3 and 5-6 highlights the differences between the effect of technology at the job design level for Cells A and B. The Primary Machine in Cell A and the four NC mills in Cell B are the dominant machines. The Primary Machine does not foster high 'cognitive loads' (NOL), unlike in Cell B, and 'transparency of machine processes' (MTR) strongly constrains the job design level. The 'opportunity for manual override' (AAF) constrains much more strongly the job design level than the same dimension in Cell B. In Cell B, the machines do allow a degree of manual override. In general, however, the impact of technology is similar.

The impact of job design features upon the ability of the Cells to self-regulate are also comparable. The impact differ, however, in terms of the 'job enrichment' (TF) feature. In Cell A, because of high cell loads and the impact of the Primary Machine on work organisation, job enrichment activities are minimal. The cell members focus on production and the supervisors maintain the Cell as well as carry out the boundary regulation activities. This is not the case for Cell B and is demonstrated by inspection of Tables 5-4 and 5-7.

At the man-machine level, apart from the high TC scores, the features for Cell B are similar to those for Cell A. The findings from the questionnaires are tabulated in full in Appendix E. At

this level, job design in Cell B is characterised by the high NOL, MTR, TC and DAC and the low AAF and DAC scores (refer to Figure 5-3). Likewise, at the job design level of analysis, job design is characterised by the high CTR, PF, TF and ER scores (refer to Figure 5-4).

The inter-relationships between these levels reflect these individual level characteristics. From the process of compiling Table 5-6, the man-machine level dimensions most strongly facilitating the features at the job design level overall are the 'cognitive' (NOL), 'decision made by cell members' (DAC) and 'competence to act upon decisions' (DAC) scores. The dimensions most strongly constraining the overall level are 'physical' (NOL), 'failure prevention' (MTR), 'constraint upon movement in the cell' (TC), and 'opportunity for manual override' (AAF).

The individual strength of the dimensions at the man-machine level identifies firstly their impact upon function allocation issues and secondly it is used as a guide to determine their impact on *individual* job design dimensions. Their *overall* impact, however, at the job design level is not determined by their individual score. For example, the remaining dominant man-machine dimensions in Cell B viewed as not strongly facilitating or constraining the job design level overall, tended to simultaneously facilitate and constrain a range of job design dimensions throughout the level. This was the case for the 'transparency of machine processes' (MTR), 'pre-defined task methods' (TC), 'workflow rigidity' (TC), 'decision making ability of machines' (DAC) and 'automation of manual tasks' (AAF).

Overall, the job enrichment (TF) and job rotation (TF) dimensions are neither strongly facilitated nor constrained by the man-machine features (refer to Table 5-6). These dimensions are determined more by company manufacturing policy than by low-level machine issues. Job enlargement (TF) on the other hand is strongly facilitated by features at the man-machine level where the design of the machines constrain the cell members to do all the low-level machine operating work. This reflects the constraining NOL, TC and AAF scores in Table 5-6.

Both of the large NOL scores strongly influence the overall job design level. The 'physical' score (-4.5) constrains whilst the 'cognitive' score (+3.5) facilitates work organisation issues. The balanced physical and cognitive loads partially reflect the large individual 'job enrichment' (TF), 'job rotation' (TF) and 'experienced responsibility for work' (ER) scores at the job design level (refer to Table 5-5). These dimensions' large scores are strongly fostered by company manufacturing policy.

The overall impact of the dominant MTR, TC and AAF dimensions strongly constrain the SUR dimensions (refer to Table 5-6). This feature is, however, facilitated by two DAC dimensions. This highlights the potential opportunity to improve SUR by extending the facilitating dimensions whilst simultaneously minimising the impact of the constraining ones. This can be done for all job design dimensions by inspecting the rows in Table 5-6.

The ability of Cell B to self-regulate is facilitated overall by the 'general awareness' (CTR), 'levels of interaction' (IR) and 'experienced responsibility for work' (ER) job design dimensions (refer to Table 5-7). It is also constrained by all three SUR dimensions. The constraining relationship between machine design and the ability of the Cell to self-regulate is apparent through these SUR dimensions. Clearly, however, self-regulation is facilitated and constrained by a wide range of other dimensions which need to be considered together during job redesign. The joint inspection of Tables 5-6 and 5-7 facilitates this process. Furthermore at the man-machine level, the SUR dimensions are themselves facilitated and constrained by a range of man-machine dimensions. This inter-relationship across the three levels, therefore, does not exist in isolation and must be evaluated in context.

Cells A and B are similar in many technological and organisational respects. The Tables identify these similarities at the various levels as well as the differences. The models differentiate between the Cells by describing the individual strengths of relationships between features at adjacent levels to accurately reflect the specific characteristic of the Cells. The model for Cells A and B differ more widely at the man-machine and job design levels because of the influence of the Primary Machine in contrast to the four NC mills in Cell B. Even though the approach to job design is similar in both Cells, the cell members have identical skill levels and the Cells share the same supervisors, the model is sensitive enough to accurately describe and reveal the differences in job design between the Cells.

5.2.3 Discussion of Quantitative Data, Cells C and D

Apart from 'decisions made by cell members' and 'cognitive loads', the features for Cells C and D are similar. At the job design level, Cells C and D differ in terms of 'general awareness', 'feedback from agents', 'job enlargement' and 'job enrichment' issues. The findings from the questionnaires are tabulated in full in Appendix E.

Cells C and D are relatively young and the procedures in both Cells are not well established. The low skill levels of the cell members in Cell C, the absence of job enrichment practices and poor Cell transparency constrains the ability of the Cell to self-regulate. This is confirmed by the constraining influence of the CTR, SUR and TF features in Table 5-9.

The technologies in both Cells and their impact upon work organisation are similar. Eight out of the twelve man-machine dimensions strongly constrain the CTR, PF, SUR and TF features at the job design level (cf. horizontal sum; refer to Tables 5-8 and 5-10). Although the strengths of the relationships between the man-machine and job design levels are not identical, their general constraining and facilitating influences are the same. At the higher levels of analysis, where management has more strategic choice in designing different job configurations, the higher skill levels of the cell members in Cell D and the higher levels of trust between them and management is reflected in Table 5-11.

The cell members in Cell D are more skilled than those in Cell C (refer to Table 4-1). The poor use of these high-level skills, however, strongly constrains the ability of Cell D to self-regulate. Their understanding of the manufacturing processes, in contrast with the cell members in Cell C, however, facilitates self-regulation (refer to Table 5-11).

5.3 Summary

This chapter validated the model by outlining the job design analysis for each Cell. The method of analysis and conclusions are fully agreed to by the industrial participants in the research. The features and dimensions at the three levels of analysis are comprehensive and are representative of the issues embraced at each level. The location of the features in the socio-technical, job design and man-machine levels provide a focus for job redesign decisions.

For Cells A and B, the model identifies job design, skill level and management similarities in both Cells as well as technological differences. Situation specific models of job designs are generated in quantitative terms that reveal and describe their similarities at the job design and socio-technical levels and their differences at the man-machine and job design levels.

For Cells C and D, each model accurately describes the state of job design in the Cells and highlights the similarities and differences between the low and high level issues. Although the two Cells share technological similarities the model differentiates between them at the job design and socio-technical levels because of differences in skill levels and skills use, work organisation and management policy. Although the technologies are the same between these Cells, the model recognises and describes accurately the impact of organisational choice in job design.

The quantitative measures afford the model enough sensitivity to differentiate between technologically and organisationally similar cell systems. The model demonstrates its generalisability by accurately describing job designs in four dissimilar cell systems differing widely in terms of cell age, the skill levels of the cell members, work organisation and management philosophy.

In Chapter Six, the model is used in three different job design scenarios involving collected data from Cells A, B and C to demonstrate the flexibility and scope for model application.

Table 5-5 Table Summarising the Features at the Man-machine and Job Design Levels of Analysis

	Cell B	Cell C	Cell D
	AVG	AVG	AVG
Man-Machine Level of Resolution			
<i>Nature of Operator Loading</i>			
Physical	4.1	5.3	4.9
Cognitive	4.1	2.0	2.9
Satisfaction	3.9	4.5	4.2
<i>Machine Transparency</i>			
Transparency of Machine Processes	4.8	2.7	2.9
Failure Prevention	4.7	2.5	2.9
Satisfaction	4.4	3.5	3.0
<i>Technical Coupling</i>			
Constraint Upon Movement In Cell	5.0	4.3	4.8
Pre-Defined Task Methods	5.0	4.8	4.9
Workflow Rigidity	5.4	5.3	5.0
Satisfaction	4.1	3.7	4.2
<i>Decision Authority and Competence</i>			
Decisions Made by Cell Members	4.8	2.4	4.1
Decision Making Ability of Machines	1.1	1.0	1.0
Competence to Act Upon Decisions	5.4	3.7	4.5
Satisfaction	5.0	4.3	4.5
<i>Adaptive Allocation of Functions</i>			
Opportunity for Manual Override	1.0	1.0	1.0
Automation of Manual Tasks	1.0	1.0	1.0
Satisfaction	2.7	3.2	3.2
Job Design Level of Resolution			
<i>Cell Transparency</i>			
General Awareness	5.3	2.9	4.8
<i>Process Feedback</i>			
Feedback From the Work Itself	4.5	4.5	4.6
Feedback From Agents	3.2	4.6	3.8
<i>Skills Use and Retention</i>			
Skills Use	3.0	3.1	3.0
Skills Retention	2.4	2.8	2.8
Satisfaction	2.3	3.4	3.9
<i>Interaction Requirements</i>			
Level of Interaction	4.7	4.8	4.9
Satisfaction	4.5	4.5	4.6
<i>Task Flexibility</i>			
Job Enlargement	5.2	3.9	4.9
Job Enrichment	4.5	2.2	3.8
Job Rotation	5.3	4.3	4.4
Satisfaction	3.9	4.5	4.9
<i>Experienced Responsibility for Work</i>			
Experienced Responsibility for Work	4.6	5.3	5.6

Table 5-6 Matrix Summarising the Impact of Function Allocation Features Upon Work Organisation Issues in Cell B

Man-Machine Level		NOL		MTR		TC		DAC		AAF		Net Impact Upon JD Feature		
		Physical	Cognitive	Transparency of Machine Processes	Failure Prevention	Constraint Upon Movement in Cell	Pre-Defined Task Methods	Workflow Rigidity	Decisions Made by Cell Members	Decision Making Ability of Machines	Competence to Act Upon Decisions		Opportunity for Manual Override	Automation of Manual Tasks
CTR	General Awareness	c	f	f	c	C			f			c		-0.5
PF	Feedback from the Work Itself	c	f	f	c					c		c		-0.5
	Feedback from Agents							f						+0.5
SUR	Skills Use	C		c	c		C	c	f		f	c		-2.0
	Skills Retention	C			c		c	c	f		f	c		-1.5
	Skills Variety	C		c	c	C	c	c	f		f	c		-2.5
TF	Job Enlargement	f	F		c		f	f	F	f	f	c	f	+4.0
	Job Enrichment	c	f	c	c	c			f		f	c	c	-1.0
	Job Rotation		f						f		f			+1.5
IR	Level of Interaction		f			c		c					c	-1.0
	Dealing With Others							f			f			+1.0
ER	Experienced Responsibility for Work	c	f	c	C		c		F		F			0
Net Impact of MM Feature		-4.5	+3.5	-1.0	-4.5	-3.0	-2.0	-0.5	+5.0	0	+4.5	-3.5	-0.5	

KEY

Code	Meaning	Score
C	Large Constraint	-1
c	Small Constraint	-0.5
F	Large Facilitator	+1
f	Small Facilitator	+0.5

Table 5-7 Matrix Summarising the Impact Job Design Features Upon The Ability of Cell B to Self-Regulate

Job Design Level	CTR	PF		SUR			TF			IR		ER
	General Awareness	Feedback from the Work Itself	Feedback from Agents	Skills Use	Skills Retention	Skills Variety	Job Enlargement	Job Enrichment	Job Rotation	Level of Interaction	Dealing With Others	Experienced Responsibility for Work
System Independence	F	c	c	f	C	C	f	C	f	F	f	F
Task Interdependence and Sources of Variance	F			C	C	c		c	f	f	f	F
Boundary Regulation	F			C	C	c	f	f		f	f	F
Net Impact Upon STS Feature	+3.0	-0.5	-0.5	-2.5	-3.0	-2.0	+1.0	-1.0	+1.0	+2.0	+1.5	+3.0

Table 5-8 Matrix Summarising the Impact of Function Allocation Features Upon Work Organisation Issues in Cell C

Job Design Level		Man-Machine Level		NOL		MTR		TC			DAC		AAF		Net Impact Upon JD Feature
		Physical	Cognitive	Transparency of Machine Processes	Failure Prevention	Constraint Upon Movement In Cell	Pre-Defined Task Methods	Workflow Rigidity	Decisions Made by Cell Members	Decision Making Ability of Machines	Competence to Act Upon Decisions	Opportunity for Manual Override	Automation of Manual Tasks		
CTR	General Awareness	c	c	c	c	c	c	c	C			c		-5.0	
PF	Feedback from the Work Itself	C	c	C	C					C		C		-5.5	
	Feedback from Agents													0	
SUR	Skills Use	C	c	c	c	c	C	c	C		f	c		-5.5	
	Skills Retention	C	c	c	c	c		c				c		-4.0	
	Skills Variety	C		c	c	c	c	c	c			c		-5.0	
TF	Job Enlargement		c						c			c		-1.5	
	Job Enrichment	C	c	C	c	c	c	c	C		f	c	c	-8.0	
	Job Rotation	f	f											+1.0	
IR	Level of Interaction						C						c	-2.0	
	Dealing With Others		c					c	c					-1.5	
ER	Experienced Responsibility for Work	C	c	C	c	c			c		f	c		-3.0	
Net Impact of MM Feature		-6.0	-4.0	-5.0	-4.0	-2.5	-3.5	-3.0	-5.0	-1.0	+1.5	-4.5	-1.0		

KEY

Code	Meaning	Score
C	Large Constraint	-1
c	Small Constraint	-0.5
F	Large Facilitator	+1
f	Small Facilitator	+0.5

Table 5-9 Matrix Summarising the Impact Job Design Features Upon The Ability of Cell C to Self-Regulate

Job Design Level	CTR	PF		SUR			TF			IR		ER
	General Awareness	Feedback from the Work Itself	Feedback from Agents	Skills Use	Skills Retention	Skills Variety	Job Enlargement	Job Enrichment	Job Rotation	Level of Interaction	Dealing With Others	Experienced Responsibility for Work
System Independence	c	C	c	C	C	C	f	C	f	f		f
Task Interdependence and Sources of Variance	C	c		C	C	C	c	C	f	c		
Boundary Regulation	C	c	c	C	C	C	c	C		C	C	
Net Impact Upon STS Feature	-2.5	-2.0	-1.0	-3.0	-3.0	-3.0	-0.5	-3.0	+1.0	-1.0	-1.0	+0.5

Table 5-11 Matrix Summarising the Impact of Function Allocation Features Upon Work Organisation Issues in Cell D

Job Design Level		Man-Machine Level												
		NOL		MTR		TC			DAC		AAF		Net Impact Upon JD Feature	
		Physical	Cognitive	Transparency of Machine Processes	Failure Prevention	Constraint Upon Movement In Cell	Pre-Defined Task Methods	Workflow Rigidity	Decisions Made by Cell Members	Decision Making Ability of Machines	Competence to Act Upon Decisions	Opportunity for Manual Override		Automation of Manual Tasks
CTR	General Awareness	C	c	c	C	c		c	C			c		-5.5
PF	Feedback from the Work Itself	C	c	c	c					C		C		-4.5
	Feedback from Agents													0
SUR	Skills Use	C	c	c	c	c	C	c	C		f	c		-5.5
	Skills Retention	C	c	c	c		c	c	C			c		-5.0
	Skills Variety	C	c	c	c		c	c	c			c		-4.5
TF	Job Enlargement				c				f		f	c		0
	Job Enrichment	c	c	c	c	c	C	c	c		f	c		-4.5
	Job Rotation	c	c											-1.0
IR	Level of Interaction							c					c	-1.0
	Dealing With Others						c	C						-1.0
ER	Experienced Responsibility for Work		c	c					f		f	c		-0.5
	Net Impact of MM Feature	-5.5	-4.0	-4.0	-4.0	-1.5	-3.5	-3.0	-3.0	-1.0	+2.0	-4.5	-0.5	

KEY

Code	Meaning	Score
C	Large Constraint	-1
c	Small Constraint	-0.5
F	Large Facilitator	+1
f	Small Facilitator	+0.5

Table 5-10 Matrix Summarising the Impact Job Design Features Upon The Ability of Cell D to Self-Regulate

Job Design Level	CTR	PF		SUR			TF			IR		ER
	General Awareness	Feedback from the Work Itself	Feedback from Agents	Skills Use	Skills Retention	Skills Variety	Job Enlargement	Job Enrichment	Job Rotation	Level of Interaction	Dealing With Others	Experienced Responsibility for Work
System Independence	f	c	c	c	c	c	f	c	f	f		c
Task Interdependence and Sources of Variance	f	c		c	C	C	f	c	f		f	
Boundary Regulation	F	c	c	C	C	C		f		f		C
Net Impact Upon STS Feature	+2.0	-1.5	-1.0	-2.0	-2.5	-2.5	+1.0	-0.5	+1.0	+1.0	+0.5	-1.5

CHAPTER SIX

DISCUSSION AND CONCLUSION

The discussion of results in the thesis is in two parts. Three application uses of the Cell Job Design Model is first demonstrated. These cases illustrate the value of the model as a practical tool for cell redesign and improvement.

The achievement of this research is then discussed in the academic context of Job Design research. After the conclusion, the contribution to knowledge is stated and recommendations for future research outlined.

6.1 Model Use - Sample Scenarios

Three sample scenarios are presented to demonstrate how the model may be used for a range of applications. These sample scenarios are outlined here:

- 1) It is proposed to improve manufacturing flexibility and reliability by replacing the Primary Machine in Cell A with a number of new NC machines. Production levels and product quality are not to be affected. The objective is to generate a machine specification from a job design perspective to improve the ability of the Cell to self-regulate.
- 2) Improve the ability of Cell B to self-regulate by improving job designs. All equipment in the Cell remains unchanged and it is essential that production and product quality are not affected.
- 3) Improve the intrinsic motivating potential of work in Cell C. Machinery may be adapted to facilitate change. As with previous scenarios, production and product quality are to remain unaffected.

For each scenario, the steps taken to use the model to meet these objectives is described. Throughout the scenarios, 'improvement' implies changing job designs in a way more compatible with human-centred design methods (cf. Section 2.2.3.2).

The purpose of describing the steps taken is not to generate solutions but to show how the model may be used effectively. Decisions to change and improve job designs are made by the users of the tool. High-level 'solutions', however, are presented to highlight, in broad terms, the types of decisions the users of the model may make to fulfil scenario objectives. The three scenarios are described in turn.

6.1.1 Sample Scenario One, Cell A

The objective is to generate a machine specification from a job design perspective to improve the ability of the Cell to self-regulate. The model may be used by the users in the following way to help generate solutions to meet scenario objectives:

- 1) Identify the dominant features at the man-machine and job design levels.
- 2) From an analysis of the qualitative and quantitative feature descriptions, identify the relationships between dimensions at the man-machine and job design levels of analysis. Sum the effects and identify the dominant man-machine level dimensions (refer to Table 5-3).
- 3) Identify the overall influence of the man-machine level dimensions upon each job design dimension. Sum the effects and identify the most strongly constrained and facilitated dimensions.
- 4) With these, the man-machine / job design matrix can be reduced to contain only those features highlighted in 1 and 2. In this form, the matrix summarises the dominant man-machine level dimensions that affect the job design level of analysis (from 2) as well as the job design level dimensions most affected by features at the man-machine level (from 3).
- 5) From an analysis of the qualitative and quantitative feature descriptions, identify the relationships between dimensions at the job design and socio-technical levels of analysis. Sum the effects and identify the dominant man-machine level dimensions (cf. vertical sum; refer to Table 5-4).
- 6) The job design / socio-technical matrix can be reduced to contain only those features highlighted in 5. In this form, the matrix summarises the dominant job design level dimensions that affect the socio-technical level of analysis. The detail of each dimension is quantitatively and qualitatively described in the research; refer to Table 5-5 and Appendix D. The characteristics of the 'facilitating' job design dimensions that need to be *maintained* are:
 - a) General Awareness (CTR),
 - b) Levels of Interaction (IR),
 - c) Experienced Responsibilities for Work (ER).
- 7) Correspondingly, it is essential to *improve* the characteristics of the following job design level dimensions:
 - a) Skills Use (SUR),
 - b) Skills Retention (SUR),
 - c) Skills Variety (SUR),
 - d) Job Enrichment (TF).
- 8) At the job design level, group together those features sharing related or common characteristics. Prioritise these groups in order of relevance and importance based on scenario objectives. Identify (from Table 5-4) the job design level dimensions that constrain and facilitate the dimensions at the socio-technical level of analysis.

- 9) To relate the characteristics of the proposed new NC machines with the socio-technical level of analysis, identify (from Table 5-3) the range of man-machine dimensions affecting the above seven job design level dimensions in 7 and 8. For example, the man-machine dimensions *constraining* 'general awareness' and 'experienced responsibilities for work' are:
- a) Physical (NOL),
 - b) Transparency of Machine Processes (MTR),
 - c) Failure Prevention (MTR),
 - d) Opportunity for Manual Override (AAF).
- 10) The man-machine dimensions *facilitating* 'general awareness' and 'experienced responsibilities for work' are:
- a) Decisions made by cell members (DAC),
 - b) Competence to act upon decisions (DAC).

The man-machine dimensions constraining and facilitating 'general awareness' are the same for 'experienced responsibilities for work' with a stronger emphasis on the DAC dimensions (refer to Table 5-3). No overall dominant man-machine dimensions affect the 'levels of interaction' dimension. Two other TC dimensions constrain 'levels of interaction'. These could be considered in the final machine specification if deemed important by the users.

- 11) Because the dimensions are inter-related and not independent, at the man-machine and job design levels, group together those features sharing related or common characteristics. Prioritise these groups in order of relevance and importance based on scenario objectives.

The dimensions outlined in 10 need to be maintained by the new equipment, whilst those in 9 need to be collectively improved. For example, whilst maintaining 10)a) and b), the users may require the new equipment to:

- a) Reduce the overall physical loads to avoid the cell members merely 'feeding' the machine with work,
 - b) Keep the cell members 'in-the-loop' and advance failure prevention by using equipment with more flexible and intuitive man-machine interfaces. This would improve the visibility of the machine processes,
 - c) Facilitate a) and b) by enabling cell members to intervene in machine cutting operations.
- 12) To build-up a full machine specification based on job design objectives, the process outlined in 9, 10 and 11 is carried out for the grouped job design features. The research provides the low-level qualitative data for each dimension with which to carry out the above task in detail.

This process ensures that the job design oriented machine specification complements existing and/or proposed cell procedures and human-centred policies to facilitate self-regulation. This is because the users deal only with the dominant man-machine and job design level dimensions. These describe the key organisational and technological issues

most affecting the shape of function allocation and job design in the Cell. It is these features that describe the central themes of the above procedures and policies.

- 13) Identify the procedures at the socio-technical level needed to accommodate the modified job design features. For example, the users would describe new procedures for the 'system independence' and 'boundary regulation' features in light of proposed responsibility and skills changes of the cell members.

Changes in groups of job design dimensions will require a redefinition of responsibilities and boundaries, the scope for decision making and job content for cell members and supervisors. Additional boundary regulation responsibilities may be allocated to the cell members requiring further training and the use of more high level skills. The impact of each group of job design dimensions upon each socio-technical dimension must be dealt with systematically to fully consider the potential impact of the proposed NC equipment at all levels for the supervisors and cell members.

6.1.1.1 Discussion - Scenario One

In this scenario, the model fosters the development of a machine specification based on job design criteria. The specification is integrated with wider job design and socio-technical considerations and with proposed new responsibilities and procedures for the cell members and supervisors to carry out.

The detail in developing 'solutions' comes from the experiences and knowledge of the users as well as from the research findings themselves. In this scenario, the scope for strategic change is broad and depend on many 'soft' issues. For example, the users of the model (i.e. managers, supervisors and cell members) need to consider political issues embracing the re-allocating of responsibilities and authority, training, pay increases and promotions.

The model guides the users to consider a *range* of issues that *collectively* influence the ability of the Cell to self-regulate. This reflects the complexity of job design and the way features at the three levels of analysis are inter-related. The model does not imply a direct relationship between features and levels.

There are, however, no cause-and-effect relationships between the low-level machine effects on function allocations and the ability of the Cell to self-regulate. It is a guide, however, to support a comprehensive step-by-step approach to job redesign by describing individual features and highlighting possible inter-relationships between ranges of features.

6.1.2 Sample Scenario Two, Cell B

The objective is to improve the ability of the Cell to self-regulate by improving job designs. All equipment in the Cell remains unchanged and it is essential that production and product quality are not affected. This scenario places the emphasis on the job design and socio-technical levels

of analysis. The model may be used by the users in the following way to help generate solutions to meet scenario objectives:

- 1) Identify the dominant features at the job design level (refer to Table 5-5).
- 2) From an analysis of the qualitative and quantitative feature descriptions, identify the relationships between dimensions at the job design and socio-technical levels of analysis. Sum the effects and identify the dominant job design level dimensions (cf. vertical sum; refer to Table 5-7).
- 3) The job design / socio-technical matrix can be reduced to contain only those features highlighted in 2. In this form, the matrix summarises the dominant job design level dimensions that affect the socio-technical level of analysis. The characteristics of the 'facilitating' job design dimensions that need to be *maintained* are:
 - a) General Awareness (CTR),
 - b) Levels of Interaction (IR),
 - c) Experienced Responsibilities for Work (ER).
- 4) Correspondingly, it is essential to *improve* the characteristics of the following job design level dimensions:
 - a) Feedback From the Work Itself (PF),
 - b) Skills Use (SUR),
 - c) Skills Retention (SUR).
- 5) At the job design level, group together those features sharing related or common characteristics. Prioritise these groups in order of relevance and importance based on scenario objectives. Identify (from Table 5-7) the job design level dimensions that constrain and facilitate the dimensions at the socio-technical level of analysis.

These six dimensions need to be maintained and/or improved collectively to improve procedures to cope with system variances and to ensure the regulation of the Cell 'boundary'. Solutions will primarily involve organisational change because of the unchanging technological features.

Consequently, new configurations of work organisation around the fixed technological elements need to be developed and existing practices fully utilised. The details of these practices can be reviewed from the research findings and used to identify potential areas for improvement. A possible 'solution' may be to:

- a) Allocate the responsibility to the cell members to implement improved SPC methods to complement and improve existing preventative maintenance practices. This would improve 'feedback from the work itself' and would help to constantly monitor product and process quality over time.
- b) Improve the maintenance skills of the cell members to enable them to carry out the preventative maintenance activities. This would help improve system ownership, the use and retention of high-level skills and the ability of the cell members to visualise the state of the Cell at any given time.
- c) Work practices may be implemented to improve 'levels of interaction' between the Cell and the downstream assembly cell to improve feedback on product quality.

Items b) and c) seek to improve 'system independence', the 'experienced responsibility for work' and help ensure the supervisors deal solely with issues beyond the Cell 'boundary'.

6.1.2.1 Discussion - Scenario Two

The issues raised in Section 6.1.1.1 also apply to Scenario Two. The relationships between groups of dimensions in adjacent levels must be studied systematically and thoroughly. The impact of change of one dimension upon another must be fully described. Changes to any of the ER, SUR and PF features will impact upon the boundary regulation responsibilities of the supervisors. The collective impact needs to be considered in detail.

As with scenario one, the model guides the users to consider a *range* of issues that *collectively* influence the ability of the Cell to self-regulate. It is essential that the dimensions are considered in related groups. The grouping is carried out intuitively by the users based on the industrial context, scenario objectives and the experience and knowledge of the users.

6.1.3 Sample Scenario Three, Cell C

The objective is to improve the intrinsic motivating potential of work in the Cell. Machinery may be adapted to facilitate change. As with previous scenarios, production and product quality are to remain unaffected. This scenario places the emphasis on the job design and man-machine levels of analysis. The model may be used by the users in the following way to help generate solutions to meet scenario objectives:

- 1) Identify the dominant features at the man-machine and job design levels (refer to Table 5-5).
- 2) From an analysis of the qualitative and quantitative feature descriptions, identify the relationships between dimensions at the man-machine and job design levels of analysis. Sum the effects and identify the dominant man-machine level dimensions (refer to Table 5-9).
- 3) Identify the overall influence of the man-machine level dimensions upon each job design dimension. Sum the effects and identify the most strongly constrained and facilitated dimensions.
- 4) With these, the man-machine / job design matrix can be reduced to contain only those features highlighted in 1 and 2. In this form, the matrix summarises the dominant man-machine level dimensions that affect the job design level of analysis (from 2) as well as the job design level dimensions most affected by features at the man-machine level (from 3).
- 5) Identify the job design level dimensions that will contribute towards more intrinsically motivating work. The selection of job design features will vary according to the objectives and priorities of the users. For this scenario, let us assume the following features were perceived to collectively need improvement:
 - a) General Awareness (CTR).

- b) Feedback From Agents (PF),
- c) Skills Use (SUR),
- d) Skills Variety (SUR),
- e) Job Enrichment (TF),
- f) Experienced Responsibility for Work (ER).

These six dimensions need to be improved collectively. The detail for these issues can be reviewed from the research data and used to identify potential areas for improvement.

- 6) Identify the dominant man-machine level features that facilitate and constrain the job design features in 5. For example, 'general awareness', 'skills use' and 'job enrichment' are constrained by eight dominant man-machine features. Likewise, 'feedback from agents' is constrained by five, 'skills variety' by seven and 'experienced responsibility for work' by six.
- 7) Propose technological and organisational measures to facilitate improvements in related groups of job design level dimensions.

This is approached by collectively considering the effects of all dominant man-machine dimension on a group of related job design dimensions. For example, the users may propose that the 5)b), c), d) and e) features are related and should be collectively improved. Possible changes may encompass:

- a) Improve the design of the two lathes, in-house, and implement SPC methods to improve feedback from the work itself.
- b) Allocate responsibilities to the cell members to act upon this feedback in the form of proposing further process improvements.
- c) As with Scenario Two, improve the maintenance skills of the cell members to enable them to carry out preventative maintenance activities. This as well as a) and b) above will help prevent machine failures and improve machine transparency.
- d) Improve co-operation and planning between the Cell and the downstream assembly cell. Allocate responsibilities to the cell members to plan workloads and to set weekly production targets.
- e) Implement formal methods to provide feedback on and record product quality between cells. Allocate the responsibility to the cell members to propose and implement related process improvements.
- f) Allocate responsibilities to the cell members to organise and act upon weekly and daily planning, cost cutting, continuous improvement and production meetings.

6.1.3.1 Discussion - Scenario Three

The issues raised in the Scenarios One and Two also apply to Scenario Three. The above and a vast range of other more detailed proposals may be implemented to achieve the scenario objectives. This process is carried out systematically for all job design dimensions to build-up a comprehensive strategy for job redesign. The model provides a formal checklist to minimise a piecemeal (i.e. non-systematic or comprehensive) approach to job redesign.

In using the model to implement effective job designs the changing roles of the supervisors must not be neglected (refer to Section 2.3). Since job design is intimately related to management structure and practice, and new forms of work organisation often lead to self-supervision for the cell members, the role of supervisors must be affected. Their roles are represented and require consideration at the socio-technical level of analysis. Supervisors must not be left in a 'vacuum' where a large part of their own job has been removed and they have no mandate or expertise to develop a wider planning and/or co-ordination function.

6.2 Application of the Model in Job Redesign

Central to the model's use is the importance of optimising the twin concerns of employee well-being and the productivity (cf. socio-technical systems theory). From an academic and practical viewpoint, the first issue involves the use of the model in developing practical knowledge from the experience of carrying out job redesigns. Here, the consistent use and re-use of the model as well as the formal measurement of the resulting job designs are of paramount importance. The second issue, from a practical perspective, is to get the best out of developments in new technology.

The approach taken in the research complements the view for the need to allocate functions in a way that results in intrinsically motivating jobs (Chapanis, 1965a; Sinclair, 1988; Clegg et al., 1993; Grote, 1994; Mital et al., 1994). Complementary function allocation methods seek to achieve the above by adopting a human-centred approach to the basic design of man-machine systems (refer to Section 3.2.2.3; Martin et al., 1990; Weik, 1993; Grote, 1994; Weik et al., 1995) and to merge function allocation and job design decision criteria (Jordan, 1963; Corbett, 1986). This model, therefore, formalises the close relationship between the process of allocating functions (at the man-machine level) and the subsequent work organisation (at the job design level). At the man-machine level, the model focuses on the individual functions of people and machines and seeks not only to tackle the social dimensions of change as is often the case with many socio-technical experiments. The model can accommodate the individual differences between people fosters an overt discussion of job design.

The model explicitly tackles function allocation issues and may be used to provide a comprehensive job design specification of cell systems. From an academic perspective, the model supports complementary function allocation tools (cf. Chapanis, 1965; Price, 1968; Gosh and Helander, 1983; Greenstein and Lam, 1985; Price, 1985; Ravden et al., 1987; Clegg et al., 1989; Clegg et al., 1993; Hin, Lou and Drury, 1993; Clegg, 1994) and plays an integral role in structuring the whole job redesign process. The model does not adopt a flowchart approach to complementary function allocation which is a characteristic of nearly all complementary function allocation methods. Instead, the data collection methodology accompanying the model facilitates the description of the state of function allocation at the man-machine level and demonstrates how this relates to wider job design and socio-technical issues.

The process of complementary function allocation can be carried out through the joint analysis of the model and the use of a flowchart function allocation method. The formal complementary function allocation process is facilitated by the use of the model. Here, the model describes in detail the state of job design in the Cells, whilst the formal function allocation method provides the complementary function allocation criteria.

The model embraces the homeostasis characteristic of open systems by integrating function allocation and wider job design considerations with issues relating to the ability of the system to self-regulate; i.e. cope with and absorb 'environment' and '(sub-)system' variances (cf. purposeful systems, refer to Section 3.1.3). The approach, therefore, considers the process of job design from low and high-level conceptual and practical perspectives. This fosters the generation of more robust and situation specific manufacturing systems.

This characteristic of the model complements the wider more embracing perspective of human-centred job design methods by moving the focus of job design beyond that of the individual and the work-group to embrace the 'organisation' (Clegg, 1984; Alder, 1986; Cooley, 1987; Blumberg, 1988; Corbett, 1989; Martin, 1990; Schmid et al, 1992; Kidd, 1992a,c; Parker et al, 1995). This is central to the design of jobs in cell systems. It achieves this by adopting a clear set of positive features embracing socio-technical and work organisational issues. As with the Job Characteristics Model (refer to Section 3.3.3), tools provide a structured approach towards the measurement and analysis of the features and their relationships. At the socio-technical level the units of analyses are the cell systems themselves. The scope for strategic choice in making job design decisions increases, in conceptual and practical terms, at the job design and socio-technical levels of analysis.

The involvement of the supervisors and cell members in the data collection and analysis process helped validate the model's structure and features. The three sample scenarios, demonstrate the range of possible applications. The data collection methodology accompanying the model provides a formal method of performance measurement and feedback. The use and re-use of the model can build-up a series of pictures describing the consequences of changes in job design over time. This facilitates a shared (or unitary) understanding between users of the inter-relationship between the organisational and technological elements of the cell systems. The model is, however, only as effective as the users' proficiency to carry out the preliminary data collection, their understanding and skill in using the model and their appreciation and experience of job design. The regular use of the model can facilitate learning about the manufacturing system in question and also about the process of job design in general.

A 'champion' needs to be selected to carry out the data collection and analysis based on the application procedure outlined in this Chapter Five and described more fully in Appendices D and E. The model should be used and validated by a multi-disciplinary team to facilitate the input of a rich set of experiences and knowledge. This needs to be done to generate a representative job design model. As a pre-requisite the 'champion' needs to have a good understanding of the job design concepts described in the model and must share this understanding with and provide guidance for using the model with all other users.

The formal capture of knowledge from the experience of job redesign in a range of manufacturing environments is essential to learn about and disseminate the benefits and shortcomings of various job design paradigms. For whatever use, the model acts as a focal point for a debate between policy makers, engineers, supervisors, cell members and trade union representatives on the use and implementation of new technologies and new forms of management structure.

6.3 Conclusion

This thesis emphasises the complexity of job design in open systems. A review of such methods and theories identifies a more human-centred trend towards job design in cellular manufacturing systems. This trend adopts an open systems perspective and extends the design view to embrace the system as the unit of analysis and change. The practice of human-centred job design in cells is an area with little formal process.

A generic model is presented to provide a systematic approach to human-centred job redesign in cell systems based on business need. An application procedure to use the model is developed and is derived from the research methodology in this thesis. It outlines the data capture, analysis and validation activities used to develop job design models for four manufacturing cells.

The combined model and application procedure are tools to help system designers accumulate additional knowledge on the factors affecting the design of jobs in a range of manufacturing environments. The effects of these factors are represented explicitly in the model by features at three levels of analysis which embrace socio-technical, work organisation and function allocation considerations. The generalisability of model application was demonstrated by the accurate context specific job design descriptions of the four Cells in Chapter Five. The flexibility and range of model applications are outlined above. Because the model is rooted in well established and generic job design methods, the features at the three levels of analysis are themselves generalisable:

- 1) Features at the socio-technical level of analysis embrace open system concepts and may be described for any purposeful system. They relate to job activities concerned with absorbing variances in manufacturing environments. Jobs in manufacturing cells are particularly suitable for description at this level because of their 'manufacturing island' and definable system boundary.
- 2) At the job design level of analysis, features describe issues relating to the grouping of tasks, work structures and how people work together. These issues embrace high-level job design issues where final job configurations are open to wide strategic choice based on company policy, management practice and political considerations. The features can be described for any man-machine system to foster work that is intrinsically motivating for people.
- 3) Features at the man-machine level of analysis describe low-level function allocation issues. These issues are by their nature system independent. Descriptions of job design at this level,

therefore, can relate to any sized collection of people and machines. Their organisation and relationships are not relevant.

The model provides a structured approach to quantitatively describe feature inter-relationships between adjacent levels of analysis. This makes more visible the 'knock-on' effects of changing individual job details upon the whole job. The quantitative descriptions of the features and their inter-relationships provide system designers with situation sensitive models of job design. These research methods and the research methodology itself can be re-applied to develop further models. They may be used to capture original job design objectives as a reference for further cell improvement and re-used to build-up a series of comparable snap-shots to formally record changes to the design of jobs.

In this thesis, the model was validated in and applied to a range of cell systems characteristic of small manufacturing cells. Because of the generic nature of the model, it may be re-applied to facilitate human-centred job redesign in any cellular environment.

6.4 Contribution To Knowledge

This research develops and validates a model that describes the factors and their relationships in manufacturing cell job design. This can be used as a template to facilitate human-centred job redesign in cell systems. The model unifies a range of existing job design theories and demonstrates how they are related within the process of job redesign in a range of cell systems. The research also extends the current base of empirical knowledge about job design in general.

6.5 Recommendations for Future Research

To improve and/or further validate the design of the model and the robustness of the research methodology, the model may be further re-used to facilitate job redesign in a wide range of manufacturing industries. The emergent properties of larger cell teams and cell members with different skill levels and task flexibilities need to be investigated to assess the generalisability and value of the model. For the same reasons, the model needs to be re-used in a range of industrial domains to assess the impact of different technologies.

The research has opened up many avenues for further research and in-depth enquiry. Opportunities for further research include:

- 1) Apply the model in a range of manufacturing domains to compile a database of case studies formally describing good and bad-practice in job redesign. From this, the model may be extended to include this good-practice knowledge to propose situation specific job design targets. Proposals may be in the form of describing good-practice feature inter-relationships and outlining methods to achieve them based on established success criteria.

- 2) Develop this database and the research methodology to facilitate job design in green field sites based on the characteristics of the proposed manufacturing systems.
- 3) Develop methods to integrate this model with group technology methods to foster the joint consideration of 'soft' and 'hard' engineering considerations throughout the whole system development process.
- 4) Fine-tune the model to embrace further features and/or extend the definition of features to modify their dimensions.
- 5) Modify the research methodology to embrace changes in 2 and to improve data validity and repeatability issues.

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