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THE IMPLEMENTATION OF CAD/CAM SYSTEMS IN THE METALWORKING INDUSTRIES

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SUMMARY

This thesis reports on a case survey of 15 UK metalworking companies and their experience of implementing an integrating technology - CAD/CAM. The thesis places this process of implementation in the organisational context of these companies by examining the ways in which the engineering/manufacturing interface is coordinated. This interface is important, because it is also critical to the effective implementation of such techniques as total quality management and simultaneous engineering.

In order to develop an incisive analysis of these companies, a contingency approach to organisational analysis is developed around the idea of flows of information and materials and their interaction with the structure of the organisation in a process of structuration. This analysis is placed in the strategic context of the organisations' relationships to their environment through the notion of a production strategy. Models of the process of implementation are then reviewed, and a recursive model of implementation as organisational changing is developed which emphasises the processes of organisational learning.

The management of the engineering design process has been little examined, in comparison to the management of manufacturing, and research and development. This thesis develops an analysis of the management of the entire production process from the conception of the product right through to its delivery to the customer in these 15 firms. It then goes on to examine the recent organisational changes in the engineering and manufacturing functions before examining the implementation process in detail. Finally, the basis of organisational integration from both a technological and organisational perspective is analysed, which provides the basis for some more general propositions on the development of production management over the next decade.

FOREWORD

Although presented as a doctoral thesis, this work is the culmination of over a decade of work on the process of technological change. It started in 1979 when I developed teaching materials around the BBC TV programme "Now the Chips are Down" for a Dockers' Day Release class at the University of Hull. It continued at Imperial College, working with Arthur Francis and Paul Willman on a Joint Committee funded project, and after an interregnum, developed fully on a project at Warwick Business School. Chris Voss was the grant holder of this Joint Committee funded project. This thesis reports on the larger part of this research, but also draws heavily on the earlier work.

The work draws extensively on the mainstream tradition of organisational sociology, but deploys many concepts from the production/operations managment literature to bolster some of the conceptual weaknesses of that tradition. It therefore presents a reformulation of the both the organisational sociology tradition, and the behavioural side of the production/operations management literature in a form that will, it is hoped, allow the trenchant analysis of the rapidly changing organisational landscape of the 1990s.

My thanks must go first and foremost to Chris Voss for his support and encouragement throughout the project both as principal investigator and doctoral supervisor. Gibson Burrell contributed enormously to the final shape of the thesis through his detailed and patient supervision of the writing of the text. Jon Clark and Peter Clark provided crucial support and encouragement as external assessors of the related SERC project. Thanks must go also to the innumerable people with whom I have discussed the ideas contained here - especially John Bessant, Dave Buchanan, Joanna Buckingham, Arthur Francis, Alan McKinlay, David Twigg, and Fiona Wilson. This work would have been impossible without the commitment and cooperation of the managers from the 15 companies surveyed, and my thanks are heartfelt and profound to these people who are actually creating the new organisational forms discussed herein. Of course, none of those mentioned bear any responsibility for my interpretations of our discussions.

INTRODUCTION

0.1 THE PARADOX OF FLEXIBILITY AND PRODUCTIVITY

> "We are beginning to look at our industrial processes as complete, integrated systems, from the introduction of the raw material until the completion of the final product...One way of defining automation is to say that it is a means of organizing or controlling production processes to achieve optimum use of all production resources - mechanical, material, and human....Fundamentally, I think automation means an optimisation of our business and industrial activities".

John Diebold (cited Bright 1958 appendix 1), speaking before a US Congress subcommittee in October 1955, thus posed the key issue facing production organisations in the middle decade of the century. As these organisations approach the end of the century, many would argue that integration remains the critical issue. Some have suggested that there has been a fundamental shift in the character of production organisation towards "flexible specialisation" (Piore and Sable 1984); or, in an echo of Daniel Bell, towards "post-industrial manufacturing" (Jaikumar 1986) since 1955, but there are also crucial continuities with earlier periods. Indeed, there is a sense in which Diebold was re-iterating the words of Andrew Ure (cited Clayre 1977 p 69) who, writing 120 years earlier, saw the factory as:

> "a vast automaton, composed of various mechanical and intellectual organs, acting in uninterrupted concert for the production of a common object, all of them being subordinated to a self-regulated moving force."

The notions of the "integration" and "system" in production operations are not new; what is new is the insistence that they should be managed flexibly. Bright, in his survey of the impact of mid fifties high technology identified one of the key issues in the management of automated production facilities as "lack of flexibility" (1958 p 212). Indeed, much of his book is a discussion of how to mitigate the inevitable reduction in production flexibility that automation then entailed. Earlier in that decade, John Diebold (1952 p 140) had identified the cost of "taping", or, as we would now call it, programming, as the most important single factor in the development of automation. The advent of microelectronics has allowed "taping" costs to be dramatically reduced, thereby enabling the development of programmable, flexible automation.

In addition to the dynamic development of efficient resource utilisation and cost reduction through productivity growth, product markets are now increasingly transmitting demands for both higher quality, and better response to customer needs in terms of both time and specificity. The emerging paradox of production management is that of managing for both productivity and flexibility. Traditionally, flexible production organisations, such as job shops, tended to be relatively "loosely coupled"; while their "tightly coupled" counterparts in the integrated mass and continuous process production sectors delivered the remarkable productivity gains that have been the foundation of post-war economic growth. The challenge now facing production management is, therefore, to deliver flexibility while at the same time, not sacrificing productivity growth - to give customers the cake of effective resource utilisation, while letting them choose the recipe, and the time they take their tea.

This paradox has its roots in the division of labour. Adam Smith lucidly expounded the benefits of the division of labour for the development of productivity, and also noted that it was limited by the extent of the market. For the subsequent 200 years, the pursuit of competitive production largely focused on an ever more detailed division of labour through the development of mass markets. This posed the problem of co-ordinating the fragmented production process; indeed, James D. Mooney, then a vice-president of General Motors argued in 1933 that

> "[co-ordination] expresses the principles of organization *in toto*; nothing less. This does not mean that there are no subordinated principles; it simply means that all the others are contained in this one of co-ordination. The others are simply the principles through which co-ordination operates, and thus becomes effective" (cited Urwick 1937).

One response to this problem was to establish bureaucratic procedures which regulated rather than reduced the fragmentation engendered by the division of labour. The most notable developments of this approach were those of scientific management and classical management theory. A second response was that epitomised by Ford which developed the assembly line in the years prior to World War 1, and the transfer line in the years subsequent to World War 2. Both bureaucratic organisation and production line technology were notable for their lack of flexibility, and it was the latter which influenced the conceptions of integrated production developed by John Diebold, James Bright, and their contemporaries. Productivity was achieved at the cost of flexibility.

A whole set of process innovations are now making the dynamic resolution of this paradox possible. The most important of these are total quality management (TQM) through which the whole production process is subject to continuous review and improvement against criteria of quality and service for the customer; simultaneous engineering in which the processes of product development and manufacture overlap with the objective of reducing "concept to customer" lead times and increasing product integrity; and advanced manufacturing technologies (AMT) which deploy a wide variety of programmable control and data base technologies in the office and on the shop floor aimed at reducing costs and improving control of the production process.

What all three have in common is that they are forcing a radical re-appraisal of the interface between the engineering design process and the manufacturing process. Poorly designed products cannot be manufactured well[1], and so TQM's continuous improvement feedback loops increasingly need to pass through engineering design to be fully effective. Greater communication, co-ordination, and trust between engineering and manufacturing, proficiently project managed, are the essence of simultaneous engineering which, as its name implies,

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1) A detailed analysis of warranty problems at one of the cases showed that the largest single source of faults was those designed into the product.

breaks down the traditional sequential linearity of the design process. The aim is to "fast track" critical decisions so that manufacturing can start work before the design process is completed. The data required for manufacturing a product are created during the engineering design process; the drawing and specification are manufacturing's key texts, without which no production can take place. Thus, the design data created by engineering is the key input into the production planning and control processes.

Engineering design has been largely ignored in the innovation literature. Talk of manufacturing and R&D strategies is now common currency, but one rarely hears of an engineering strategy. The focus has tended to be on the research and development process leading to radically new technologies, rather than on the more mundane, but equally crucial process of combining existing technologies in new ways, spiced as appropriate with a radical innovation. Arguably, the engineering design process will become even more important source of competitive advantage in the future as product liability legislation and reducing product development lead times reduce the space for radical innovation. [2]

The aim of this thesis is to explore the relationship between the engineering design process and the manufacturing process through the medium of one of these innovations - Computer-Aided Design and Manufacture (CAD/CAM) technology. It has been chosen because of the broad role that it plays in the development of the new organisation of production. Firstly, it forms, together with Computer-Aided Production Management (CAPM) systems, one of the main building blocks for Computer Integrated Manufacture (CIM). Secondly, it has posed for many companies in a stark way the nature of the interface between the engineering design and manufacturing processes. Thirdly, it is, as one informant put it, an "enabling technology" which facilitates the implementation of TQM and simultaneous engineering. Finally, it is relatively well diffused through industry and so finding compatible cases with a significant

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2) Thus, one of the cases, under the influence of its Japanese partner, was aiming to shorten its product development lead times by reducing the number of untried technologies in each new product initiative.

level of experience which allow detailed empirical work is not too difficult.

The focus on the engineering/manufacturing interface implies that the emphasis of the thesis will be on the processes of organisational change associated with the implementation of CAD/CAM. In this way, the findings will not only be relevant to the analysis of the implementation of other AMTs such as CAPM and, as it develops, CIM, but also to the implementation of TQM and simultaneous engineering. It is suggested here, and will be reviewed in the conclusions, that the organisational issues associated with CAD/CAM implementation are not significantly different from those associated with the other two innovations in the management of production processes.

0.2 PARADOX RESOLUTION AND ORGANISATIONAL ANALYSIS

Much of the literature that has tried to explore these and similar issues, particularly the literature on innovation, has tended to be what Gibson Burrell has called "Heathrow Organisation Theory" (HOT). This is the type of management literature, typically found in airport and station bookshops, which attempts to provide management guides "in search of excellence", or to present entrepreneurial role models capable of "making it happen". While at its best - such as Kanter's "The Change Masters" - this literature provides effective theoretical analysis combined with an accessible, anecdotal style, it very often reduces to a set of nostrums which yield little indication of how they might be applied. Given that many of the insights provided by this literature are sound, the problem would seem to be the lack of a sense of contingency. Cases are treated as sources of best practice without any attempt to understand how and why that firm developed the practice. In the absence of a sense of contingency, no assessment can be made of the extent to which cited best practice is transferable to any other firm.

A fully effective analysis of contingent relations within and between organisations requires a clear conceptual framework for analysis, and a set of firms which are varied enough for interesting differences to emerge, but not so varied that comparison becomes either futile, or so general that the lessons of best practice are lost. For this reason, the first part of the thesis develops a conceptual framework through the traditional method of a critique of the existing literature. This, I believe, is an essential foundation for the building of the case analysis in the subsequent chapters. As Kurt Lewin (1947) said, "nothing is quite so practical as a good theory". This is also why a single industry, metalworking, was chosen for analysis which is the largest single user of CAD systems.

The case studies are presented in a rigorous, rather than anecdotal, style. This is at some cost to the lucidity of the prose, but I believe that if the reader is to understand the dynamics of the processes at work, then it is important to present the evidence as a whole, rather than to pick highlights. It is this process of systematic presentation which allows the development of models of contingent relationships which will, it is hoped, allow readers to analyse other organisations with which they may be concerned either as managers, consultants, or researchers in relation to the cases analysed here.

In developing the conceptual framework, the argument treats a number of themes in a distinctive way. Firstly, it views technological change as a special case of organisational change, rather than a phenomenon in its own right. It thereby develops a processual view of the implementation of new technologies as organisational changing through a recursive process of organisational learning. Secondly, it articulates the contingencies facing the organisation of production as being dependent upon the production mission on the one hand, and upon the nature of the information and material flows chosen to fulfil that mission on the other. These, it will be argued, provide more readily operationalisable measures, than those of environment and task/technology usually found in the contingency literature. In this way contingencies become elements of process in the organisations under study.

Flows of information and materials are amongst the most important actions, or *processes*, in any production organisation. Similarly, the development of the production strategy as part of the overall business strategy is a dynamic process of enactment of the outer context of the organisation. These processes are in turn *structured* in relation to the organisation - information flows between sections; materials flow from department to department; strategies are formulated to utilise existing capabilities. In turn, changes in the process of strategy formulation or the character of information and materials flows through the dynamic resolution of internal paradoxes and external competitive pressures stimulate changes in structure. This dynamic interplay between structure and process is what Giddens (1979; 1984) has called the process of "structuration" - the institutionalisation of process into structure and the dissolution of structure through process.

Thirdly, the thesis offers a distinctive "case survey" methodology whereby 15 comparable cases are researched as case studies with a longitudinal dimension and then analysed cross-sectionally. The aim is to combine the richness and depth of qualitative case studies, with the typicality and breadth of survey data. The collection of basic performance data on each case also means that the outcomes of effective organisation design can also be assessed. Examples from the cases allow the expansion of main points in the argument, while frequency counts across the cases allow the reader to assess how widespread the relevance of the point is.

0.3 PLAN OF THE THESIS

The first chapter discusses the existing approaches to technological and organisational change and innovation. The "diffusion approach" to technological change is, perhaps, most commonly associated with economists concerned with the processes by which firms adopt innovations, rather than with how they get the innovations to work once they have chosen to adopt them. The "impact approach", more favoured by industrial sociologists, tends to examine the outcome of technological change in terms of the impact on work organisation or organisation structure, without a concern for the decision processes leading up to that impact. The "social shaping approach" is very much concerned with such decision issues, but for the individual firm implementing technologies such as CAD/CAM, many of the issues of technological shaping have already been closed off. An "implementation approach" will then be proposed which emphasises the totality of technological change as a process. A review of the more general literature on organisational change will take Pettigrew's critique of the linearity of much of the literature and agree with his call for a contextualist, processual approach. It will finally be suggested that technological change is merely a special case of organisational change, and not a qualitatively different organisational phenomenon, despite the almost complete separation of the two literatures.

The second chapter moves on to review the various ways in which the "technology" has been conceptualised and deployed in organisational analysis and thereby explores the "content of change". It advocates the utility of the distinction between the technology and its dimensions advocated by Clark and his colleagues. Drawing on Kaplinsky, it then goes on to discuss the distinctive character of CAD/CAM as an *integrating technology* which distinguishes it from many other advanced manufacturing technologies and shows they way in which it forms a crucial stepping stone on the road to computer integrated manufacture - CIM. Finally the chapter reviews the development and present state of the art of CAD/CAM, indicating the ways in which changes in computer hardware over the last 10 years have radically altered its potential.

Moving on to the analysis of organisations which provides the "context of change", the third chapter reviews the organisation design literature, and proposes a distinctive way of analysing "contingencies" which draws upon the production/operations management literature to provide more tractable operationalisations of "technology" and "environment" than have been used before. In particular, the notion of *flows* of information and materials is developed as the key contingency facing organisations together with the market environment as enacted through the *mission* of the organisation. This framework is then deployed to develop a model of the operational functions within manufacturing organisations which provides the basis for the case studies in subsequent chapters.

On this basis, the current debate on the integration of organisations is addressed. Drawing on the work of Lawrence and Lorsch, the fourth chapter first analyses the sources of "differentiation" in manufacturing organisations which mean that "integration" is required. It then goes on to review the extent to which such integration can be achieved through information technology alone, before assessing the frameworks developed by Adler and Galbraith for appraising the process and structure of organisational integration. These frameworks are extensively used in the analysis of the case studies.

Building on the earlier analyses, and a critique of existing linear models of the implementation of advanced manufacturing technologies, chapter five advocates a dynamic and recursive model of organisational changing and thereby explores the "process of change". The model presented it is argued, is simple, robust, and capable of handling variety across an number of different cases, without loosing grasp of the essentially political nature of organisational and technological change. Finally, the chapter emphasises the importance of "organisational lag" and "organisational learning" for the implementation process.

The first five chapters are aimed at setting up a conceptual framework for understanding the processes of changing within production organisations as they attempt to resolve the paradox of productivity and flexibility. The sixth chapter moves on to review the existing empirical literature on the implementation of advanced manufacturing technologies. It is structured around the model developed in the previous chapters, and shows how few studies have examined the entire process of implementation from the decision to adopt at the evaluation stage through to the associated organisational changes in the consolidation stage.

Turning to the empirical findings, the seventh chapter reviews the established approaches to organisational research before going on to discuss the distinctive research methodology deployed in this research, the *case survey*. The research instrument is then presented before the 15 companies studied are reviewed to help the reader understand the character of the firms involved in the case survey.

Chapter eight presents the context of innovation. Firstly, the *outer context* of the firms surveyed is examined before their relationship to this context as enacted in four distinctive types of relationship to the customer are identified. This is followed by a detailed review of their *inner contexts* in terms of the production processes as articulated in each case's information and materials flows. The relationship between the information and materials flows is then developed in terms of how the three distinctive types of information flow identified are related to the two main types of material flow. On the basis of this analysis, three generic production missions are identified - two established ones which are called *engineering led* and *manufacturing led*, and a third, emergent, *production led* mission.

Developing from the analysis of context in the previous chapter, chapter nine analyses the variety of organisation designs found amongst the cases. Firstly, the overall design of the companies is reviewed, and the stability of traditional, functional, "line and staff" organisation shown. The evidence for the relative instability of deviations from this form such as matrix and product orientated organisation designs is then presented. The argument then moves on to suggest that this level of analysis is incomplete, and the discussion reviews the organisation designs of manufacturing and engineering separately. Here, a considerable dynamism is found, with major changes in organisation design being implemented in most cases within recent years. Matrix organisation within the engineering function is the predominant form. Within manufacturing, very different organisation designs are reported, with the *manufacturing led* companies favouring a vertical division of labour between planning and operational functions, while the *engineering led* companies favour attaching the manufacturing engineering department to the part of the factory which it serves.

The process of *evaluation* of CAD/CAM in the 15 firms is covered in chapter ten. It starts with a more detailed review of the actual systems implemented and the stage of technological integration achieved by each company. It then goes on to show the importance of internal "implementation champions", and specialist task forces in the process. The chapter then discusses the extent to which the evidence shows that evaluation is an inherently political process, and benefits from organisational learning.

Chapter eleven shows the way in which the approach to the evaluation process influences the later stages of implementation as the new technology is *installed and commissioned.* The firms are assessed on the extent to which they have achieved technically successful systems. Particular attention is paid to the large number of difficulties which firms had, and are still having, in achieving effective and reliable CAD/CAM links. Although some of the initial problems were patently technical in nature, it is also clear that the remaining problems are largely organisational. The importance of effective project management of the implementation process, and the noticeable lack of attention to human resource management issues are also discussed.

These organisational problems are explored further in chapter twelve through an examination of how achievement of successful implementation, defined in terms of business rather than technical criteria, was attained. This is cast as the process of *consolidation*. Then, one of the most immediate organisational changes associated with the consolidation of CAD/CAM is investigated - the arrangements for the management of the system. Finally, the overall experience of the 15 case firms with implementation is summarised.

Chapter thirteen reviews the empirical evidence deployed in the previous four chapters to show the ways in which the case study companies have tried to achieve integration across the engineering/manufacturing interface, while retaining flexibility and responsiveness to market demands. The integration mechanisms at the level of both organisational process and organisational structure are identified before they are brought, together with the data presented in chapter ten, into a typology of organisational and technical integration. In turn, this is related to the performance data presented in chapter eight to suggest that the more integrated companies in terms of the relationship between engineering and manufacturing are also the more successful.

The following chapter summarises the evidence and argument while the concluding chapter focuses in on two areas of more general relevance:

1) The current state of organisational analysis is briefly reviewed and an approach some way between the generalities of the Montreal school's configuration analysis, and the over-detailed and cumbersome methodology propounded by Van de Ven in his organisational assessment analysis is proposed.

2) A view of organisational change as the dynamic resolution of tensions and paradoxes generated within and without the organisation is advocated, and the implementation of new technologies and techniques is shown to be central to the overall process of organisational change. In this process, the role of organisation design as a method for resolving dynamically the paradox between productivity and flexibility is examined.

1

APPROACHES TO TECHNOLOGICAL AND ORGANISATIONAL CHANGE

1.0 INTRODUCTION

The dynamic of technological change has been one of the most profound characteristics of the capitalist system since the industrial revolution. The sense of awe captured in Philip de Loutherbourg's painting of "Coalbrookdale by Night" still reflects our frequently contradictory responses to the latest technological breakthroughs today. As the pace of technological change has quickened over the last few decades, increasing attention has been paid by commentators to the processes by which these changes occur. This chapter will briefly review the main approaches to analysing those processes within organisations with the intention of identifying an "implementation approach" which views technological change in a way which overcomes some of the weaknesses of more conventional approaches. The more general literature on organisational change will then be reviewed, and a methodology for identifying the point of entry into organisations when analysing technological change will be suggested.

1.1 APPROACHES TO TECHNOLOGICAL CHANGE

One of the major concerns of analysts of technological change has been the research and development (R&D) process which yields inventions, and the ways in which inventions are turned into usable innovations. The agenda set by Freeman (1974) and others has yielded a substantial body of work, relating innovative activity to economic performance. More recently, the concept of a "technology strategy" has been developed to help to analyse the ways in which organisations develop and sustain competitive advantage through innovation (see the review by PREST 1989). However, the focus of this literature has been almost entirely devoted to the analysis of *product* innovation, rather than innovations in production *processes*. While, of course a firm's process innovation was at one time their vendor's product innovation, it is to be expected that the nature of the two different types of innovation process will be different. Crucially, process innovations occur in the operational parts of the organisation, while product innovations usually take place in the more rarefied atmosphere of the R&D function, relatively buffered from the daily tasks of managing production.

Economists concerned with process innovations have tended to focus on the *diffusion* of process innovations measured by the rate at which the innovation moves from first commercial use to predominance, or "saturation", within the relevant industry. Attention then turns to the factors which explain differences in diffusion rates between industries, and between countries (Nabseth and Ray 1974; Ray 1989). While such an approach yields valuable data for the analysis of industrial and macroeconomic issues, it gives us little insight into how individual firms come to make the decision to adopt an innovative process technology.

Others, such as Rogers (1983), have taken a more processual approach, emphasising the process of "communication" of new ideas to examine the factors which encourage an organisation to take the decision to adopt a particular innovation. Here, the research is focused upon the social processes which influence the rate of diffusion through the population, including the characteristics of the innovation, adopters, and change agents. While this approach provides a sophisticated framework for understanding how organisations adopt, it gives little help in understanding what happens once the adoption decision has been made. While Rogers does recognise that there are problems with the implementation of innovations in organisations, the relevant part of the argument (1983 chap 10) is relatively underdeveloped.

The framework developed in this thesis is intended as a complement to Rogers' diffusion analysis.

The general weakness with such *diffusion approaches* is that they make the assumption that once a firm has decided to adopt an innovation, then reaping the returns on the investment made is unproblematic (Voss 1988; Zaltman et alia 1973 chap 2). However, evidence that many adopted innovations simply do not work, or work far below their specified capability, is overwhelming. In Fleck's (1983) survey of UK robot applications, nearly half the cases experienced initial failure, and over one fifth abandoned robot applications completely. Jaikumar (1984) found that no US Flexible Manufacturing System (FMS) was actually being managed flexibly, as measured by the number of different components machined by the system, and that this was in distinct contrast to the Japanese who did use their new systems flexibly. New and Myers (1986 table 4.2) report that in their survey of British manufacturing plants, the benefits from AMT were typically perceived to be in the low to moderate range. Manufacturing Resource Planning (MRP II) systems have proved particularly intractable - only 28% of US firms surveyed by Duchessi and his colleagues (1989) could be rated as successful in implementing such systems. There are clearly major problems of implementation amongst firms who would be counted as successful *adopters* of new technologies.

The main tradition in analysing the implications organisations that have adopted a new technology has been that of the *impact approach* in which the outcomes of technological change are assessed without a prior examination of the means by which those outcomes were attained. The outcomes, thereby, are presented as the inevitable consequence of a decision to adopt a particular technology. The approach is a venerable one, and has influenced much of the sociological work on technological change. Williams and Williams (1964), in a pioneering study were concerned with the impact of the installation of NC machine tools on the organisation of the manufacturing function. Whistler (1970) was more concerned with office automation, but both concluded that the main impact of automation was the centralisation of decision making, and this is a common theme amongst much of the early work on technological change in organisations. Other studies from the same period which focused more upon the work organisation implications - see the cases reviewed in Meissner (1969) - similarly took the adoption of the new technology as given, and turned to the impact upon job content, pay or whatever.

Much of the work stimulated by the revival of interest in technological change and organisations since the "microelectronic revolution" has adopted a similar line. The large body of work within the labour process school which has built upon the agenda set by Braverman in "Labor and Monopoly Capital" tends to move straight from an asserted capitalist imperative to adopt AMT to an analysis of the inevitably deskilling consequences of that adoption. Valuable collections of papers on the debates around this theme can be found in Knights and Willmott (1987), and Wood (1989), while Attewell (1987) critically reviews the evidence to date for the deskilling hypothesis. Similarly, a review of the recent research by Jones (1988) concludes that no secular trend towards deskilling or reskilling can associated with developments in flexible automation, and that the outcomes depend on the circumstances.

Perhaps one of the most sophisticated recent explorations of the implications of technological change is Zuboff's (1988) analysis of the "age of the smart machine". In particular, she offers a valuable contribution to the debate on the types of competencies most appropriate for working with information technologies with the development of the concept of "intellective", as opposed to "action-centred" skills. In many ways, her work is reminiscent of that of Blauner (1964) who also advocated automated continuous process plants as the model for the development of new forms of less alienated work. However, she moves on from the analysis of automated work systems to those which offer a new transparency of the process, or are "informated". Some of the issues which this distinction rises will be explored in chapter 2, while the point to be made here is that Zuboff has little sense of the process by which particular work organisation outcomes are achieved. Her explorations of the impact on skills in the two main case studies of pulp mills and financial services are fascinating, but only cursory attention is paid to either the market environments in which these firms operate, or the actual work processes that are being automated/informated.

The problems with the impact literature are at two linked levels - firstly, the lack of a sense of contingency, and, secondly, the failure to examine the process of choice around technological change. The detailed comparative work of Sorge and his colleagues (1983; see Nicholas 1983 for a summary) has shown the ways in which differences in the implementation of CNC machine tools in the FRG and UK is dependent upon a number of factors: the national social and economic context; the size of organisation; the market conditions it faces; and the complexity of the manufacturing process. Similarly, Finch and Cox's (1988) study of the design of production planning and control systems shows the importance of factors such as variability in production volume and mix, and differences in the production process and lead times. Rarely have these contingency factors been coherently analysed in the examination of the impact of AMT.

In his critique of the contingency theory work of the sixties, Child (1972) argued that it was essentially determinist in its formulations, and failed to allow a role for a process of "strategic choice" by the members of the organisation's "dominant coalition". In other words, contingencies deriving from environment, task, or, size only provide bounds to the organisation design process, and do not determine it. Miller and his colleagues empirically investigated the proposition that the strategic decision making process by an organisation's most powerful actors, particularly the CEO, is the key intervening variable between the organisation design and the market environment. They conclude that "strategic content and process appear to play a central role in relating context to structure" (1988 p 565).

Bessant (1983) has developed these ideas specifically in the context of the implementation of AMT. He suggests that the "design space" around any particular technology allows room for manoeuvre and choice during the implementation process. The outcome of that process, he suggests, will be influenced by environmental factors, existing organisational factors, management objectives, employee objectives, and the mediation process between all these factors. Technological change is, therefore, a negotiated process, and perhaps, most crucially for the following argument, the actual character of the AMT itself is also open to varying levels of negotiation in terms of its "malleability". Empirical support for this position is provided by the cases reported in Wilkinson (1983) and Boddy and Buchanan (1983).

Others have had more of a concern for the process of change. Those investigating the trade union response to technological change and the implications for collective bargaining have provided detailed case studies of implementation. Willman and Winch (1985) studied the dynamics of collective bargaining associated with the implementation of auto body framing and robots at what is now Rover. Clark and his colleagues (1988) similarly provide considerable detail of the process of negotiation around the installation of new telephone exchanges for British Telecom. Batstone and his colleagues (1987) take a broader range of information technologies to explore the same issues. The more general issues in this area are reviewed by Willman (1986).

A second group of more process orientated approaches are those deriving from social-psychology. Blackler and Brown (1986) identify three strands. Perhaps the most important is that developed from socio-technical systems theory (STS) - Cherns (1976; 1987), and Taylor (1975) provide reviews. Wider in the scope of its concerns than the other approaches, it draws much of its inspiration from the well established work of the Tavistock Institute. STS concerns itself with the "joint optimisation of the social and technical systems" (Trist 1981 p 37) at work through the involvement of the user in the design of the manufacturing system. Perhaps the main weakness of STS is its championing of semi-autonomous workgroups despite its purported contingency approach which one would expect to lead to a variety of outcomes (Hackman 1981), and problems in handling conflicts of interest over what the optimal work system might look like (Brown 1967).

A second strand is ergonomics which concerns itself with the "human factors" in system design. Useful though it is, ergonomics is limited in its ability to address more general concerns around the implementation of new technology due to its inability to analyse the organisational context of work activity (Perrow 1983). The third is "participative" system design which advocates the involvement of users in the design of information systems. Here, the relationship between operatives and management is cast in an co-operative rather than the inherently conflictual perspective of industrial relations. For this reason, participative techniques have been accused of being manipulative and managerialist. Mumford and Henshall (1979) describe such a process during the implementation of a management information system at Rolls Royce, and also indicate the limitations of such an approach which turn around the low aspirations of the users involved and the limitation of the user participation to the customisation of the basic system already selected by management

Very much within the spirit of this literature, and that on social shaping summarised below, is the work on "human-centred systems", which develops a more thorough-going critique of the tendencies within the development of AMT. (Rosenbrock 1990). Corbett (1989) has distinguished between conventional AMT which automates the production process, and "hybrid" systems which "innervate" by leaving key production decisions in the hands of skilled operatives. The essence of the argument is that it is impossible to remove all variance from production systems, and that it is more efficient to locate decisions which cope with that variance at the operator level, rather than in the production planning function which programs the system. While of considerable interest, this work is still at an experimental stage, and has yet to start to diffuse out to operational environments, although the lessons from the implementation of participative techniques associated with TQM such as quality circles may well be relevant.

There is much of value in these approaches, but they all share a common weakness - their almost total concern for job design issues and associated questions such as payments systems. While such a focus may have been adequate for the earlier generations of AMT such as CNC and FMS, the development of integrating technologies such as CAD/CAM and CAPM starts to expose serious shortcomings. The concept of an integrating technology will be elaborated in chapter 2, but the point to be made here is that they pose questions of organisation design as well as job design. The level of intervention of these approaches is *within* individual functions, while the key issues of the implementation of integrating technologies occur *between* functions. They are also, with the exception of the "human-centred systems" approach, essentially reactive in that the fail to articulate clearly the extent of the "design space" around new technologies. A broader perspective is required.

This is provided by the *social shaping* approach. Its basic contention is that technological development is not an autonomous process driven by the disinterested pursuit of science, but a process fundamentally shaped by the society in which it takes place (Williams and Edge 1990). Thus the development of integrated circuits was, to a critical extent, driven by the concerns of the US military - in particular, the desire to catch up with the Russians in the "space race" (Braun and MacDonald 1978). Similarly, Noble (1986 part 2) charts the way in which the development of NC was dominated by the theoretical concerns of academic researchers at MIT with mathematical modelling, in alliance with the US Air Force which desired to control quality in the production of complex aircraft components. As a result the needs of managers responsible for managing machine shops for simpler point-to-point and record/playback technologies was marginalised and even actively suppressed. It is difficult to think of any major element of AMT which has not had the financial support of the US military at some key stage of its development. It is perhaps notable that it is the developments in production management which do not depend on information technology, such as kanban and total quality management which are of Japanese provenance.

However, while the evidence for the social shaping of AMT is strong, this does not mean that at the level of the individual firm, a full range of technological options exists. Firms which commission the development of major advances in AMT are rare; the extent of technological choice at the level of the firm is, therefore, limited to what the vendors have to offer, or are prepared to customise. The amount of customisation, or reconfiguration, that is either possible or necessary varies from technology to technology, but in the case of most types of AMT is highly constrained. Thus the most crucial parts of the social shaping process have taken place before the individual firm is able to have any influence - all that is left is customising as part of the negotiations which form the implementation process. The process of customisation will be explored conceptually in chapter 2 and empirically in later chapters, where it will be seen that it is part of the process of organisational change associated with implementation.

So far, product and process innovations have been distinguished, and the limitations of research which is restricted to the diffusion of process innovations for an understanding of the processes within adopting organisations as they struggle to get the new technology into a usefully productive state were identified. The research on the impact of new technologies within organisations was then criticised for its lack of concern for process, while researchers who have concerned themselves with processes of negotiation around the new technology's design space were criticised for a concentrating on job design issues without taking into account the broader organisation design issues associated with integrating technologies.

Voss (1988) has proposed that three linked fields of study are required for a full understanding of technological change in manufacturing: the development of process innovations; the diffusion of process innovations; and the implementation of process innovations. The first two areas of study are well established, and have been complemented, in the main, by *impact* studies within organisations on job design, payments systems, organisation design and similar issues. Without a concern for the dynamic of strategic choice around the design space inherent in the implementation process as the AMT is configured, there is a risk of what might be called an *adoption/impact short circuit* in the understanding of the process of technological change in organisations. The focus on implementation chosen for this thesis aims to indicate how such a risk can be avoided.

1.2 APPROACHES TO ORGANISATIONAL CHANGE

The discussion has reviewed various approaches to technological change within organisations, but, as Buchanan (1983 p 78) argues, "technical changes are usually organisational changes". The traditions of analysis which take organisational change itself as the focus of interest are also of relevance to the our understanding of implementation. Closer to the issues of technological change is the analysis of organisational innovation. Traditionally, research in this area has focused on the appropriate organisation design and human resource management policies for the nurturing of innovative activity. A considerable body of empirical literature has now built up (Daft 1978; Hull 1988; Moch and Morse 1977; Sapolsky 1967; Zaltman et alia 1973 chap 3), which is remarkable in its unanimity arguing that what Burns and Stalker (1961) called "organic" organisation design is more capable than "mechanistic" design of stimulating innovation.

The argument is, perhaps, best summarised by Kanter (1985) who, along very similar lines to Burns and Stalker, identified "integrative" companies which facilitate innovation and "segmentalist" companies which stifle it. Integrative organisations have organisation designs in which

> "job charters are broad; assignments are ambiguous, non-routine and change directed; job territories are intersecting, so that others are both affected by action and required

> for it; and local autonomy is strong enough that actors can go ahead with large chunks of action without waiting for higher-level support" (ibid p 143).

Segmentalist companies, on the other hand, have a structure

> "firmly divided into departments and levels, each with a tall fence around it and communication in and out restricted - indeed, carefully guarded. Information is a secret rather than a circulating commodity. Hierarchy rather than team mechanisms is the glue holding the segments together, and so vertical relationship chains dominate interaction. Each segment only speaks to the one above and one below, in constrained rather than open exchanges. The one above provides the work plan, the one below the output. Pre-existing routines set the terms for action and interaction, and measurement systems are used to guard against deviations." (ibid p 75).

However, many commentators have noted, including Kanter herself (ibid chap 6), the paradox that organisations that are good at innovation are not necessarily good at implementation - the flexibility required for the former undermines the integration required for the latter. Zaltman and his colleagues (1973 chap 3) identify "high complexity", and "low formalisation and centralisation" as favouring the initiation of innovations, while "low complexity", and "high formalisation and centralisation" favour implementation. The innovation literature has mainly concentrated on exploring ways of creating greater flexibility within organisations so that ideas flow, rather than on the problems of implementing those ideas once they have been managed into good currency and adopted.

The organisation development (OD) literature is concerned with how members of the dominant coalition and their advisors can redesign the organisation to meet the tasks they have set for it. In a sense it explores the means by which "structure follows strategy" (Chandler 1963 p 314) as powerful actors implement their strategic choices for the business. It is this focus on implementation that is particularly attractive here, but the approach still has limitations for those concerned with the implementation of AMT. Beckhard and Harris (1987) is a widely accepted model of planned change, which lays great stress on "defining the future state" as an essential prerequisite for embarking on a change management programme. This, however, assumes that decision-makers have the capability to articulate a vision of that future state in something more than general terms, and does not allow for the redefinition of strategy as the lessons from the implementation of the new structure are absorbed.

This weakness is particularly unfortunate for those concerned with the implementation of new technologies. The explosive dynamic of innovation in AMT, particularly over the last decade or so, means that it is virtually impossible to clearly specify a future state over a reasonable time horizon. The dimensions of the problem are indicated by the vast variety of available definitions of the term CIM - Boaden and Dale counted 10 (1986) in their review. Too little is known, by individual adopting organisations, about the full potential of the systems they have just installed, never mind the promise of the generation of systems just announced, for the coherent articulation of realisable future states. Organisations need to learn how to review simultaneously where they are, and where they are going on a continuing basis, modifying their targets in the light of their experience of technological change. This dynamic will be explored further in chapter 5.

The OD literature has been extensively reviewed by Pettigrew (1985 chap 1). He criticises its tendency towards a linear and rationalist view of the process of organisational change, and notes how "research on change continues to focus on change episodes, and more likely, a change episode, rather on the processual dynamics of changing" (ibid p 10). In particular, he argues that little of the OD work has taken into account the organisational context of the change process, which is a serious weakness because "change processes can only be identified and studied against a background of structure or relative constancy. Figure needs ground" (ibid p 36). From this critique he develops a "contextualist approach" to processes of organisational change resulting from the implementation of strategic decisions.

The approach can be most usefully summarised in figure 1.1, which is developed from Pettigrew (1987). He identifies the three crucial elements in the analysis of any form of organisational change - the "context", the "content", and the "process". Echoing the distinction of Zaltman and his colleagues between the "internal environment" and the "external environment" (1973 p 114), he then distinguishes between the "inner context" and the "outer context", as two distinct levels of analysis of the context of change. Pettigrew has rightly identified one of the major problems in this type of research to be the specification of the interactions between the various possible levels of analysis of the context both within the organisation under study and also the environment within which the organisation is located - what he calls the vertical form of analysis. However, his approach reveals few clues as to how to specify the relevant levels of analysis for any particular change.

The model of strategy implementation developed by Hrebiniak and Joyce (1984) offers one way of attempting to define the relevant levels of analysis of the inner context for the implementation of AMT. Their framework firstly asserts that decision-makers in organisations are intendedly rational in that they face bounded rationality, but at least attempt to act rationally. Secondly, it asserts that the two basic activities in implementing strategy are planning, and organisational design. The key processes are those of setting objectives, and then designing structures and processes that allow those objectives to be met. This process is conceptualised as a cascade down the organisation of ever more detailed decisions in the context of the primary strategic aims.

Three main points can be made about this framework:

1) Strategy implementation is deltaic as well as a cascadal. As Hayes and Wheelwright (1984, chap 2) point out, strategic decisions at the corporate level are passed onto the various business levels within the corporation. In turn, these business strategies form the context for decisions on the functional strategies relating to marketing, manufacturing, and so on. For instance, manufacturing strategy can be conceived as a third order functional strategy within a framework set by the business strategy and the over-arching corporate strategy.

2) Like much organisational literature, the model conflates job design, and organisational design. It also conceptualises "incentives and controls" as elements of the

THE DYNAMICS OF CHANGING

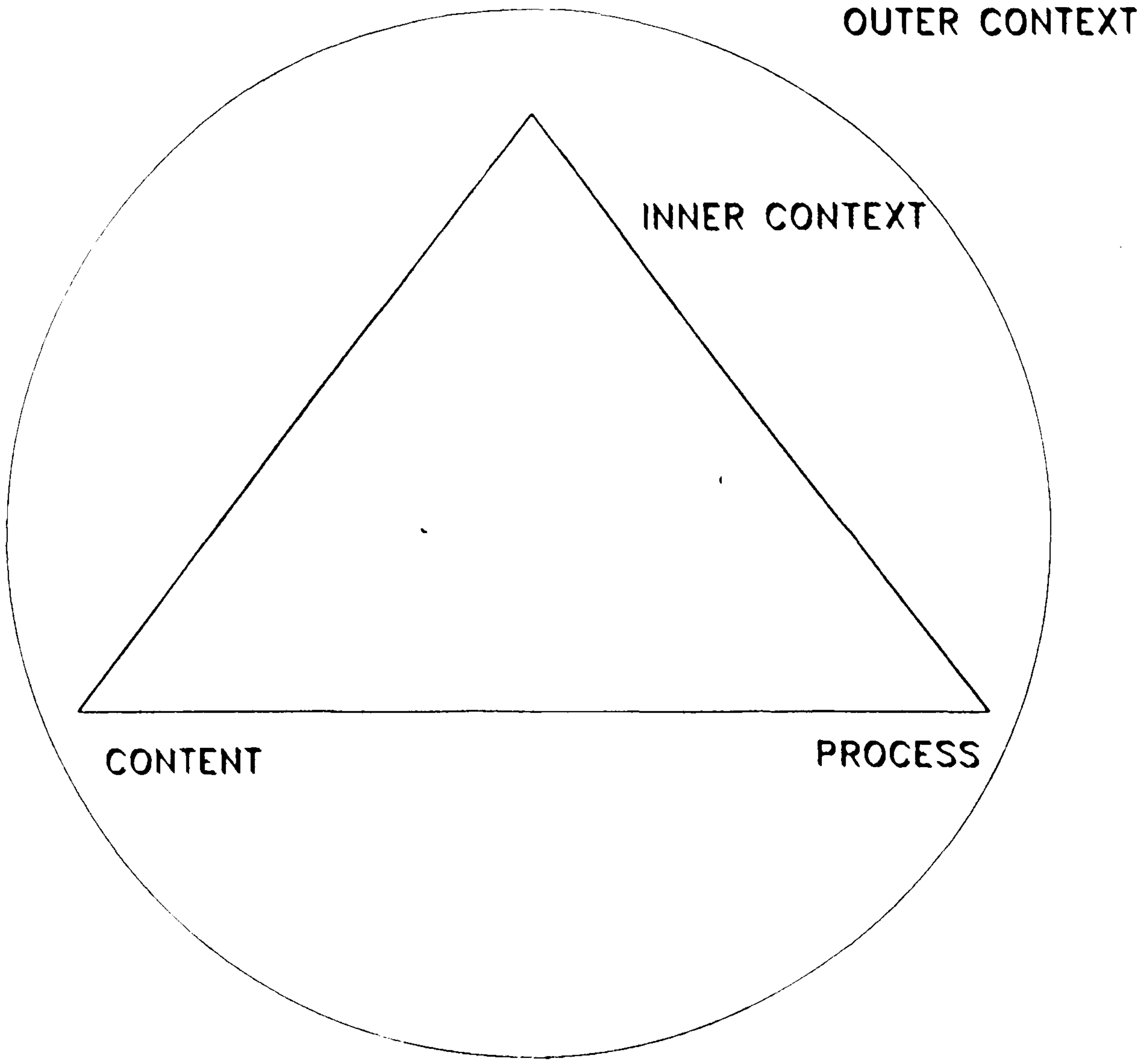
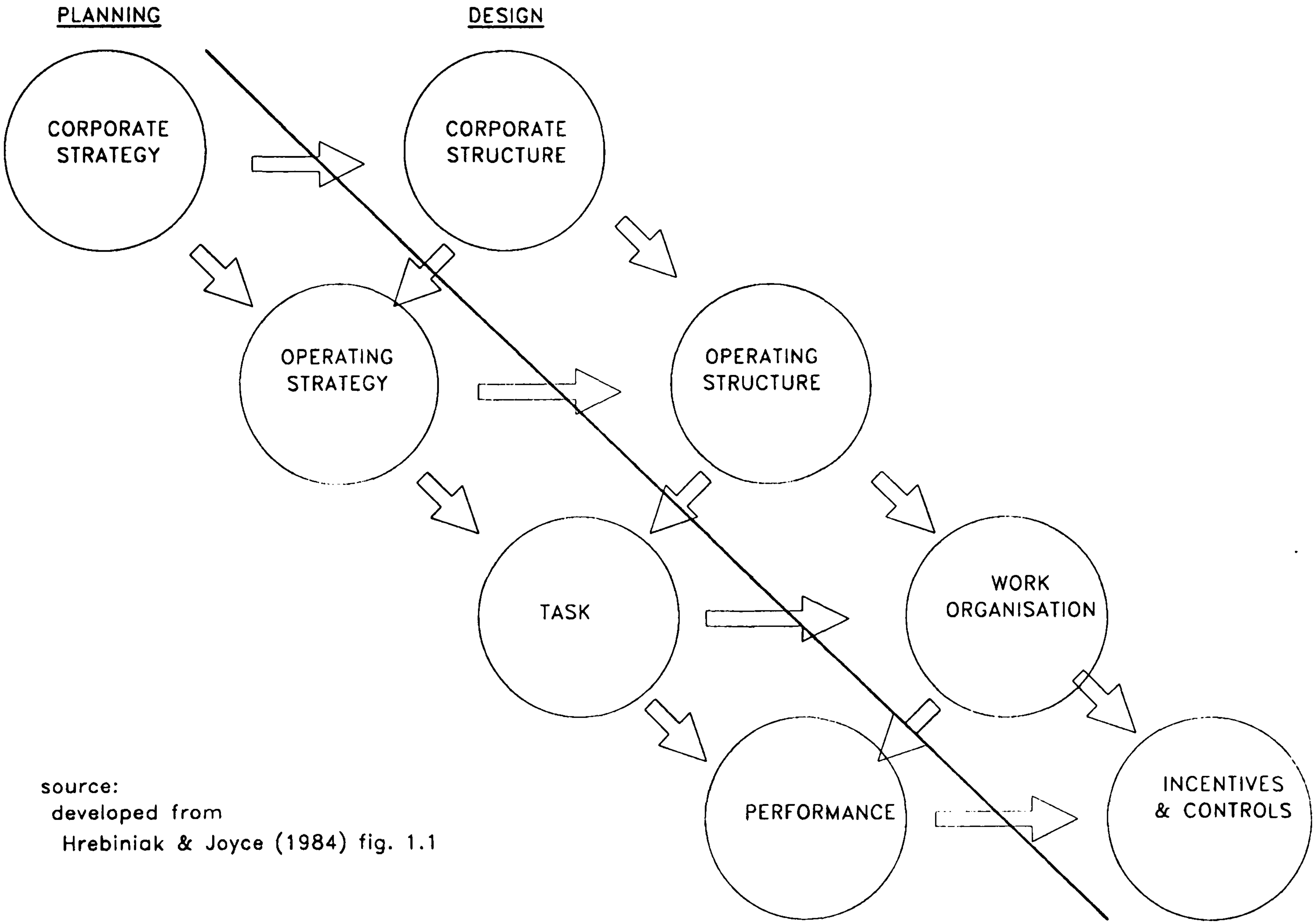


FIGURE 1.1

IMPLEMENTING STRATEGY



source:
developed from
Hrebiniak & Joyce (1984) fig. 1.1

Figure 1.2

process of planning rather than organisational design. It seems more plausible to suggest that the plan should specify a level of performance, and that the incentive and control system should be designed to generate that level of performance. Figure 1.2 presents an amended version of Hrebiniak and Joyce's strategy implementation model.

3) It assumes implementation is unproblematic in the sense that opposition from managerial interest groups and workers' organisations will not be encountered. Any full model of strategy implementation should include the processes of the garnering of commitment and the resolution of conflict.

Bearing these reservations in mind, the amended Hrebiniak and Joyce model presented here is a useful heuristic for establishing the different levels of the analysis of organisational change in general and the implementation of AMT in particular within a contextualist approach.

Hrebiniak and Joyce (1984 chap 8) propose that the analysis of the strategy implementation process should commence by examining one of the "triads" formed within the model. The choice of triad for the start of the analysis is dependent upon the content of the change being implemented. Analysis then proceeds by examining the consistency within the chosen triad before looking at its relation with the other elements of the model. It is proposed to adopt this methodology for identifying the point of entry into the vertical form of analysis for the implementation of AMT.

1.3 SUMMARY

This chapter has laid out the issues deriving from the existing research on processes of technological and organisational change. Focusing on organisations as users of innovations rather than creators of innovations (Kimberly 1986), it identified an *implementation approach* which complements the *diffusion approach*. Rejecting the *impact approach* due to its lack of concern for the negotiation processes inherent in implementation, it also identified the limitations of existing process orientated research which focuses solely on job design issues. While such issues are very important, the parameters within jobs are designed can only be understood within the broader context of the organisation and changes in its structure. The research on organisational change was reviewed so as to help in the understanding of such broader processes and a the development of a methodology for identifying the point of entry into the organisation was proposed.

The following chapters will explore this implementation approach conceptually and empirically. Firstly, an analytical framework building upon Pettigrew's distinction between the context, content, and process of change will be developed, which will then be used to structure the presentation of the empirical data from the 15 cases. The emphasis will be on the dynamic interplay between the processes of organisational and technological change in the context of the market environment facing the firm. Thereby, as Child proposes, "the argument is that advanced technology and organizational structure should both be constituted so as to facilitate the co-ordinated and controlled pursuit of strategic objectives" (1987 p 106).

2

THE CONTENT OF CHANGE

2.0 INTRODUCTION

The revue of the literature in chapter 1 provides the basis for the development of a conceptual framework for understanding the implementation of AMT. This chapter will explore the content of implementation - the advanced manufacturing technology itself. It will start by briefly discussing the ways in which "technology" has been conceptualised in organisational analysis, and distinguish between a technology and its "dimensioning" in a particular implementation. It will then provide a typology which allows the identification of the those AMTs which may be considered to be "integrating technologies", and hence of wider significance for the organisation of the nineteen nineties than other new technologies. Finally, the process of social shaping of CAD/CAM will be explored and some of its possibilities and limitations identified.

2.1 TECHNOLOGY IN ORGANISATIONAL ANALYSIS

The use of "technology" as a variable in organisational analysis has a long and venerable history. Some of the earlier work, particularly the US industrial sociology of the fifties, is reviewed in Meissner (1969). The traditions deriving from the work of Woodward and the Tavistock Institute which shaped the organisational sociology of the sixties and seventies are reviewed in Fry (1982), Gerwin (1981), and Mintzberg (1979 chap 14). The later work laid great stress on technology as an independent variable, or contingency, in the structuring of organisations. The debate on the precisely what effects technology has on organisations has raged ever since, but the overwhelming evidence is that there are major causal relationships

(Fry 1982). Mintzberg uses his five part model, or "logo" of organisational structuring to identify the varying effects of the "technical system" (1979 fig 16.1) - the "prime effect" is at the level of the "operating system", while it only has a "selective effect" on the higher levels of the organisation.

In much of this work, the notion of "technology" was often vaguely and broadly specified, with considerable inconsistency between authors - Fry counts 6 different operationalisations (1982 table 1). What they all have in common, however, is that they are attempts to capture an overall measure of the technology an organisation deploys in its business. This means the measures are too crude to catch changes in the actual machinery which makes up the production process. Collins and his colleagues (1988) provide an interesting attempt to assess changes in levels of "automaticity" over eight years, but they can tell us little about how these changes were achieved - whether, for instance, robots or CNC machine tools were involved. The definition of "technology" needs much greater precision if it is to be a useful concept for the study of the implementation of AMT.

Clark and his colleagues (1988), drawing on their study of the implementation of computerised telephone exchanges, have argued strongly that "technology" is a crucial variable in organisational analysis. They have also been very careful to define "technology" in a clear way as an "engineering system" (ibid p 13). The engineering system consists of an "architecture" consisting of the system principles and configuration, a "technology" of "hardware" and "software". These primary elements are then "dimensioned" for a particular organisational setting, and have a particular "appearance". The stress on architecture suggests that this formulation is strongly influenced by the computerised information technologies. One problem with the concept of an "engineering system" is its lack of obvious application to what might be called non-engineered technologies. For instance, the paper drawing is a well developed and robust information technology which can be used in a number of ways, yet it is straining the language to describe it in terms of systems principles or software. The term also tends to imply analogies with concepts such as "manufacturing system" which is not the intention. Secondly, the model is very detailed, and unwieldy in practice - Clark and his colleagues do not deploy it themselves in full array.

Perhaps the crucial distinction they make is between the primary elements which are largely fixed so far as the individual implementing organisation is concerned, and the secondary elements which can be altered by that organisation. It is, therefore, proposed to define the primary elements of the engineering system as the *technology*, and the secondary elements as the technology's *configuration* in the organisation under study. This two part definition allows us to distinguish two distinct processes of social shaping. The primary elements are the responsibility of the vendor organisation, and largely controlled by that organisation, and the more general processes of social shaping identified in section 1.1 apply. The secondary elements, on the other hand, are under the control of, and therefore can be shaped by, the implementing organisation during the implementation process. This is the process which Rice and Rogers (1980) have called "re-invention" within the innovation process.

One strength of this definition is that it reminds us that an individual production process may be composed of more than one technology. For instance, a typical secretary may use a telephone, a word processor, and a photo-copier daily. Each is a distinctive and sophisticated technology, with its own history of social shaping and implications for work organisation, but rarely will any one be determining in the formation of the secretarial task. Thus production processes can be conceived as arrays of *technologies* which are *configured* to form a co-ordinated whole according to the needs of the organisation deploying them. The *technology* is conceived as an independent variable at the level of the adopting organisation, while its *configuration* is bounded by the hardware and software specification, and shaped by the negotiations within the implementation process.

This distinction between a *technology* and its *configuration* allows the equipment adopted, and the use to which it is put through configuration to be distinguished. In making a similar distinction between technology and task, Cooper (1972) argued that the same technology, for instance an oil refinery can be run on a single or multiple shift system, that decision depending on the organisation's goals as articulated in the manufacturing strategy, rather than the technology itself. Thus, while in practice capital intensive plant tends to be utilised on a multiple shift basis, that is a result of decisions regarding market demand and overhead recovery rates, not the characteristics of the technology of oil refining itself.

One corollary of this approach is that it is incumbent upon the researcher to understand what the technology actually does so that its influence on the task can be traced. The point has been made most recently by Rose et. alia (1986), who stress the importance of understanding the technological differences between telephone exchange systems for the analysis of work organisation options. This insight is, however, central to the "socio-technical systems" approach and is responsible for the incision and continued relevance of Trist and Bamforth's study of coal-getting (1951). However, few studies of technological change have given much detail of how the technology actually works. The latter part of this chapter examines the nature of CAD/CAM technology more closely, while later chapters explore some of the ways in which CAD/CAM technology is configured within metalworking organisations, and then indicate the ways in which those configured systems influence organisational structures and processes.

2.2 A TYPOLOGY OF TECHNOLOGY

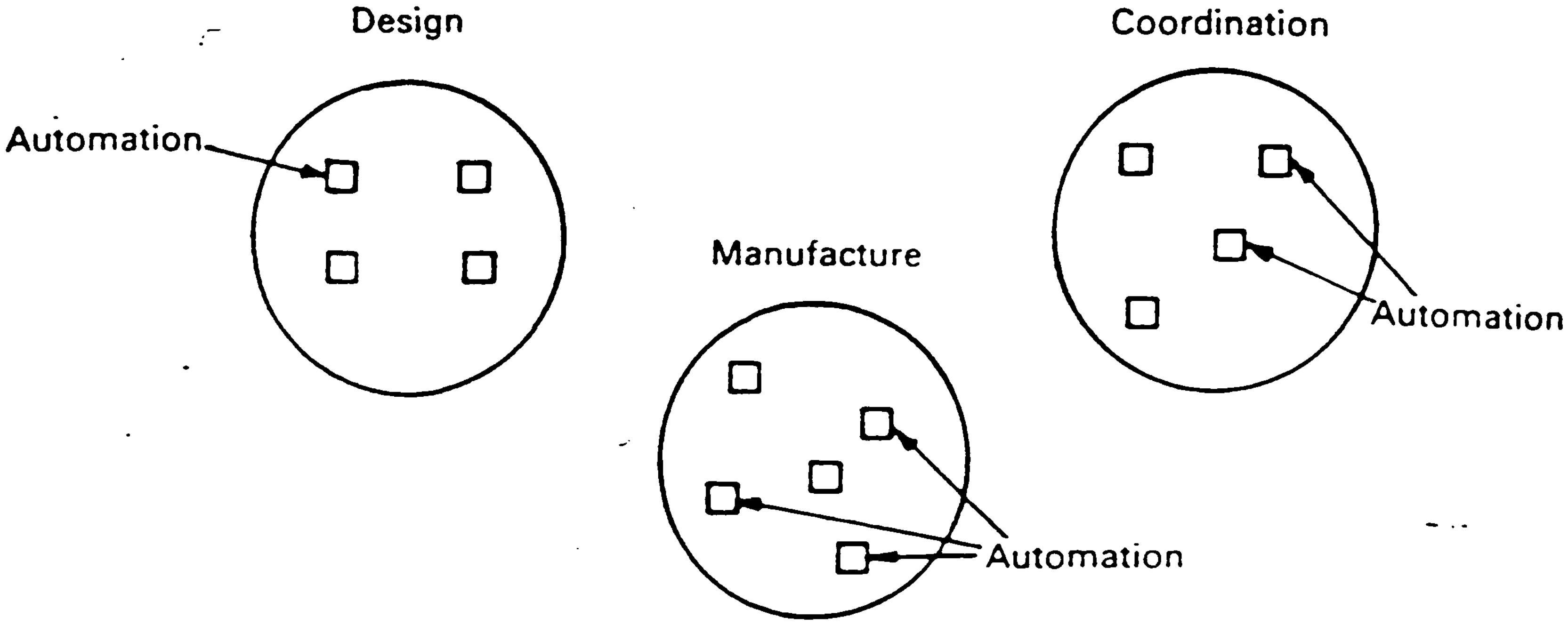
A number of writers on organisational and technological change have distinguished between "routine" or "incremental" innovations, and "radical" innovations. Thus, Zaltman and his colleagues (1973 chap 1) distinguish between "routine" and "radical" innovations in terms of their novelty to the organisation in question, and also in terms of the solutions adopted by the organisation for the implementation. In their definition, "solution radicalness is defined as the extent to which an implemented [adopted] innovation implies changes in the various subsystems of the organization or in the behavioral patterns of its members" (ibid p 23). In terms of novelty, AMT is by definition a radical innovation, and so the issue to be addressed is the radicalness or routiness of the solution. Similarly, Hage (1980 p 191) defines a radical innovation as "a change of input, process and output that represents a significant departure from existing technologies". He goes on to state that "radical innovation causes a disequilibrium......(it) usually involves some transformation of the organizational form. Therefore it is a process that leads to change of the system and not just change in the system" (ibid p 207).

Writing specifically about AMT, both Gerwin (1984) and Ettlie (1984) draw on Hage and deploy the same basic distinction. The dichotomy is intuitively attractive for analysts of AMT implementation; unfortunately, it is also tautological if the concern is with the organisational change which accompanies innovation. Both Zaltman and his colleagues, and Hage effectively define radicalness in terms of its impact on the organisation. This is explicit in the former's discussion of "solution radicalness", and in the Hage definition, the only way of measuring the "significance" of an innovation is in terms of its impact. The dichotomy is, therefore, of no use as a variable in the analysis of the implementation process. The problem appears to be that both Hage, and Zaltman and his colleagues tried to develop a general theory of innovation which takes no account of the intrinsic characteristics of the technology in terms of its functions and performance. Even the novelty dimension which both identify does not make any attempt to understand what the innovation actually does. Such an understanding is crucial to the analysis of the implementation process.

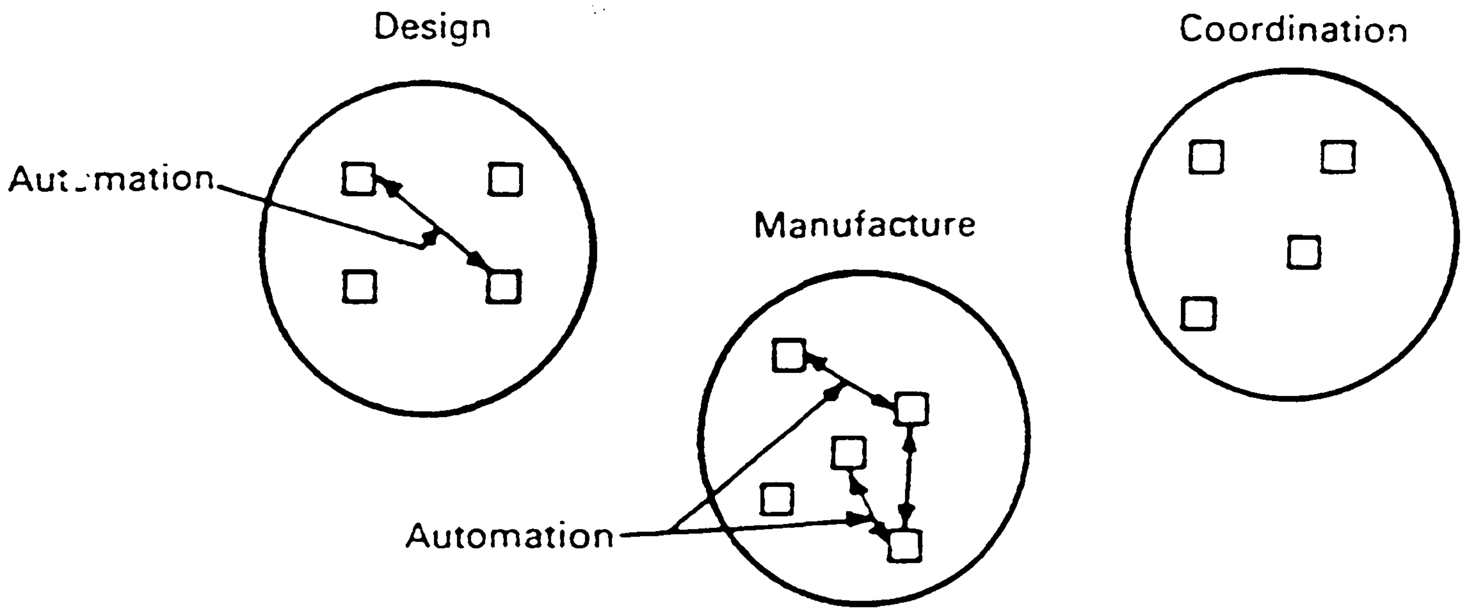
Kaplinsky (1984 chap 2) has attempted to categorise AMT in a way that comprehends the functions of the technology. He first identifies three spheres applicable to any production process - design; co-ordination; and manufacturing. Within each sphere, the production process is divided into a number of activities. He goes on to identify three types of AMT - those

The three different types of automation

(*a*) *Intra-activity*



(*b*) *Intra-sphere*



(*c*) *Inter-sphere*

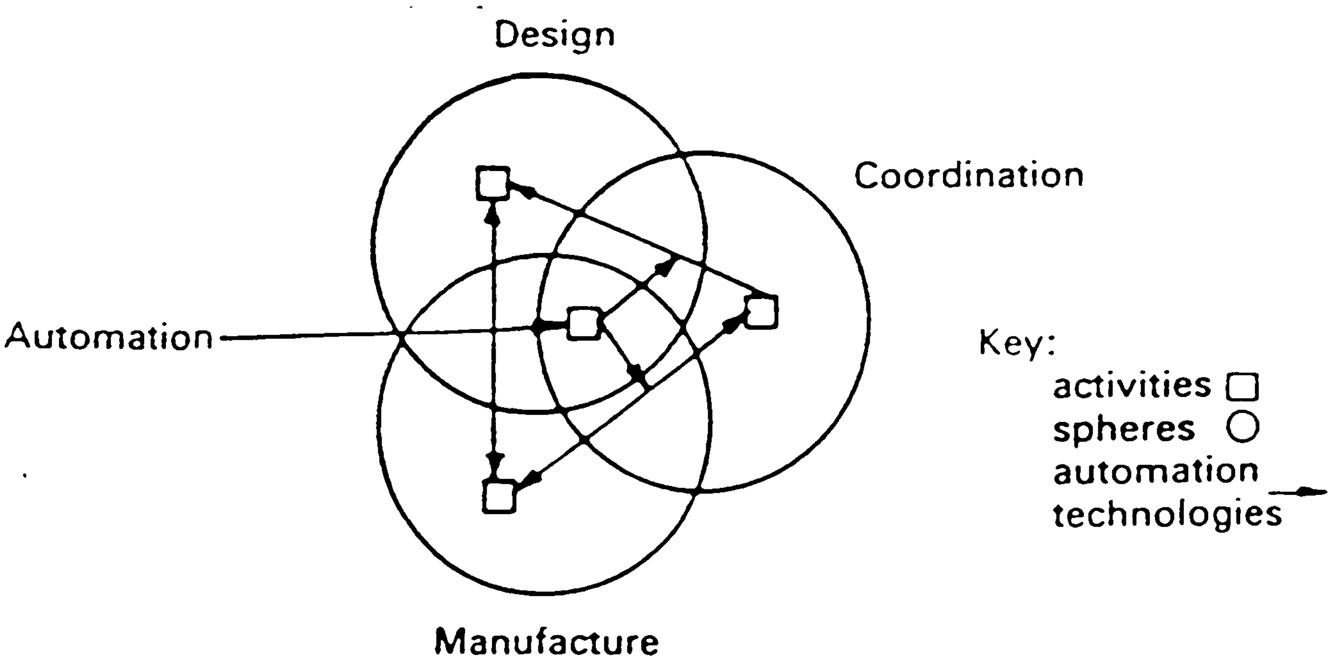


Figure 2.1
Source: Kaplinsky (1984)

THE TWO DIMENSIONS OF AMT

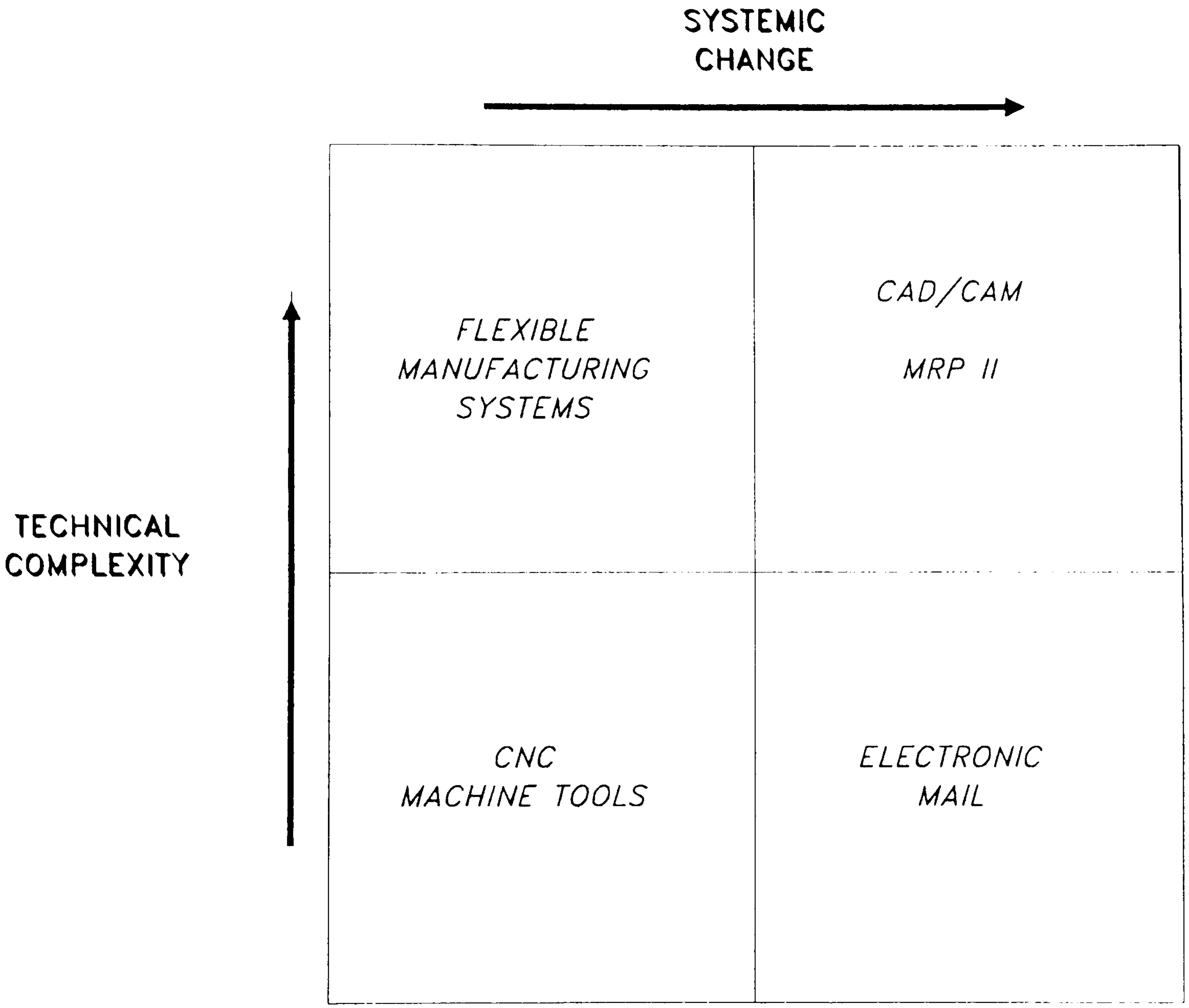


FIGURE 2.2

which automate a single activity, or intra-activity automation; those which automate linked activities, or intra-sphere automation; and those which involve co-ordination between different spheres of production, or inter-sphere automation. This evolution is shown in figure 2.1. The fifties were noticeable for the diffusion of a form of intra-sphere co-ordination - the transfer line. During the sixties, other forms of intra-sphere co-ordination, such as computers for accounting functions and process plant, took the imagination of researchers. During the seventies, attention tended to focus more on a form of flexible intra-activity automation - the NC/CNC (numerically controlled/computer numerically controlled) machine tool. Recent work on the implementation of AMT has often concentrated on another form of intra-sphere automation - the FMS (flexible manufacturing system).

The same issue has also been tackled by Tyre (1988). She studied 48 innovations in 8 plants of one multinational corporation in Italy, West Germany, and the United States. A factor analysis produced a two dimensional typology which is illustrated in figure 2.2. Essentially, innovations can vary on the systemic dimension in terms of their breadth of implication for the production process, and on the complexity dimension in terms of their depth of implication. When a change is high on both the systemic and complexity dimensions, then it can truly be described as radical (ibid p. 15). Examples of each type of technology have been added to indicate the range of technologies which can be categorised using the model.

Tyre's work supplies a dimension missing from that of Kaplinsky. His typology has only a single, systemic, dimension, and does not comprehend the possible implications of varying levels of technical complexity of the innovation. Tyre's typology also has the attraction of being derived inductively from a study of actual innovations, rather than from a swift review of the very general literature on levels of automation. However, Kaplinsky's review can be used to give a point of inflection to her systemic dimension. The brief historical review suggested that the key shift at the moment is from "intra-sphere" to "inter-sphere" automation. Within this framework, systemic technologies for inter-sphere automation can perhaps be described as *integrating technologies*, which may be more or less complex, depending on the particular application. This more spectacular end of AMT naturally attracts the attention of commentators, but, the cumulative effect of low complexity non-systemic change should not be underestimated. Abernathy, in his research on the car industry (1978), has shown the ways in which productivity gains come as much through the detailed fine tuning - what might be called the *re-configuration* - of process technology as through large step changes. The extent to which CAD/CAM can be considered to be an integrating technology will be explored in the next section.

2.3 CAD/CAM TECHNOLOGY

The arrays of technologies which makes up contemporary CAD/CAM systems have three main elements. The first array is the alpha-numeric systems which process the vast amounts of data required for engineering design calculations which began to develop during the fifties. These relied upon conventional main frame computers, while the software was often written by the users themselves. Perhaps the most characteristic application is stress analysis. Diffusion then took place as the more successful packages were marketed by the users themselves, or licensed to software companies. This area of application is often known as Computer Aided Engineering (CAE). Although a number of standard packages are available, the idiosyncratic nature of many applications means that this is still an area where individual developer/users and small software houses can thrive. CAE received a major boost with the development of minicomputers such as the PDP 11 series which allowed engineering departments to run their own computer facilities completely independently of other applications within the business.

The second element is CAM which developed from the requirements of the part programming of NC machine tools. A number of fairly standard alpha numeric systems were developed, one of the most widely diffused of which is APT. Noble (1986 section 3) charts the development of these systems during the fifties, and notes their over-complexity which severely inhibited their diffusion in the early years. The diffusion of CAM systems is essentially a function of the diffusion of NC and, more recently, CNC machine tools, and so CAM systems diffused widely during the seventies. Again, they were usually run on either the business mainframe systems, or on dedicated mini-computers.

The third element is the development of interactive graphics for engineering drawing work - usually known as computer aided draughting (CAD). The history is reviewed by Arnold (1983) who states that the original impetus for such systems came at an MIT meeting in 1959 when the idea of extending the work on NC programming upstream to the drawing office. This research was funded by the same US Air Force group which funded the NC work, and by 1963, a working "man-machine communication system" called SKETCHPAD had been developed. By 1965, all the main US aircraft manufacturers were experimenting with interactive graphics systems using mainframe computers and refresh screens.

The sixties generation of CAD was much too expensive for diffusion outside the state subsidised sectors - mainly defence. Around 1970, though, four key developments took place - cheap minicomputers; storage tube terminals; structured programming; and virtual memory. These innovations allowed by the mid seventies the development of "turn-key" systems which could be sold to engineering companies without internal computer expertise. A number of specialist companies set up to serve this new market - often as spin-offs from the large US aerospace companies - and began to actively sell such systems in the UK. Most of the 15 companies in this case survey bought this type of system for their initial investment. These systems were usually mounted on dedicated mini-computers - usually different mini-computers to the ones supporting CAE and CAM applications.

The development of interactive graphics capabilities is the key breakthrough which allows the emergence of CAD/CAM systems. The link between the design process and manufacturing process has always been the engineering drawing, supported by text such as specifications and parts lists. The engineering drawing is the means by which the conceptual design is fully resolved into a working component, and then communicated to manufacturing. Thus the alpha numeric outputs and inputs of the old CAE and CAM systems always had to be translated to and from the graphical form manually. Now, the whole process could, potentially, be performed on the computer, with the graphics system at its heart.

As these CAD systems developed, interactive graphic part programming systems also began to replace the old alpha-numeric systems, and the systems could also be used for tool design. Similarly, the tremendous advantage of performing routines such as stress analysis and kinematic simulation graphically, where the engineer can look at a visual presentation of the performance of the component at the design stage began to be appreciated. However, many of the early CAD systems, such as CADAM, were developed solely for draughting as a way of increasing productivity in the drawing office - there was little or no concern for the interfaces with the developing graphics systems for CAE and CAM. Crucially, both require 3-D images, while the early draughting systems were content to emulate the 2-D manual drawing. The diffusion of such draughting systems was then driven by justifications based upon drawing office productivity.

By the mid eighties, the microelectronics revolution was having a profound effect on CAD/CAM systems. The main developments were the workstation, which, unlike the terminal, has its own computing power, and local area networks (LAN) such as Ethernet which allow workstations to communicate with each other. The results were that, firstly, much more powerful and responsive processing power was available to the individual user. Secondly, individual users could communicate much more easily with other, remote, users. Thirdly, much more powerful programs were available which could effectively manipulate images on a number of dimensions. In particular, software that could model surfaces or solids in 3-D began to diffuse widely. Integrated CAD/CAM systems sharing a single engineering data base became, for the first time, a reality rather than a rhetoric. Figure 2.3 illustrates the differences in configuration between the earlier terminal/minicomputer based systems and the modern workstation based systems. The switch to workstations has been rapid - Bessant (1991 p 166) cites figures to show that in 1985, over 80% of European sales were for minicomputer based systems, while by 1987, 85% of sales were for workstation based systems.

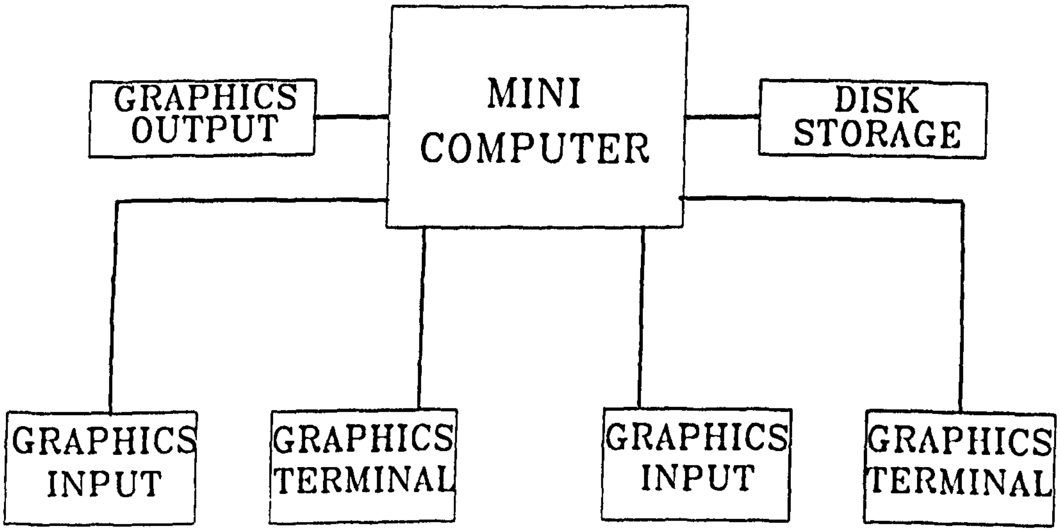
As Marx noted in a rather different context, "men make their own history, but they do not make it just as they please: they do not make it under circumstances chosen by themselves, but under circumstances directly encountered, given and transmitted from the past" (1968 p 97). The main problem facing the development of integrated CAD/CAM systems is that the two ends of the systems, alpha numeric processing for engineering calculations and part programming, developed independently for nearly twenty years before the crucial linkage - the ability to create engineering drawings - became available in the mid seventies. By that time, sunk costs in the two earlier technologies made moves towards integration difficult. These sunk costs are as much in human capital in terms of learnt expertise and incremental re-configuration on the old systems, as in fixed capital in terms of hardware and software. It is as if two builders set out to build an arch without having any idea what the keystone looked like. Having built the individual columns, they find that one is Ionic and the other Corinthian; each expects the other to knock his down and start again, but they cannot even agree on the specification for the keystone. The character of some of these arguments will be illustrated in chapter 10.

Undaunted by such problems, the rhetoric is now that of Computer Integrated Manufacture (CIM) - Bessant (1991) describes the development of both the elements and the overall concept. The objective can, perhaps, be most easily described in terms of Kaplinsky's spheres which were presented in figure 2.1. CAD is at the heart of computerisation in the design sphere, and has already linked across to the co-ordination sphere with CAM. The main element of computerisation in the co-ordination sphere is the suite of systems, generically called Computer Aided Production Management (CAPM), of which the most widely diffused are MRP and MRP II. These systems are responsible for planning the production process in terms of capacity and material requirements, and then controlling against that plan to ensure manufacturing objectives are met. In the manufacturing sphere CNC controlled machine tools such as robots, machining centres, and FMS are being combined through networks such as MAP into automated, integrated manufacturing systems. It is the combination of intra-sphere computerisation and automation from the design, manufacture, and co-ordination spheres into a single inter-sphere system so that the product data base generated on the CAD system can be accessed freely both to plan and to control the manufacturing process which can be considered true CIM. This evolution is illustrated in figure 2.4.

Until recently, computer developments within each sphere proceeded autonomously, with little thought for interfaces. The data analysis basis of CAD/CAM; the data processing basis of CAPM; and the control, or "mechatronic" (Bradley et alia 1991) basis of automated manufacturing systems all have distinctive histories and process of social shaping, and the task of integrating them into single CIM systems poses major technical problems. There are significant differences in the basic computing techniques between each group of applications, and they have, historically, been the responsibility of different departments within the business organisation. The arches are coming together to form a temple, but some builders have been working on Doric columns, while the remainder have adopted Roman styles, and nobody is yet quite sure about the roof details.

Zuboff has attempted to capture the organisational implications of such developments in her concept of technologies that potentially "informate" as well as "automate". They are systems which render transparent processes which were previously opaque by generating a quantity and quality of information previously unavailable. In this way, informating technology "supersedes the traditional logic of automation" (1988 p 10). Earlier conceptualisations of "automation", such as those of Amber and Amber (1962); Bell (1972); and Bright (1958 chapter 4) have taken the main criterion for the level of automation as the degree of removal of the operative

CAD/CAM SYSTEM CONFIGURATION



TERMINAL SYSTEM CONFIGURATION

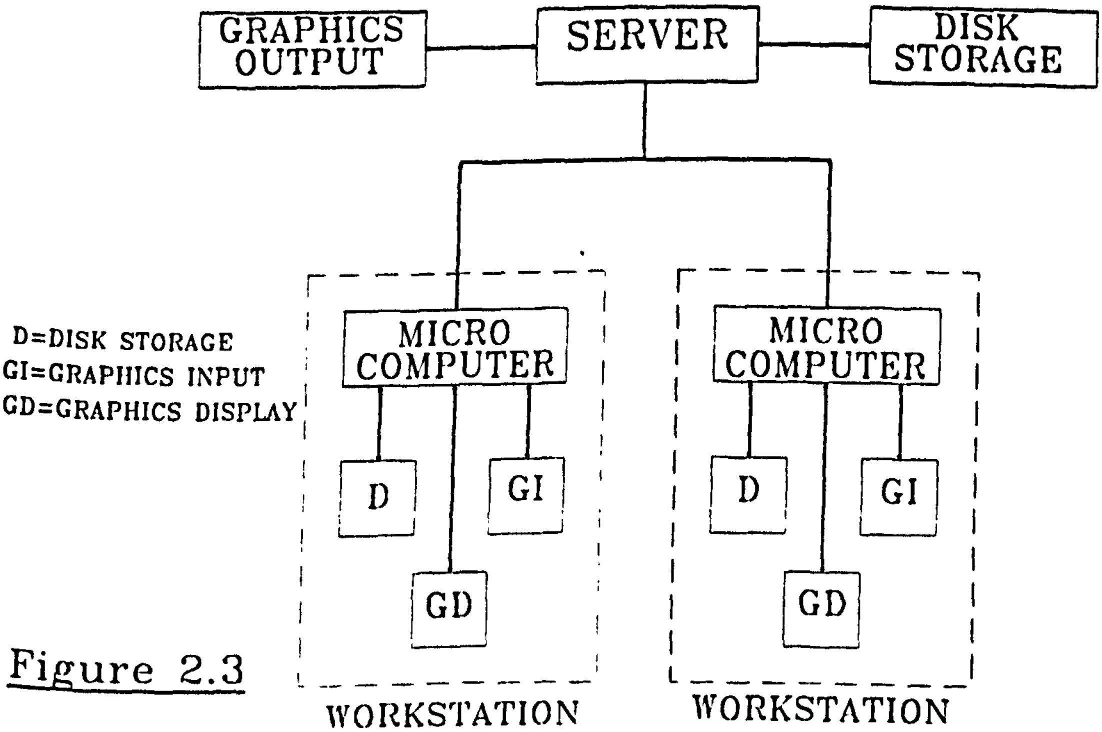
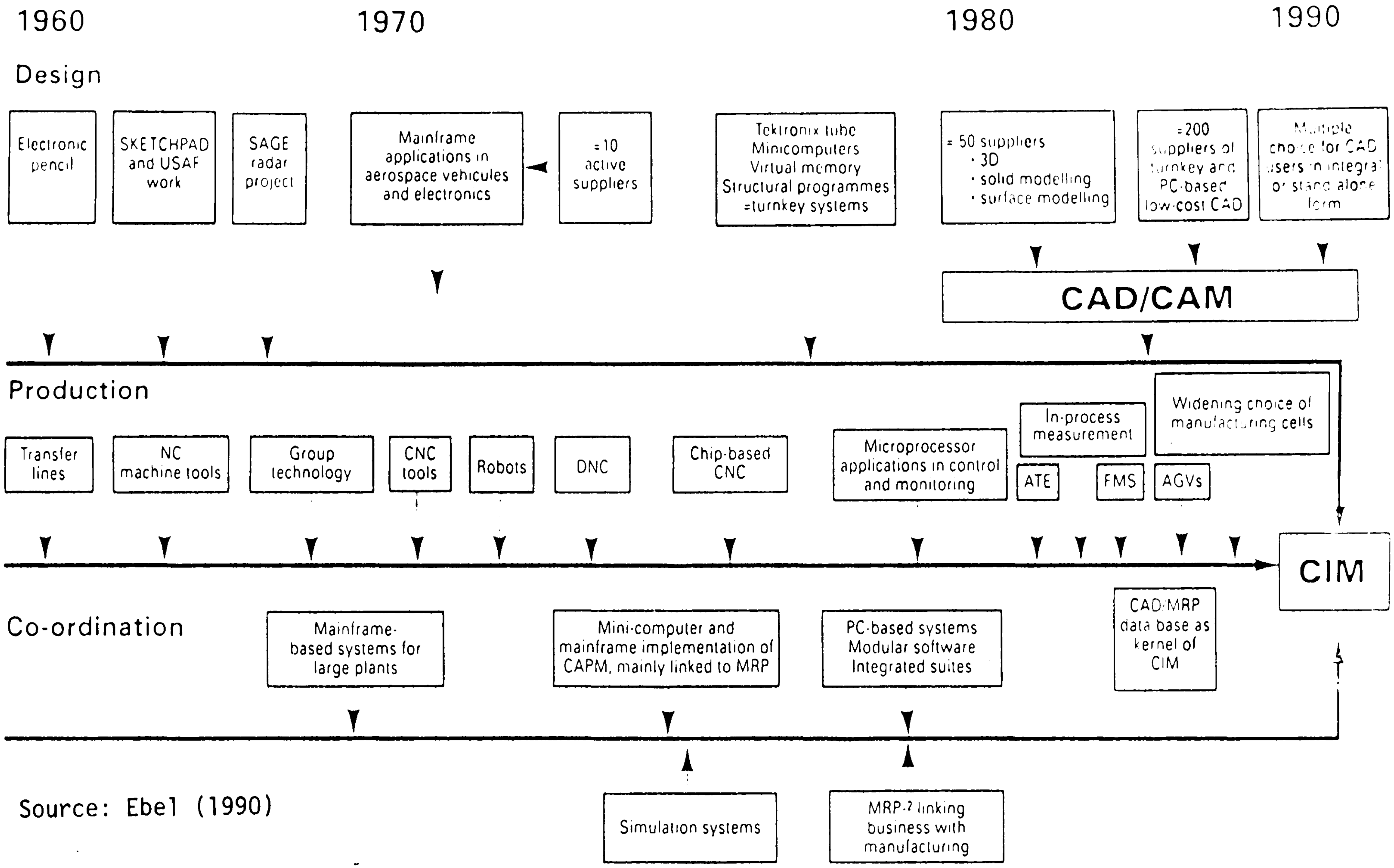


Figure 2.3

WORKSTATION SYSTEM CONFIGURATION

source: adapted from Besant and Lui (1986) figs 3.11 & 3.12

Figure 2.4 Convergence of technological trends towards CIM



Source: Ebel (1990)

from the control cycle of the machine. The latest developments in manufacturing systems engineering do indeed move beyond this stage to the type of informating that Zuboff describes, and her contention holds. However, computer developments in the other two spheres have not led to significant automation in the sense identified above. For instance, except in a vary few cases of "variant design", design decisions are still taken by engineers and drawing staff, yet CAD systems can be fairly said to "informate". A technology, then can "informate" without automating, and can automate without "informating".

Venkatraman (1991) has argued that on his typology of "IT induced reconfiguration" of organisations, CAD/CAM only features at the "evolutionary" rather than "revolutionary" levels of "degree of business transformation". From an overall business perspective, this may well be true, but within the production information flow and the associated activities of engineering and manufacturing, the implications of CAD/CAM are revolutionary. As one car industry executive put it:

> "The creation of a fully integrated master data base holding all the engineering information on a product, and used by everyone involved in that product's design, development and manufacture, is the single most important development in our industry since the first continuously moving assembly track" (cited Whipp and Clark 1986 p 105).

The distinctive nature of CAD/CAM, then, is the way it informates across the two spheres of design and manufacture. While CAD and CAM on their own might be considered intra-sphere computerisation, and CAE might even be considered intra-activity computerisation, the emergence of integrated systems is producing inter-sphere computerisation. This inter-sphere characteristic means that the appropriate level for the analysis of its implementation in terms of figure 1.2 is the organisation design triad of operating strategy/operating structure/task, rather than the job design, or incentive system triads on the one hand, or the business strategy triad on the other.

2.4 SUMMARY

The concept of "technology" has often been vaguely and misleadingly specified in organisational analysis, yet a clear conception is vital for understanding the implementation of AMT. The distinction between the basic technology, and its dimensions in a particular implementation was introduced, and the sense of production processes consisting of arrays of mutually configured technologies was suggested. An examination of the distinctive characteristics of CAD/CAM technology allowed the identification of a central feature - that of being an *integrating technology* - which distinguishes it from many other AMTs which have been the focus of implementation research. The social shaping of CAD/CAM was than briefly described, and located within the more ambitious framework of CIM. Finally the way in which CAD/CAM informates, but does not automate was discussed, and the appropriate level of entry into the organisation for studying the process of implementation was identified.

CAD/CAM, then, is one of the central manufacturing technologies of the 1990s. It forms one of the three main building blocks of CIM, and is already posing many of organisational issues that the implementation of CIM will face due to its integrating nature. Probably the only other innovation in manufacturing that is presently posing the same range of issues is TQM. For this reason, a focus on organisation design, rather than on the job design issues more commonly explored in the research on AMT implementation, is appropriate. The implementation of such a technology and the attend process of dimensioning poses a number of critical organisational issues. For this reason, the argument will now turn from the content of change to the context of the implementing organisation.

3

THE CONTEXT OF CHANGE

3.0 INTRODUCTION

The organisation provides the context of change within which implementation occurs. The "greenfield" site is very much a special case in the diffusion of AMT; the vast majority of implementations occur within existing organisations. It is, therefore, helpful to have a conceptual framework for understanding those organisations in terms of their structures and processes. This, of course, has been the central focus of organisation theory, particularly those elements derived from sociology. However, in line with the criticisms made in the last chapter about the over-general conception of "technology" typically deployed, this chapter will try to specify in more detail than is usual a model for understanding the organisational contexts of implementation.

Firstly, the way in which the organisation relates to its outer context through the process of strategy formulation will be reviewed. As the concern is for the operational elements of the organisation, concepts derived from the manufacturing strategy literature will be deployed to aid understanding of how organisations enact their environments. Then, the main elements of internal process in organisations - flows of information and materials - will be analysed to show the ways in which they, too, shape the inner context. These two contingencies will then be brought together in an heuristic model of the organisation of manufacturing operations to form the basis for the development of specific measures of contingency deployed in the case analyses which follow.

3.1 PRODUCTION STRATEGY

Strategy formulation is the way in which the organisation relates itself to the economic, social and political environment in which it lives. The outcomes of this process can be formal plans, articulated positions, shared perspectives, patterns of action, or even deliberate ploys. However formulated, strategic intentions will differ from what is realised in practice (Mintzberg 1987) - the strategy process is dynamic. Strategies can be formulated at the corporate level, the level of the individual business, or at the main functional levels within the business (Hayes and Wheelwright 1984 chapter 2), but their essence is the coherent and proactive articulation of the relationship between the organisation and its environment. Strategy formulation is, therefore, one of the main processes in the structuration of organisations.

As discussed in chapter 2, our concern with an integrating technology means that the operational levels of the organisation - particularly the engineering and manufacturing functions - are the prime foci for analysis. In terms of the strategy process, therefore, the emphasis is on functional-level strategies. The concept of a "manufacturing strategy" has been one of the major developments in production management of the last few years. Following on the work of Skinner (1974), writers such as Hill (1985), and Hayes and Wheelwright (1984) have elaborated the contribution that manufacturing can make to the overall success of the business, and the ways in which manufacturing strategy formulation can be incorporated into the business strategy development process.

The first stage in the development of manufacturing strategy as part of the overall business strategy is to identify the particular product market(s) which the plant is intended to serve, then to analyse the requirements for success in that product market, and finally to design the organisation of the manufacturing operation to meet those requirements. Throughout, the compatibility of this strategy with the overall business and corporate strategies should be maintained; in particular, close links with the marketing strategy are important (Hill 1985 chap 2). From the manufacturing strategy flow decisions regarding the choice of production process and, as shown in figure 1.2, the appropriate operating structure, work organisation, and incentive and control systems.

The focus on production means that the concern here is for the business - either as an independent company, or as a strategic business unit of a larger corporation. While manufacturing management do make an input into the development of the overall corporate strategy, corporate strategy and structure can be taken as environmental factors for the development of manufacturing strategy. Strategic choices as to which markets to be in, and whether to divisionalise by product, process, or geography are given in the development of manufacturing strategy. Thus corporate strategy can usually be treated as part of the outer context for the process of change at plant level.

The key environmental factor in the analysis is the chosen product market. Hill formulates his analysis in terms of the criteria which win orders for products. These criteria can either be "qualifying", in that the product is not viable in the market unless it meets them, or "order winning", which are the criteria by which products are chosen for purchase by customers (1985, p 49). However, as will be discussed in section 8.4, Hill's model fails to relate empirically order winning criteria and process choice. A more helpful way of looking at the issue might be the nature of the contract with the customer. In particular, the main variable could be whether the customer selects from a defined product range, or commissions the product individually. This possibility will be explored further in chapter 8.

The two environmental contingencies most frequently discussed in the manufacturing policy literature are *corporate strategy and structure*, and the *product market*, yet there are a number of other environmental factors which also need to be taken into account as part of the outer context for a full understanding of the development of manufacturing strategy. The *materials* *market* can be an important factor in both choice of technology and location. For instance, transport costs of the main raw materials play a role in locational decisions in the steel and heavy building materials industries (Estall and Buchanan 1966), and relative energy costs may play a role in process choice in energy intensive industries.

For the independent firm, the *capital market* may well play a role in manufacturing strategy by supporting investment in one type of production technology rather than an alternative. In particular, capital markets can strongly influence the setting of "hurdle rates" for investment appraisal. The *labour market*, especially in terms of the level of skills available in the local area may also influence choice of technology. For instance, in my previous research on process innovation, a number of managers interviewed stated that they had chosen to adopt NC machine tools because they felt that they could not obtain the level of skills required for conventional machining in the local labour market. This, of course, begs the question of why they are not prepared to train people in these skills, but, where firms are unwilling or unable to train, this too can be an important factor in the development of strategy.

Finally, there is the whole range of contextual factors against which the markets themselves operate, which may be called the *regulatory system*. Product markets are regulated through British and International technical standards, and also the more specific regulations in high technology areas such as aerospace and pharmaceuticals. Production processes are regulated by both pollution and worker welfare legislation. The latter, for instance has encouraged the adoption of robotics and telechirics in noxious environments. The industrial relations system for the industry concerned can also influence manufacturing strategy decisions (Kochan et alia 1984).

A notable feature of the manufacturing strategy literature, however, is the almost complete lack of concern for the strategic aspects of the engineering design process. With notable exceptions, such as the work at Harvard (Clark and Fujimoto 1991; Hayes et alia 1988 chaps

10 and 11), and SPRU (eg Rothwell and Gardiner 1984), the strategic role of the interface between R&D and marketing on the one hand, and manufacturing on the other - engineering design - has received little attention (Kotler and Rath 1984). In metalworking production, new products are mainly development of existing technologies. While there may be major innovations with particular components, most of the new product consists of proven elements in new configurations. For this reason, the ability to create "families" of technologically similar products is a major source of competitive advantage (Rothwell and Gardiner 1983).

The interdependent relationship between manufacturing strategy and engineering strategy strongly suggests that their development might best be seen as a joint activity. There is little point in planning to manufacture products without knowing what they look like; similarly, the problems of trying to design products without taking into account how they will be manufactured are now well known. Perhaps the most useful way of thinking is in terms of the *production strategy* as a complement to the business' financial, marketing and R&D strategies. The manufacturing and engineering strategies can then be conceived as symbiotic elements of the production strategy and their relationship will be explored empirically in chapter 8.

3.2 TECHNOLOGY AND TASK

The previous section showed how the development of the *production strategy* is the means by which the activities of the firm are focused to accommodate the environmental contingencies that it faces. It is the process by which the outer context is articulated within the organisation to create an inner context. In order to carry out those activities, the factory requires a specific operating structure and process. By *operating structure* is meant the organisational and departmental structure of the manufacturing unit under review; by *operating process* is meant the flows of activity through those structures which enable production to take place. The operating structure and process are contingent upon the actual combination of capital and labour chosen for the production process. This is what Van de Ven and Ferry call the "production function problem" (1980 chap 4), or the question of "process choice". Hill identifies five generic processes - project, jobbing, batch, line, and continuous process[3] (1985 chap 3).

This choice sets the parameters for the further decisions regarding production technology and organisation design. The technologies which make up the production process are not fixed in the sense that no development takes place. However, there is a high level of fixity once technologies have been implemented - capital is sunk, and incremental improvement takes place within the relatively narrow bounds of the re-configuration of the technology. Only when the investment has been amortised, and the option of scrapping is, therefore, open, can the choice of technology adopted be re-evaluated in a fundamental sense. The operation of the process technology in the manner required to meet the objectives of the production strategy defines the production task.

Lynch (1974) has usefully distinguished between the "system" and "individual" levels of task measurement. At the system level, task is assumed to be a contingency whose effects permeate the entire organisation, while at the individual level, its effects are presumed to be restricted to the immediate work group or department. The earlier work of people such as Woodward, Blau, and the Aston group tended to operationalise a system-level definition, while more recent work drawing on Perrow's (1967) formulation such as that of Van de Ven has taken a more individual-level definition. These two levels are both relevant to the analysis here. The system-level definition is analogous to the formulation of the "manufacturing task" or "manufacturing mission", while the weight of contemporary organisational sociology tends to favour the individual-level definition (Withey et. alia. 1983). In order to retain clarity of analysis and exposition, the argument presented here will reserve the term *task* for the

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[3] These are, of course, very similar to Woodward's (1966) original typology with the main addition of "project" processes.

individual level, and deploy the term *mission* for the system or plant level task.

3.3 MISSION AND TASK

How, then, is the *production mission* translated into the tasks which influence the design of jobs and departments? Clearly, there is a range of tasks within a single production mission, and the organisation may be unfocused and have more than one mission. Product design is a different task from production control; the foundry's task is different from that of final assembly. Within a single mission, there is a level of differentiation which will vary contingently, and for a given mission, there is a level of requisite integration which will also vary contingently. Within this conceptual framework, adapted from Lawrence and Lorsch's study (1967) of the relationship between organisation and environment, the work of Van de Ven and Ferry (1980) helps us to draw out the linkages.

There is a variety of operationalisations of task available in the literature, but in the opinion of Withey et. alia. (1983), Van de Ven and Ferry's is one of the better ones in terms of "discriminant" and "convergent" validity. For our purposes, their operationalisation has the overwhelming advantage of being part of a suite of organisational assessment methods. They analyse task (1980 chap 5) in terms of "difficulty", broken down into "predictability" and "analysability", and "variability", and show that these contingency factors are correlated with measures of departmental structure and process. Departments are defined though a "linking pin" analysis. They then analyse relationships between departments in terms of work and information flows (1980 chap 7). These flows vary along the dimensions of "direction", "intensity", and "variability". So,

> "for the organization as a whole, the *direction* of work and information flows between organizational units and levels identifies the network or cluster of relationships within a complex organization. The *amounts* of work and information flows indicate the intensity of the intraorganizational network, that is, the strength of the task-instrumental and maintenance activities in the network. The variability or standardisation of work and information flows indicates the routinization of network relationships" (p 247; emphasis in the original).

The production mission can, therefore, be conceived as consisting of work and information flows differentiated into a series of *tasks*, which require a particular level of integration - the requisite level of integration - in order to function effectively. Structurally, this differentiation takes the form of departmentation, and integration takes the form of organisational linkages (c.f. Galbraith 1977). Processually, differentiation takes the form of interdependence and conflict, and integration takes the form of co-ordination and control. This conception will be explored further in chapter 4 in terms of the differentiation between the engineering and manufacturing functions.

While the analysis of tasks and departmental structure and process proposed here may be well established and widely acceptable, the analysis of relations between departments in terms of flows is a useful innovation which requires further development. The main issues would seem to be these:

1) The nature of the flows needs to be carefully specified. Economists distinguish between stocks and flows. Van de Ven and Ferry seem to confuse the two in their organisational analysis.

2) Information flows are conceived only as control flows, yet, I would suggest that there are many types of information flow in organisations.

Van de Ven and Ferry define work flows as the "materials, objects, or clients and customers that are transacted between units". They are a subset of the resource flows which include "money, physical equipment, staff, support services and work". If, however, we take the comparison with the economists' view of stocks and flows we can see that much of these supposedly flow elements are part of the assets of the manufacturing operation. Work is processed through and by the physical equipment and staff of the manufacturing unit. It is the raw materials of production which flow through the manufacturing operation. A linked issue is that the flow of information also involves work in the intuitive sense; indeed, a large and growing number of people are employed solely to process information in organisations.

It seems useful, therefore, to call the work flow the *materials flow*, at least in the operating core of businesses engaged in the production of goods.

In terms of the content of the *information flow*, Van de Ven and Ferry restrict its scope to the co-ordination and control of the work flow. While the control system which the finance function imposes on the operating functions of the organisation does represent a major information flow, it can be usefully distinguished from the other information flows within the organisation. Firstly, the sales and marketing flow required for positioning and developing the firm's product in the market is a major and distinctive information flow. There are also other environmental monitoring information flows. Secondly, and of more immediate relevance here, there is the *production information flow*. This comprises the entire flow of information from the conception of the product to its execution, and it both instigates and controls the materials flow.

Thus the organisation can be seen as a set of structured flows - the precise character of which varies with both the organisation's mission, and the function of the flow within it. Within a business, the accounting flows will consist of cash and control information, the marketing flows will be of customers and market intelligence, while the personnel flow will be of staff and the associated information. Thus what appear as the assets (or stocks) of the manufacturing operation - fixed assets (machines) and the workforce - appear as flows of financial and human resources in other parts of the business.

3.4 THE PRODUCTION INFORMATION FLOW

The contention is, therefore, that the *production information flow* is a vital element of process in organisations on a par with the flow of materials that forms the production process. Van de Ven and Ferry argue that a focus on work and information flows is useful because

> "they (1) appear to be the basic elements of process in organizations, (2) behaviorally indicate the task-instrumental and pattern-maintenance functions necessary for any organization to survive, (3) provide a way to operationalize sociotechnical theory, and (4) provide ways to link the micro- and macro-levels of organizational analysis" (1980

p 358).

The following chapters will show the ways in which the same claims can be made for the material and information flows identified above.

The concept of the materials flow is a well developed one, at least amongst industrial engineers, and may be specified at varying levels of detail from the generic to the product, or even component, specific. The most detailed level of description is provided by method study techniques which can be used to develop "flow process charts" (see Lockyer 1983 chap 15). In the context of the model being developed here, method study is most appropriate for analysing *tasks* within departments. At the more aggregate level of the production mission, "process flow diagrams" (Marshall et. alia. 1975 chap 1) can be used to identify the relationship between departments. Wield (1985) gives an example of such a diagram for boiler-making.

The technology with which this thesis is concerned is CAD/CAM. As is clear from the discussions in chapter 2, it does not, of itself, affect the other spheres of the business. The following discussion will, therefore, concentrate on the production information flow. Figure 3.1 shows the main elements of the production information flow - the concept was first presented in Winch (1983). This is submitted as a process model in that it is meant to encapsulate real activity. The core of the model is the *main data flow.* It can be divided into four distinct stages in which the characteristics of the product are specified at cumulatively greater levels of detail:

1) *Design* - the overall conception of the product has to be outlined and clarified, and then put into a communicable form.

2) *Draughting* - the detailed characteristics of the product must be specified and documented in order to eliminate ambiguity once material processing starts.

3) *Planning* - the sequence of material processing must be specified, and costings calculated. The availability of raw materials, labour and plant must also be

established.

4) *Control* - once material processing is under way, its progress must be monitored against the criteria laid down in the previous three stages.

It is through this process that the "information assets" (Clark and Fujimoto 1991 chap 2) of the production organisation are generated. Within this overall framework, the precise range of tasks within stages will vary contingently with the production mission.

Transient data were identified by Wix and McLelland (1986). They are the data sets which are manipulated entirely within a stage, and from which only the output enters the main data flow. For example, the use of finite element analysis routines within the design stage, or the stock control system in the stores are examples of transient data flows. The importance of transient data flows comes from the historical tendency for them to be the first areas to be computerised within the production information flow, in what, to paraphrase Bright (1958 p 99), might be called "islands of computerisation". Wix and McLelland also identified *fixed data* as an additional data flow providing the standards by which the production process is undertaken. These can include elements of the *regulatory system* such as British Standards, and the scientific properties of the materials to be processed. These data are relatively unchanging both over time and between companies. They have not been included in the model for ease of exposition.

Feedback data are perhaps the most overlooked element of the production information flow. Two of the most important flows are identified in the model, but there are others. The first is the loop from planning to design. This might be called the *value loop* by which production data is fed back into the design stage to enhance the manufacturability or buildability of the design. The second is the *control loop* by which the materials flow is controlled against both the criteria laid down at the design stage (the specification), and the planning stage (the production schedule). It is arguable that the effective management of these two loops is the most significant source of competitive advantage that the production operations can offer the

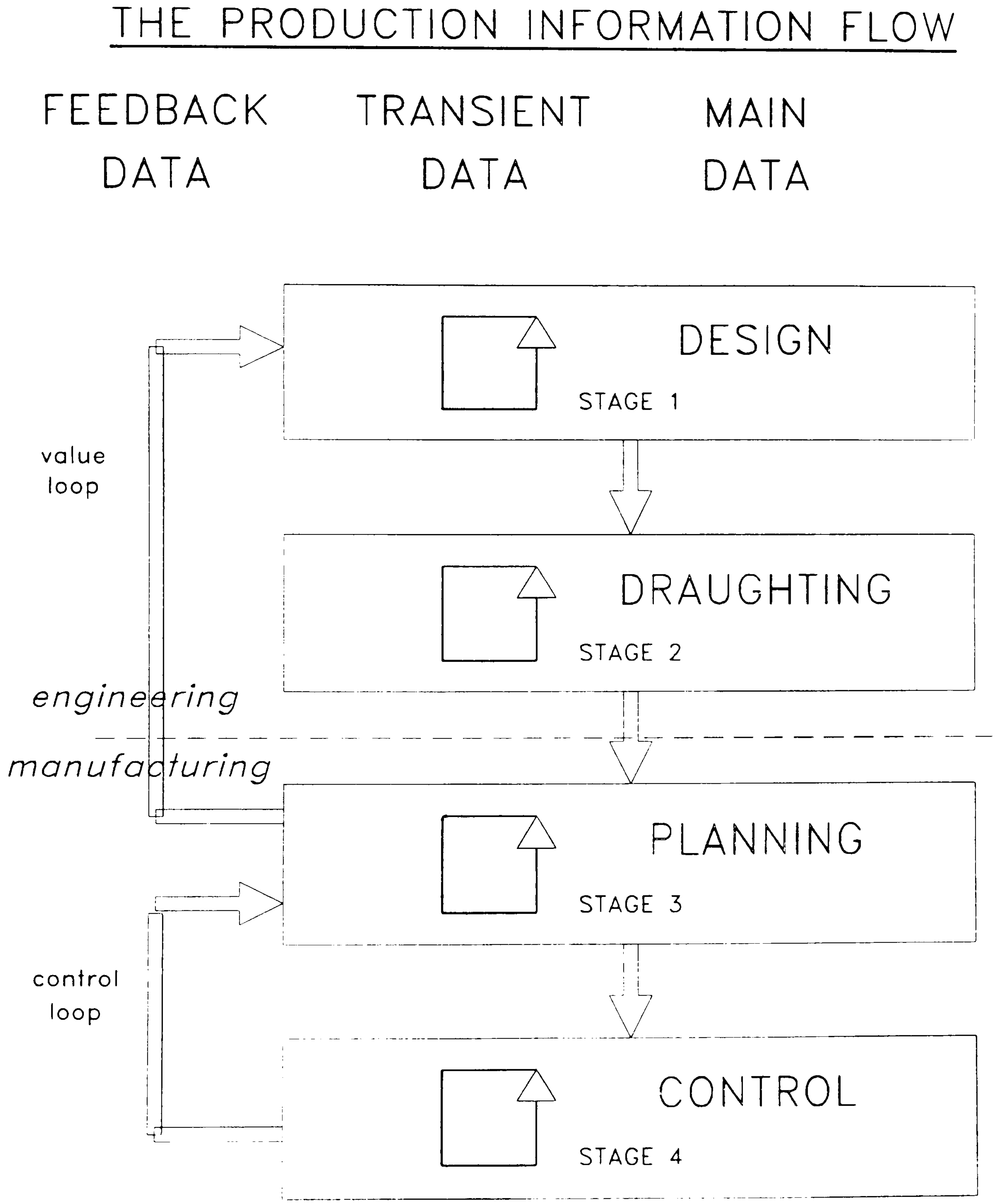
THE PRODUCTION INFORMATION FLOW

FIGURE 3.1

business.

Van de Ven and Ferry suggest a number of dimensions along which the materials and information flows can vary (see 1980, fig 7.1). Perhaps these can be summarised as direction and intensity. *Direction* clearly affects the ordering of tasks, and hence departments, along the main data flow, while *intensity* refers to the frequency and variability of transactions along the flows. In their analysis of job design within departments, Van de Ven and Ferry draw on Thompson's (1967) three part typology in terms of "pooled", "sequential" and "reciprocal" interdependence. They then go on to add a fourth type - "team" interdependence in which transactions are both reciprocal and iterative. This analysis is equally apposite to analysing flows of information and materials between departments, and will be developed in the next chapter. Thus, the manner in which flows of information are interdependent, or the *coupling*, through pooling, sequence, reciprocity or teams will also have a major impact on the ordering of tasks.

These flows of information and materials form series of transactions in the sense developed by Williamson (1975). In Williamson's definition, "a transaction occurs whenever a good or service is transferred across a technologically separable interface" (1981 p 552). Just as technological insepcrabilities segment the materials flow, the production information flow can be conceived as being broadly segmented by these four stages. They can, therefore, be subject to a variety of transaction governance regimes (Williamson 1985 chap 3). These can be predominantly "hierarchical", as in the 15 metalworking cases studied here, or predominantly "trilateral" as in the case of project processes such as construction[4] (cf Winch 1989). Thus it is the governance of transactions within the flows of information and materials which defines the boundaries of the organisation as a "nexus of treaties" (Aoki at alia 1990). However, within the transaction cost approach, the analysis of internal, or hierarchical, governance

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4) Pure market governance is unlikely due to the high levels of uncertainty inherent in the ign process. Only where conditions favour the purchase of the completed product as a "black box" design market governance predominate.

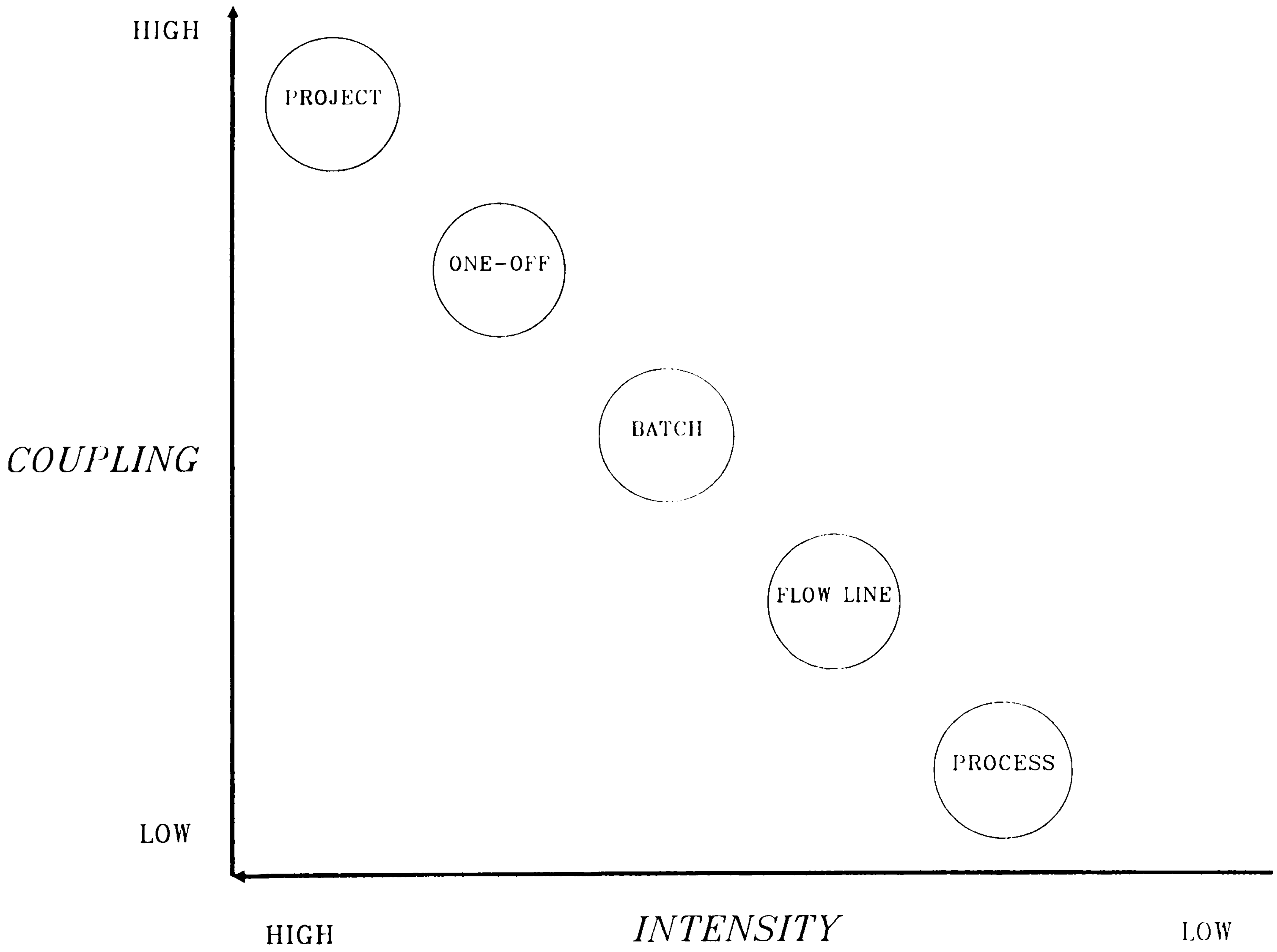
HIGH
COUPLING
LOW
PROJECT
ONE-OFF
BATCH
FLOW LINE
PROCESS
HIGH
INTENSITY
LOW

Figure 3.2

regimes is underdeveloped, an issue which will be explored further in chapter 4.

Differences in transactions between the materials flow and the production information flow between firms are contingent upon the production mission. The dimensions of this variation can be sketched out in the manner shown in figure 3.2, which shows the relationship to the production information flow of each of the materials flows indicated in the circles[5]. As we move along the abscissa away from the origin, the level of *intensity* decreases, to the point where, at the process plant end, there may have been no information transaction between the plant designers and the manufacturing management running it since the day the plant was commissioned. In the production information flow, *direction* will remain broadly constant, as by definition, conception is prior to execution. *Coupling* will vary according to the level of requisite integration between the production information flow and the materials flow. It may be suggested that the level of coupling between these two flows will tend to increase as we move away from the origin along the ordinate. Thus jobbing production represents a highly intensive reciprocally coupled mission, while car production tends to be a low intensity sequentially coupled mission.

The interaction of the production information flow with the sales and marketing flow is also a source of contingent variation. The point at which the external transaction with the customer interacts with the internal transactions along the information and materials flows is of key relevance to the design of the organisation. In project and jobbing production, the transaction usually occurs at the beginning of the production information flow. In firms selling a portfolio of standard designs it will come at stage two as a design configuration, and in make-to-order production it will come at stage three. In production for stock it will come after stage four. This point of interaction will again have implications for intensity and coupling, and possibly even direction. Its profound implications for the production mission will be explored

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[5] As will be explored in chapter 8, this is not the same as the relationship between the gineering and manufacturing functions. As chapter 9 will show, many of the "flow-line" firms have liberately decoupled much of manufacturing planning from the materials flow.

THE PRODUCTION MODEL

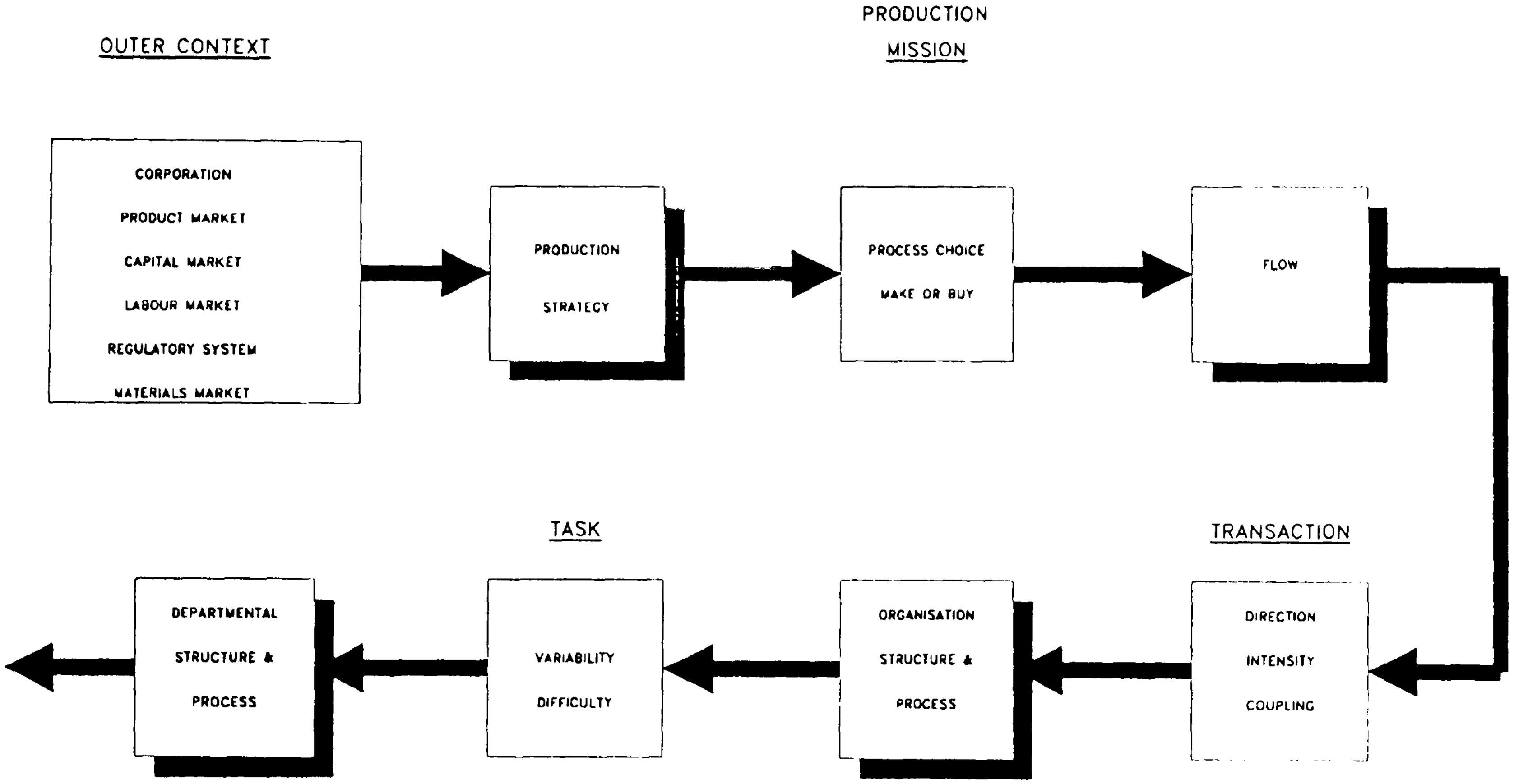

FIGURE 3.3

empirically in chapter 8.

3.5 THE PRODUCTION MODEL

A summary and formalisation of the preceding argument is given in figure 3.3. This model is an heuristic of the contingent choices regarding internal transaction governance that are made in designing the operational, or production orientated elements of an organisation engaged in the manufacture of goods. It is only an heuristic because it is not claimed that organisations are designed by following the sequence through as if it were a decision tree. In practice the choices are made both simultaneously and iteratively, and often by default. However, it does indicate the set of contingent choices that characterise the process of organisation and job design, and the main direction of dependency between them, and provides a framework for the analysis of each of the organisations included in the case survey.

Contingencies, are indicated by shaded boxes, while the dimensions along which they vary are indicated by plain boxes. The outcomes of strategic choices become contingencies when they influence the next level of the organisation. The model could be read from top left to bottom left, but a linear reading cannot be sustained. This is most obvious with the relationship between organisation structure and departmental structure. In practice, it is simply not possible to say which comes first, whether organisation structure depends on departmental structure or departmental structure depends on organisation structure. Therefore, a sense of moving from the general to the particular, or an increasing sense of detail, has been the guiding criterion in drawing up the heuristic.

The environmental elements have been discussed in some detail already. While the first two are clearly the most significant, the other four may be influential in particular cases, and their role is an empirical question. The outcome of strategic choices with reference to the environment is the *production strategy*. There is then a choice of process to meet the requirements of that strategy. The ways in which the array of technologies which make up the production process are configured - whether, for instance, they are managed for flexibility, worked on a three shift basis, or deskill existing jobs - will be contingent upon both the technical nature of the process, and the production strategy. It is these two elements of strategy and an array of technologies configured into a production process which are the main contingencies affecting the character of the *materials flow* and *production information flow* in the organisation. The notion of the *production mission* describes the relationship between the production strategy and the associated flows - it binds together strategy and flow[6]. In chapter 8, three generic production missions will be identified.

Distinctive flows of materials through the production technology, and distinctive flows of information from the conception of the product to its despatch are associated with each type of production mission. The character of these information flows and the relationship between them form the prime contingency for the design of the organisation. These flows are differentiated into series of transactions, the character of which varies in terms of *intensity, direction,* and *coupling*. The character of the flows constrains the choices that can be made about the most appropriate design of organisation structure and process. Within this chosen organisational form, the individual structure and process of the various departments within the organisation is the result of choices contingent upon the *variability* and *difficulty* of the *task(s)* that the department in question is expected to perform. Linked with the design of jobs is the design of the payments system to motivate satisfactory achievement of the planned performance. In order to ensure that holders of jobs have the resources to meet that planned performance, they are recruited with certain levels of skills, and given further training. The level of requisite expertise of job holders is also an important factor in departmental organisation design. Chapter 9 will explore the implications of the three generic production missions for organisation structure and processes.

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6) Thus the *mission* is seen as the outcome of the production strategy and the process choice. s is a slightly different sense from that in the manufacturing strategy literature where the mission is outcome of the strategy directly, and process choice follows.

3.6 SUMMARY

This chapter has outlined a contingency theory of organisation design which combines both environmental and technological factors, and has thereby elaborated a conceptual framework for the analysis of the inner and outer context of the implementation process. The precise weight of each in any particular organisation is seen as an empirical question. The environment, or outer context, is conceptualised as being enacted through the production strategy which, combined with the choice of production process, yields a production mission. It is this mission which is most influential in determining the character, or inner context, of production organisation. Associated with the mission are distinctive flows of information and materials, and it was suggested that it is these flows which are the main contingency for the design of the operational elements of the organisation through the transaction governance regimes developed for their co-ordination and control. Within the overall design, the organisation is seen as being differentiated into departments, or functions, whose internal structure and process is contingent upon its task within the overall organisational flows. In turn, the design of jobs within the department is contingent upon the factors identified by Van de Ven and Ferry.

4

DIFFERENTIATION AND INTEGRATION IN METALWORKING PRODUCTION

Perhaps the major issue to emerge from the preliminary investigations into the role of engineering discussed in section 3.1 is the importance of the mode of transaction governance between the engineering and manufacturing functions and the quality of relations across the engineering/manufacturing interface. Traditionally, transactions have been sequentially coupled; now the pressure for improved product development performance is generating pressures towards more interactive coupling in what Hayes and his colleagues call a new paradigm of product development management where

> "development is characterised by extensive overlap, with continual two-way interchange of information at low levels. Different phases of the project are integrated through a shared understanding of the primary purpose of the product or process. Fast, effective problem solving and early conflict resolution are the rule" (1988 p 331).

This chapter will use the heuristic presented in section 3.5 to explore this interface as an example of its analytic power. In so doing, it will embrace a theme within organisation design which has recently become a major focus of debate - that of "organisational integration" (see Whiston 1989 for a review). This literature tends to assume that integration is, by assertion, a good thing. It does not, therefore, provide any mechanisms for assessing the requisite level of integration in any particular situation, an analysis which can only be carried out in the light of an understanding of the sources of differentiation which gave arise to the need for integration in the first place. In developing such an understanding, a conceptual framework will be developed for the governance of internal transactions between functions. While some of the framework will be specific to the engineering/manufacturing interface, other elements will be of more general application to internal organisational governance.

4.1 DIFFERENTIATION AND INTEGRATION

Perhaps the first question to be addressed is the necessity to identify separate design and manufacturing functions. Lawrence and Lorsch have argued that "differentiation is defined as the state of segmentation of the organizational system into subsystems, each of which tends to develop particular attributes in relation to the requirements posed by its external environment" (1967b p 3). In the context of metalworking production, the design, or engineering, function can be considered as differentiated from the manufacturing function due to the different environmental contexts that each faces.

Lawrence and Lorsch go on to state that "integration is defined as the process of achieving unity of effort among the various subsystems in the accomplishment of the organization's task" (ibid p 4). The point is that the requisite co-ordination between engineering and manufacturing cannot necessarily be achieved simply by merging the two functions, because this may reduce their individual abilities to cope effectively with their particular environments. This suggests that it may be more effective to retain the benefits of differentiation for the functional level, and achieve co-ordination at the organisational level through integration. Thus, as Lawrence and Lorsch indicate, and Rueschemeyer emphasises, "differentiation" and "integration" are not the poles of a single spectrum, but two heterogeneous spectra (1986 p 143), as indicated in figure 4.1. Crucially, integration may be achieved either through further differentiation in the shape of specialist co-ordinating functions, or through the merging of functions in a process of "de-differentiation".

For a long time, manufacturing firms have only had the choice between these two options. Over the last decade or so, a third option has begun to emerge with the development of integrating information technologies. Unity of effort can be facilitated, and perhaps even achieved, through ensuring that all functions within the organisation are working off the same information. This can be achieved by establishing a centralised or distributed data base of

Differentiation and Integration in Organisation Design

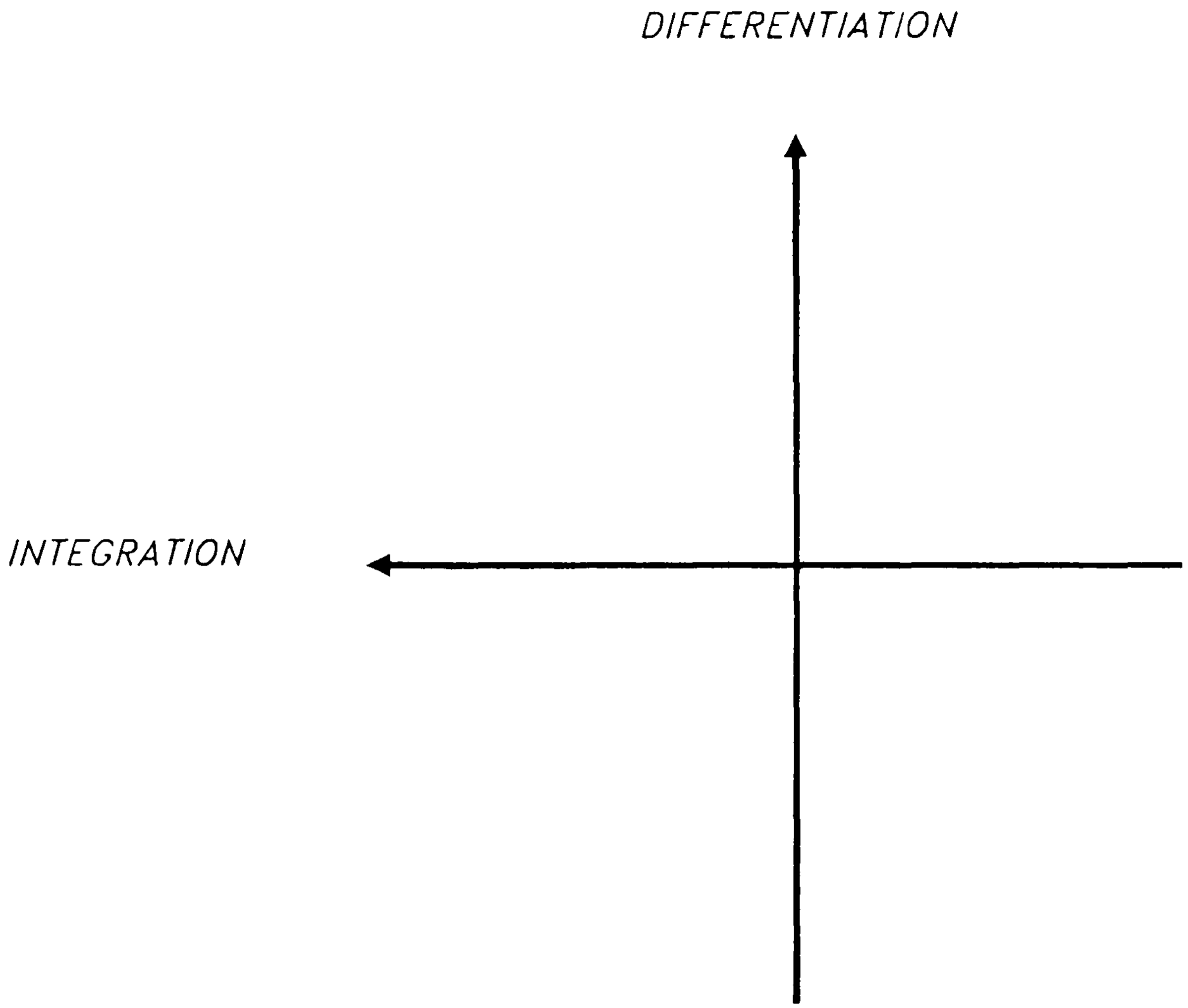

FIGURE 4.1

information which is shared between functions. In the manufacturing context, this is the goal of Computer Integrated Manufacture (CIM), which was described in section 2.3, where all the functions which play a part in the production information flow access a single data base - the *product data base.*

This discussion poses a number of questions for the nature of interactions at the engineering/manufacturing interface:

1) what are the sources of differentiation between design and manufacturing?

2) to what extent is dedifferentiation a viable option in contemporary manufacturing firms?

3) how much can data base technologies contribute to integration on their own account?

4) what are the appropriate ways of governing the internal transactions across the engineering/manufacturing interface?

These will be discussed in turn.

4.2 THE SOURCES OF DIFFERENTIATION

The investigation of the first question is hampered by the almost complete lack of comparative empirical work on the differences between the contingencies facing the design and manufacturing functions. Most of the work on organisation and environment, and organisation and technology has treated the organisation as a homogeneous unit. Indeed, this has been one of the major criticisms of contingency theories of organisation. Lawrence and Lorsch themselves do not offer much guidance for two reasons. Firstly, despite the explicit role that the environment[7] plays in their framework, they present only proxies for differentiated

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[7] In their model, the term "environment" includes the task or technology of the function under study.

environments. In particular, they deploy formalisation of organisation structure, and the orientations of staff in terms of others, time and goals (1967 chap 1). Degree of integration is then measured in terms of the reported amount of inter-departmental conflict. This approach is unsatisfactory because it effectively infers the cause of differentiation from the observed effects; it attempts to measure the independent variable by examining the dependent variables. Secondly, Lawrence and Lorsch were examining companies in three process industries with very different production information and materials flows from the norm in metalworking production. In particular, science-based research and development plays a much more important role than engineering design.

The differentiation between engineering and manufacturing has its source in both of the main contingencies discussed in chapter 3, and has led to the development of a *professional* form of organisation in engineering and a *bureaucratic* one in manufacturing. Firstly, engineering processes only flows of information, while manufacturing processes flows of both information and materials. In fulfilling their roles within the production mission, they perform distinctive *tasks*. Secondly, they have distinctive relationships to the external environment through differences in the *tasks* deriving from the engineering and manufacturing elements of the *production mission*. The task of engineering is to articulate the customer's requirements in the design. This articulation, made either in conjunction with a marketing department or directly with the customer, encourages a product orientated organisation design. Manufacturing, on the other hand is relatively "buffered" (Thompson 1967 chap 2) from the environment, either by a marketing function or by engineering directly, and tends to seek effective resource utilisation through a functionally orientated organisation design (Winch 1983).

The two main contingencies at the task level are, as discussed in section 3.5, *difficulty*, in terms of the extent of the search process required to perform the task, and the degree to which its outputs can be fully specified in advance; and *variability*, in terms of the number of exceptions encountered in performing the task. Engineering design work is inherently innovative - if the outcome of the task were fully known, then there would be no need for a design process. Outcomes, cannot, therefore be completely specified in advance, much to the chagrin of many customers. The task of manufacturing, on the other hand, can be fully specified in advance, thanks, mainly, to the work of engineering, and is, therefore, relatively predictable. The design process is also inherently conceptual, and, therefore, relatively difficult to analyse. In manufacturing, the conceptual element is largely restricted to the planning stage, and most materials processing is relatively easy to analyse.

Engineering also faces greater variability than manufacturing because each design project is a one-off by definition. There is little point in designing the same product more than once, but in manufacturing the production run may be in the thousands, and is rarely one-off. Even in heavy engineering, many components are manufactured in pairs on a two-off basis. Between firms, there will be considerable variations in the levels of variability and difficulty with which they have to cope, depending on the nature of the production mission. For instance, the diesel pump maker customising a product through "variant design" is likely to have lower levels of task difficulty and variability in its engineering function than the builder of submarines has its manufacturing function. However, issue being addressed here is the differentiation between engineering and manufacturing within a single business, not between businesses.

These differences in task contingencies lead to profound differences in the organisation structure and processes of the two functions (cf Van de Ven and Ferry fig 5.2). Firstly, there are important differences in the expertise deployed by the majority of workers in each function. In Zuboff's terms (1988 chaps 2 & 3), materials processing traditionally involves "action-centred" skills which are characterised by "acting-on" physical materials, while information processing in design work involves "intellective skills" which are characterised by "acting-with" abstract ideas. The greater difficulty in engineering tends to favour the recruitment of more highly skilled workers who are deployed in job designs allowing greater discretion. Levels of interdependence also tend to be higher between groups in engineering, and co-ordination processes more reciprocal.

Secondly, the lower difficulty and variability in manufacturing has favoured greater specialisation and standardisation of work. Littler (1982) has argued that the development of scientific management in manufacturing was essentially a process of increasing bureaucracy. In comparison to engineering, the emphasis has been on rules, programmes, and procedures. This contention is supported by evidence from Whalley's case study of a pressing plant where on a measure of "organisational constraint", the drawing office was found to have the lowest organisational constraint, while the production engineers were found to have the highest after the production managers themselves (1986 fig 4.1). Similarly, Smith (1991) in a comparison of the work and ideology of design engineers at British Aerospace and manufacturing engineers at Cadbury compared the "craftism" of the designers and the "Taylorism" of the manufacturing systems developers.

Thirdly, the greater standardisation and specialisation has favoured the development of automation, and so one of the major differences between the two functions is capital intensity. Manufacturing deploys a whole range of technologies which are simply not relevant to the engineering. In manufacturing, the largest elements of costs are fixed capital and materials, while in engineering, the largest single element of costs remains labour, despite the advent of CAD. This means that the performance criteria laid down in each function are likely to be different - while the focus of management control on the shop floor is turning increasingly to machining times and material control, in the design office concern still focuses directly on the performance of workers.

Fourthly, the two draw on different types of labour market. Design engineers are now highly professionalised. Even if they do not meet the full criteria of a liberal profession or enjoy the autonomy of their counterparts in the construction industry, they are now supported by such institutions as the Engineering Council and espouse many of the tenets of the professional ethos (see Francis and Winstanley 1988). In contrast, organisations of managers in manufacturing are pale imitations, and are more along the lines of specialist interest groups within bureaucratic structures. So far as manual workers are concerned, the changes symbolised by the decline in apprenticeships means that craft labour markets have now largely disappeared. While this choice of a professional form of work organisation may well be a response to the distinctive task of design engineering, it is now so embedded through the process of structuration that it must now be considered an independent variable in the organisation of the design function.

Deploying the Schein (1984) model, Adler (1988) has reviewed some of the outcomes of these differing contingencies for the cultures of engineering and manufacturing in the American context. He identifies three main areas of difference, even in organisations where the two functions are on the same site. At the level of "artefacts and creations", rewards such as pay and fringe benefits tend to differ between the two, with engineering usually more favoured. At the level of "values", the implicit hierarchy of status and influence within the organisation runs from conceptual design, through detail design and down to manufacturing engineering. At the level of "basic assumptions", the root of creativity is seen as individual expertise, rather than a sense of collective responsibility for a successful product.

Of course, the "bureaucratic" model of manufacturing organisation has long been under attack. McGregor (1960) contrasted the "theory X" view of management deriving form scientific management with the "theory Y" view of a more open, participative style. Writers as varied as Piore and Sabel, and Peters and Waterman have advocated a move towards more organic forms of organisation. More recently Walton (1985) has reported shifts in the management of human resources away from attempts at "control" of the workforce towards generating "commitment" from the workforce at a number of factories. These changes have been accompanied by a shift towards more "organic" organisational forms such as those charted by Hayes and his colleagues (1988), Jaikumar (1986), and Nemetz and Fry (1988) amongst others. However, the evidence from these cases is that there is still a long way to go, and the contingencies outlined above will not go away. Indeed, they are in many cases increasing in their strength.

The differentiation between design and manufacturing, therefore, has deep roots and a sturdy trunk. It may well be possible to train some of the branches towards a less differentiated state, but the survival of the whole will continue to depend upon this differentiation. Only in very small organisations, or highly focused factories in stable markets is a merger between design and manufacturing likely to be viable in terms of competitive advantage. These conditions are not widely met, as is indicated by the fact that in only one of our case study companies are the manufacturing and design operations under a common (manufacturing) director. Even this organisation retains a separation between the chief designer, the manufacturing engineering manager, and the manufacturing manager at the next level of the hierarchy, and uses organisational linkage mechanisms between them.

4.3 INTEGRATION BY INFORMATION TECHNOLOGY

The notion of technical, or systems integration is central to the literature on the implementation of AMT. As discussed in section 2.3, the contemporary literature abounds with the notion of CIM, and, indeed, the further interface of the *product data base* with other data bases within the business such as those in finance and marketing to create what is sometimes known as the Computer Integrated Business. However, as Ingersoll Engineers (1985 p 13) point out, CIM is not the same as "Integrated Manufacture". They argue that it needs to be supported by organisational developments to turn a technical integration into a business integration. For instance, Bertodo (1988) shows the way in which relying on an "engineering data base" for design team communication meant that decisions tended to be made sequentially rather than being overlapped, and reducing product development lead times through overlapping the various elements of the design process required organisational linkages.

For a number of reasons, *integrating technologies* do not offer a "technical fix" - a way of achieving technical and organisational integration on their own. Firstly, the elements of the system must be compatible. While the compatibility problem may well be fairly simply solved through greater senior management control of the evaluation process, the second reason is more intractable. Essentially, the problem is that of determining the content of the *product data base*, and the protocols for its use. This is not a question of coming to a single agreement which can then be implemented by each function separately, but a continuing negotiation which requires close and balanced co-ordination between all parties who generate or access the product data base.

This issue, in turn, raises the question of the responsibility for the product data base. In its paper form - drawings, parts lists, and specifications - the design has traditionally been the responsibility of engineering. However, the increasingly demanding requirements of the NC programming process, particularly with the advent of 3 and 5 axis machining centres, means that manufacturing engineering departments are increasingly manipulating, rather than merely interpreting, the design. In some cases, this can lead to manufacturing engineering, rather than the drawing office, generating the 3D models required for NC programming, which can generate issues around the "ownership" of the product data base. If engineering develop the three-dimensional models that manufacturing require, this increases their costs for little perceived return to the function, but if manufacturing generate them, then engineering lose control over the design.

CAD/CAM systems, as presently available, suffer from a number of limitations as integrating technologies for handling the production information flow. Firstly, CAD/CAM systems are most effective at generating, storing, and transmitting data in graphical form. Much of the design information transmitted to manufacturing - particularly specifications and schedules -

is textual in form, describing attributes of the components, and CAD/CAM systems tend to be poor at handling such data. Secondly, another very important way of transmitting design information is in physical representations in the form of prototypes, models, and mock-ups. At the present state of the art, it is difficult to use CAD/CAM systems for textual and physical data. While, developments are presently taking place which will overcome these limitations, such as bill of material capabilities, and various visualisation techniques such as solid modelling, holograms, and stereolithography, these are only just beginning to be implemented, and are seen as next generation tools by users.

Thirdly, as discussed in section 2.3, CAD/CAM systems only automate the design process in a very few cases of "variant" design, when tailoring a generic product to meet the requirements of a particular customer. For the vast bulk of design work, design decisions are still made mentally, and it is the content of those decisions which is critical. Iterative debate within the design team is a crucial part of the process, and one which is unlikely to be computerised in the foreseeable future. Organisational integration remains, therefore, vital for the release of the potential of the business potential of technically integrated CAD/CAM systems, and it is to this issue that the argument will now turn.

4.4 ORGANISATIONAL INTEGRATION

The earlier sections of this chapter have shown the way in which the engineering and manufacturing functions are differentiated, and the limitations of information technology alone in providing the requisite level of integration between them. This section will discuss some of the conceptual issues associated with organisational integration between engineering and manufacturing, which will be taken up in more detail in Chapter 13. It will be remembered from section 3.5 that the key variables by which transactions within the production information flow vary are *direction*, *coupling*, and *intensity*. The *direction* of the main data flow is unproblematic in this case - it is from engineering to manufacturing.

A useful basis for analysing the type of *coupling* between differentiated functions is Thompson's typology of interdependence (1967 chap 5), which can be summarised in terms of information flows as follows. Organisations are characterised by "pooled" interdependence when functions merely share overheads, and little or no information flows between them on a routine basis; by "sequential" interdependence when information flows in a linear fashion from one function to another; and by "reciprocal" interdependence, where there are feedback loops in the information flows. To this basic typology, Van de Ven and his colleagues (Van de Ven et alia 1976; Van de Ven and Ferry 1980) have added that of "team" interdependence where there is simultaneous exchange of information between groups. The term "team" is more descriptive of the organisational means by which such a simultaneous information flow is achieved, and so the term *iterative* to describe interdependence in such an information flow is preferred here.

However, as Adler (1989) argues, this typology ignores the temporal dimension in the engineering/manufacturing interface. The character of interdependence varies, depending on whether the design project is being planned, or at the "pre-project" phase; is in the design or "project" phase; or is in the manufacturing or "post-project" phase. This typology gives one way of measuring intensity appropriate to this particular transaction. Adler has related these two dimensions of the production information flow in a typology of co-ordination procedures. He defined coupling in terms of the "communication pattern" across the design/manufacturing interface, which varied according to whether it was "one-way", "stilted two-way" or "two-way". These appear to be synonymous with the categories developed above, and so the latter will be preferred.

The discussion has, so far, concentrated on the procedures, or processes, of engineering/manufacturing co-ordination. However, just as processes within organisation structures are their life-blood, those processes have to be embedded in structures in order to define their flow in the dynamic of the structuration of the organisation. In other words, what types of organisation design can best facilitate the kinds of co-ordination procedure identified above? Galbraith (1977) has extensively reviewed organisational linkage mechanisms, and his typology can be applied to linkages across the engineering/manufacturing interface.

Galbraith starts from the premise that organisations are designed so as to cope with uncertainty, defined as the "difference between the amount of information required to perform the task, and the amount of information already possessed by the organisation" (1977 p 36). He then reviews the variety of ways that organisations have coped, suggesting that they essentially fall into two categories - reducing the level of uncertainty, and hence the amount of information required to be processed, or increasing information processing capacity. In the former category, he includes environmental management, or buffering; the deployment of slack resources, thereby reducing organisational performance; and creating self-contained tasks.

He then suggests four strategies for increasing information processing capability. The first is the introduction of what Weber called bureaucracy (1947 S 3.2) - taking the form of hierarchy, rules, programmes and standards. The second is professionalism,[8] where workers with known performance capabilities are given local autonomy to solve problems. As discussed in section 4.2, these have been the classical solutions adopted in manufacturing and engineering respectively. However, both professionalism and bureaucracy suffer from strictly limited information processing capacities as hierarchical lines of communication become overloaded, rules and programmes need to be continually updated, and professionals need to be co-ordinated. Committees can be considered as the most distinctive co-ordination mechanism of bureaucratic and professional organisation designs in that they meet to set rules and decide on programmes.

The third strategy is the introduction of computerised management information systems. While these do indeed increase the organisation's information processing capabilities, they can only

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8) Parsons, in his introduction to Weber's text, and Stinchcombe (1959) have both argued that Weber's flation of bureaucratic and professional organisation is a mistake. I concur with this critique.

handle quantitative information and all suffer the types of limitations identified in section 4.3. The fourth strategy is the implementation of lateral, as opposed to hierarchical, relations. All the strategies identified for increasing capacity incur costs; but, Galbraith argues (1977 p 55), if they are not chosen, slack resources are the default option. He goes on (1977 chap 8) to propose a hierarchy of lateral relations with the aim of reducing the need for information processing vertically within the organisation, and enhancing the capacity to process it at lower levels. He identifies six distinct mechanisms: direct contact; liaison roles; task forces; teams; integrator roles; and matrix organisation.

The structures proposed by Galbraith and the processes proposed by Adler can be considered as the ways through which the structuration of internal transaction governance along the information and materials flows takes place. Pressures from the environment, particularly through the shortening product life cycles, the reduction of product development lead times, and demands for the implementation of JIT-type production systems are all placing increasing pressures on internal transaction governance. Slack resource is no longer a viable default option, and bureaucratic and professional solutions are no longer capable of the speed and quantity of information processing required. Information technology cannot do the job on its own, and so increasing attention is being paid to organisational integration. Organisations are moving from simpler transaction governance methods towards iterative coupling and matrix-type structures.

4.5 SUMMARY

This chapter has explored in more detail the heuristic developed in chapter 3 by focusing on the engineering/manufacturing interface and the sources of differentiation between the engineering and manufacturing functions in organisations engaged in metalworking production. It demonstrated that the sources of differentiation are contingent upon the outer context, and the associated process choices. The option of "dedifferentiation", or the merger of functions is, therefore, limited to a very few special cases, and is not widely available. While information technologies can help with the problem of integration in differentiated organisations through increasing their information processing capabilities, such a "technological fix" on its own is inadequate - information systems need to be managed. While *integrating technologies* such as CAD/CAM can provide useful elements of integration by making it easier for everybody to be working off the same timely information in the *product data base*, it is still necessary to develop organisational co-ordination procedures for managing transactions across this interface within the production information flow.

Attention, therefore, turned to the organisational means of governing transactions between departments. Typologies of process and structure, derived from the work of Adler and Galbraith respectively, were presented. These two typologies form the basis for an understanding of the structuration of transaction governance across the engineering/manufacturing interface and can, therefore, be considered to be complementary to Williamson's typology of governance forms for external transactions within the outer context. The requisite level of integration in an organisation is a combination of, on the one hand, the extent of differentiation which remains once dedifferentiation, or merger, options have been exhausted, and, on the other, the type of transaction governance that the information or materials flow requires. The level of organisational integration can be measured by the extent of use of these structural and processual governance modes, and will be explored empirically in chapter 13.

5

THE PROCESS OF CHANGE

5.0 INTRODUCTION

The process of technological change, or implementation, within the organisation is the main issue addressed by this thesis. However, influenced by the development of Pettigrew's model presented in section 1.2, it was necessary to present the *content of change* in terms of the characteristics of the technology being implemented in chapter 2, and the *context of change* in terms of the organisation within which implementation takes place in chapters 3 and 4. The argument will now return to the main theme by developing a robust, recursive model of the *process of change*. It will then examine the types of structures adopted by organisations to enable this process to happen, and discuss their different properties in terms of the capacity to generate "organisational learning".

5.1 STAGE MODELS OF CHANGE

The literature on the diffusion and implementation of innovations has tended to specify the process in terms of stages. As a result, Zaltman et alia (1973, chap 2), writing in the early seventies, could specify seven different stage models in their review of the literature before adding their own. Time has only added to this cornucopia of models - see Partridge (1987) for a review. Before attempting to derive a generic stage model which can be applied across the 15 cases investigated here, it is worth trying to specify the criteria which a stage model should meet. Zaltman et alia, commenting on the stage models of diffusion and implementation prevalent in the sixties, argued that they all tended to be inductively generated from limited case study data (1973 chap 2). Little has changed in more recent work on this topic. Hage (1980 p 207), however, argues that any model proposed should be theoretically justifiable. This is surely right - the continued generation of slightly differing models from non-comparable case studies is not going to advance knowledge very much.

The work of Gardiner and Rothwell (1985) on the criteria for "good" engineering design stresses the importance of "robust" as opposed to "lean" design. Robust designs are ones that can be both consolidated and stretched, while lean designs are unadaptable. Such a criterion would seem to be appropriate for the assessment of both methodologies and models in organisational research. In particular, any model of change proposed should be capable of adaptation and re-adaptation to the case under study without loosing its conceptual integrity. This suggests that the generic model itself should not be over-refined, but clear in its specification and plausible in its application.

Any stage model is an analytic device to segment a flow of activity through time. The point of transition, or inflection between stages, therefore, ought to be meaningfully specifiable. Many stage models attempt to describe the content of each stage, but do not specify the outcomes of the activities within each stage. The inflection points, therefore, tend to be arbitrary. A simple, but related point, is that the nomenclature of the stages ought to be intuitively meaningful as well. There are, therefore, three basic criteria by which to assess stage models - they should be theoretically justifiable, robust, and specify clearly both the content and inflection points of each individual stage. The following discussion will focus on implementation models; diffusion models will not be addressed because, as discussed in section 1.1, they tend to assume that implementation is unproblematic.

Hage (1980 chap 7) proposes a four stage model, which he justifies on the grounds that each stage corresponds to one of the four problems of the Parsonian social system. "Evaluation", is the pattern maintenance functional problem - how the organisation perceives a performance gap and the selection of the option of change. "Initiation" is the adaptive functional problem of how the search for resources is carried out. "Implementation" is the goal achievement functional problem, its objective being the reduction of the performance gap. Finally, "routinization" is the integration functional problem and the process through which the change is accepted or rejected by the organisation. This model of implementation is largely based on research in hospitals and other service sector organisations such as schools. It seems reasonable to suppose that the implementation of AMT might be different. The key difference lies in the fact that in manufacturing organisations, capital budgeting procedures mean that it is not very meaningful to distinguish between the evaluation process, or the choice of technology, and the initiation process or the garnering of funds to pay for it. Keeping with Hage's terminology, it is suggested here that the justification procedure simultaneously "evaluates" and "initiates" the innovation.

Lewin (1952 chap 9), writing from a social psychological perspective, identified three stages of change in group standards - "unfreezing", "moving" , and "freezing". This model has been developed by Schein (1964) who gave a rich content to each of the stages. White (1980) has usefully applied this model to the implementation of MRP systems, and, as Melin (1987), has pointed out, this metaphor is a helpful one for analysing change in organisations. However, the emphasis upon the reactions of individuals to the change, and, in particular the implied problematic of "resistance to change", means that organisational and technical problems associated with implementation, such as those suggested by Beatty and Gordon (1988) tend to be overlooked. While striving for a holistic approach, it does not give any guidance as to where to look for the forces acting in the field upon the organisation under study.

Voss (1988a) has proposed a three stage model of implementation, moving through "pre-installation", "installation and commissioning", and "post-commissioning". The outcome of the first stage is the "go/no go" decision. The problem with this terminology is that it tends to imply that the most important stage is the "installation and commissioning phase", when the importance of the different stages may well vary between implementation projects.

Secondly, it only suggests a point of inflection for the end of the evaluation stage. However, elsewhere, Voss (1988b) has distinguished between "technical success" and "business success" as outcomes of the implementation process. Technical success occurs when the system is fully de-bugged and working reliably. Business success, on the other hand, is only reached when the original benefits that were sought have been realised.

Drawing mainly on these three models, the following generic model for the implementation of AMT is proposed - it is summarised in figure 5.1. The first stage is the *evaluation* of the new technology both technically and financially following upon the recognition by the organisation of what Zaltman et alia (1973 p 55) call a "performance gap". This evaluation process has the effect of unfreezing the perceptions of at least the key decision makers. Its most characteristic procedure is the "justification" by which the bidding for funds takes place. The outcome is the *adoption* decision on whether to proceed with the implementation. This stage is, in effect, a combination of Hage's first two stages, and it lays down the criteria by which the success, or otherwise, of the implementation will be assessed.

Walton (1989) has identified a number of organisational process that occur principally at this stage. The first is what he calls "creating a strategic vision" through which the technology is evaluated both in the context of the existing *production strategy*, and in terms of external opportunities and threats posed by the technology. The second is the promotion of "commitment and competence" amongst those that will use the system. Thirdly, "broad and informed political support" is generated. The extent of this activity varies depending on whether other members of the "critical mass" required for implementation are required to "let it happen", "help it happen", or "make it happen" (Beckhard and Harris 1987). The evaluation stage, then, is a quintessentially political process through which the objectives of the implementation are determined.

In terms of the typology presented in section 2.2, this stage is likely to vary with the *content*

THE IMPLEMENTATION PROCESS

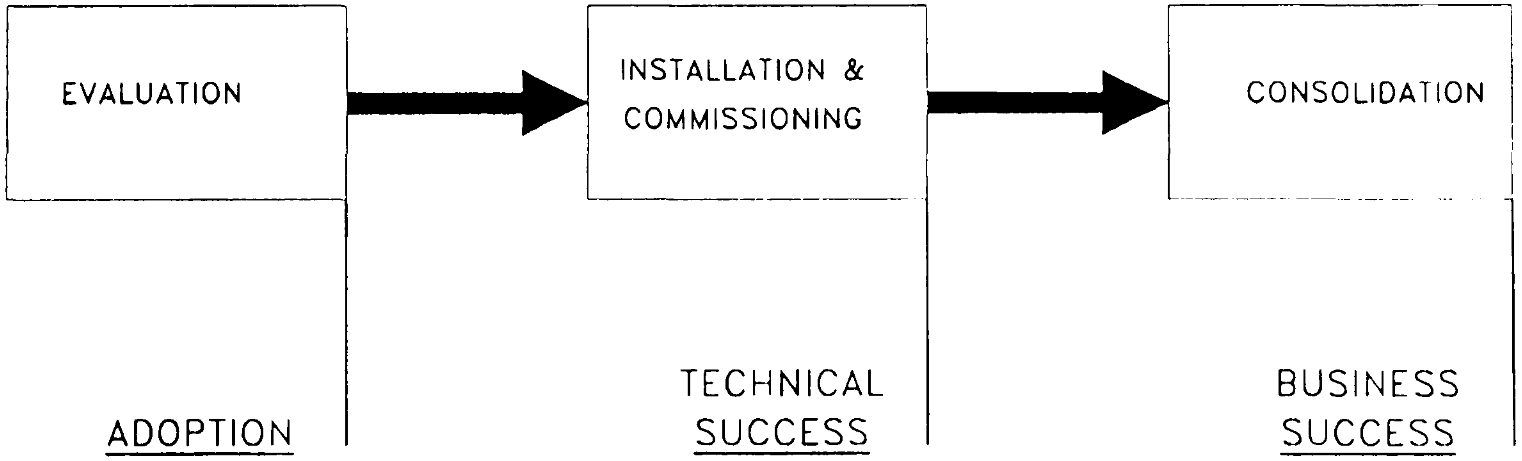


FIGURE 5.1

of change so far as the level of technical complexity and systemic change of the technology. The more *complex* the technology, and the more *systemic* the technology, the more likely is the evaluation process to be extended and far ranging. Similarly, the *context of change* will also have an impact, particularly in terms of how the technology affects the existing production mission, and how the capital budgeting procedures as part of the organisation's resource flows are organised. Thus, in some organisations, as implied in the comments on Hage's model above, it may be useful to identify the mode of search for resources as a dimension along which this stage can vary.

The second stage is the *installation and commissioning* of the new technology. During this stage, the commitment of those immediately involved with the system is usually gained, and workers are trained to operate the system. The first stage of the *configuration* of the systems takes place during this stage, and may be organised on a participative basis (Walton 1989 part II). Relationships with the vendors of the technology will also be at their most important. The intended outcome is *technical success* in the sense that the performance of the technology as laid down in the specification at the evaluation stage is met or surpassed. This is the same as Hage's "implementation" stage.

The contingencies by which this stage varies are likely to be largely technical, particularly the level of *complexity*. The objective is to get the new technology working by mobilising the required resources internally and externally, mainly through configuring it to the meet the specifications laid down earlier. High technical complexity will involve the intensive mobilisation of a depth of skills, while systemic features will imply the deployment of a broader range of skills. The physical characteristics of the technology will also be important. A basic CAD system can be installed in a existing office merely by plugging it in; a new press line requires a major construction project, perhaps lasting over a year. The more complex the technology, the longer commissioning is likely to take.

The third and final stage is *consolidation*, or what Hage calls "routinization". During this stage, the organisation makes the adaptations in its internal structure and process so that the performance of the system can be improved. If necessary, a system management section is established to ensure its routine operation. There may also be a further configuration of the technology so that it complements the organisational context. During this stage, the freezing of the implementation into the organisation takes place. The intended outcome is *business success* in that the objectives laid down at the evaluation stage are either met or surpassed, or that sufficient unforeseen benefits are reaped to counter-balance the disappointments with the original aims.

Technical complexity is not likely to have much of an influence on this stage, but *systemic* technologies will tend to imply that major organisational changes will be required, particularly in terms of increased organisational integration between the departments affected. The amount of change required will also be contingent upon the existing extent of differentiation and integration within the organisation. For instance, the implementation of CAD/CAM into an organisation which is already highly integrated will require less consolidation than in one where integration across the engineering/manufacturing interface is underdeveloped.

Using this generic model, analysis can be focused on how it varies contingently between different implementing organisations. The key question for research on implementation is how and why each of the stages changes in terms of its content and its relationship with its adjoining stages. For instance, Ettlie (1980) in a survey of 34 innovations shows that, in terms of a version of Rogers' diffusion model amended to include an "implementation" stage, the stage that most often varied in terms of its absence or presence was the "trial" stage. The problem is that some technologies are quite simply not amenable to trial. Rather than specify this as a separate stage, it seems more sensible to characterise "trialability" as one of the dimensions by which the evaluation stage can vary.

All three stages of the model can be considered to comprise the *implementation process*. It is submitted as a process model, because, as will be demonstrated in chapters 10, 11, and 12, implementations can be seen to pass through these stages. The model is theoretically justified on the basis of Hage's analysis, robust in terms of its ability to handle contingent variation within stages, and has clearly specifiable content and inflection points between stages. However, this is precisely the sort of model that Pettigrew has criticised on the grounds of excessive linearity and rationality (1985 p 16). Although not totally averse to stage models himself (see 1985 p 473), Pettigrew is right to reject a reliance on such crude formulations. They can only serve a useful role as parts of more dynamic and recursive models; the next section will develop such a model.

5.2 A RECURSIVE MODEL

Leonard-Barton presents a model of implementation as a process of "mutual adaptation". She argues that most of the literature on process innovations "focuses on either what can be done to the technology to adjust it to its environment or what is done to the organization by the technology". She proposes that the process is more fruitfully conceived as one of mutual adaptation between the technology and the organisation as a process of the "re-invention of the technology and the simultaneous adaptation of the organisation" (1988 p 253). This process of mutual adaptation proceeds through a series of long and short cycles of adaptation. "Long cycles" are major evaluations and redirections of the implementation process, while "small cycles" are minor adjustments to the flow.

There are two main points that can be made about this model. Firstly, Leonard-Barton is clearly influenced by socio-technical systems theory, and conceives the end process of mutual adaptation to be an equilibrium between the social and technical systems. In particular, she stresses the simultaneity of the adaptation process. Ettlie has similarly proposed a model of "synchronous innovation" (1988 chap 1) in which the *installation and commissioning* and *consolidation* stages overlap. Damanpour and Evan (1984), however, have noted that organisational adaptations tend to lag behind technical ones due to "organizational lag". This is because, as Leonard-Barton herself points out in a later work (1990 fig 9.2), organisational issues have a much slower learning curve than technical issues. We have then three possible routes for the "alignment" AMT with the organisation: the enabling organisational conditions already exist; the adaptation occurs simultaneously; and the technology is implemented and then the organisation adapts, with the last being the most common (McKersie and Walton 1991).

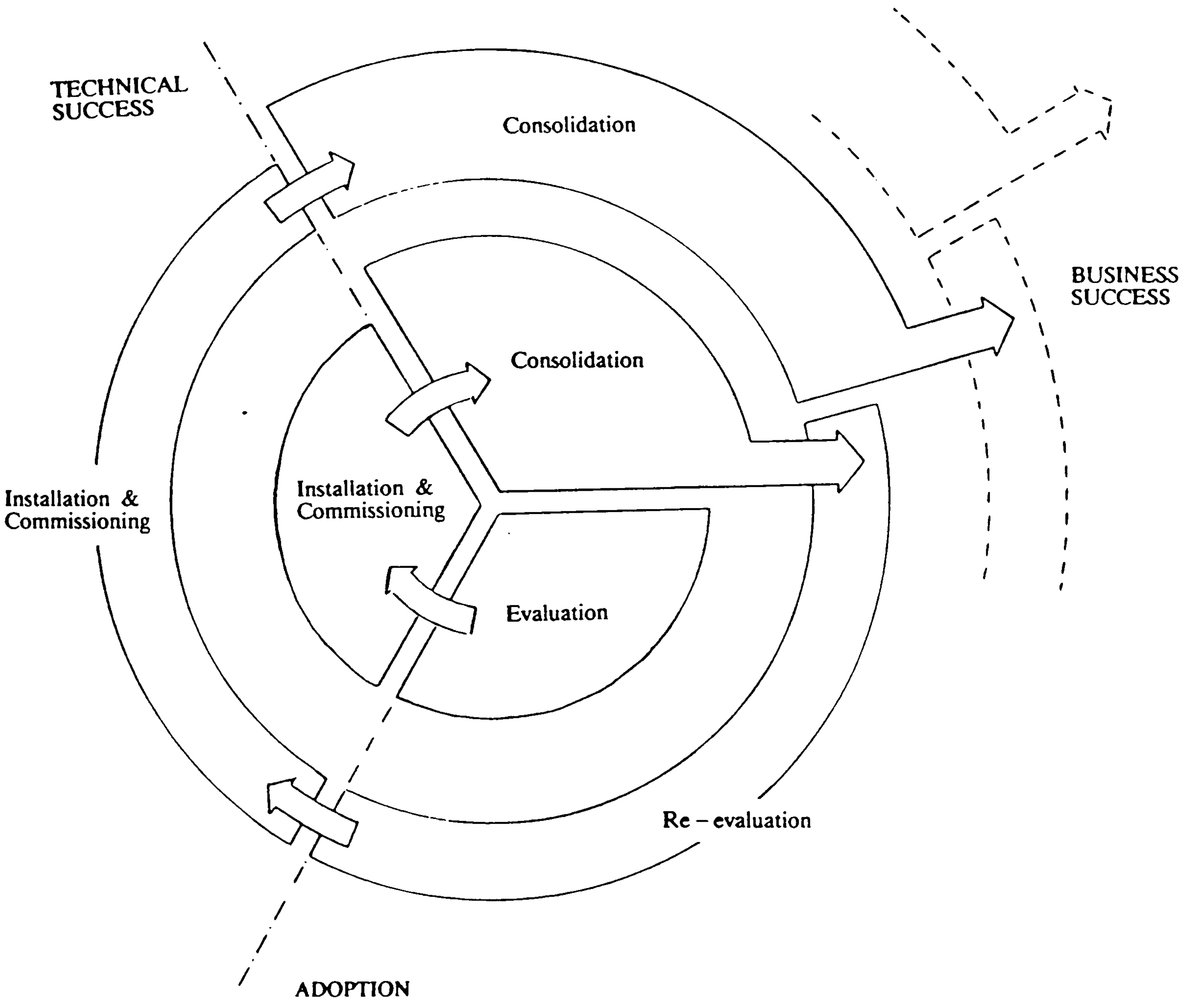
A second issue is how to distinguish between the large and small cycles. Leonard-Barton gives examples, but does not give more general guidelines. So far as technical adaptation is concerned, the distinction between the primary elements of the technology identified earlier in section 2.1, and its configuration is the key. Small cycles can be defined as those which affect the configuration, while large cycles are those which take the implementor back to either scrapping the technology and choosing another, or changing the primary elements of the technology. So far as organisational adaptations are concerned, Leonard-Barton appears to equate small cycles with job redesign, and large cycles with organisational redesign (see 1988 figure 3).

The Leonard-Barton model meets many of the requirements for a dynamic and recursive conception of the implementation process, but is limited by its assumptions of simultaneity and equilibrium. Like Ettlie's model of "synchronous innovation", it is more a picture of an ideal, than a model for understanding actual change processes. The greater the *consolidation* required, the less likely is synchronous implementation to be achieved. The process of mutual adaptation means that implementation does not occur in a linear fashion, but recursively through time. At each stage the organisation iterates around strategic choices within the design space. The lag within the process means that each stage is interactive with the others. The achievement of technical or business success can mean that a new performance gap is perceived; it may reach such a level that a completely new evaluation of CAD/CAM is required, and so the cycle starts again. Indeed, the achievement of success, in both technical and business terms is likely to encourage re-evaluation as awareness of the potential of the technology is heightened. The dynamic of the development of the technology itself, as articulated by vendors' marketing, also ensures that perceptions of the performance gap are constantly changing.

A recursive model of implementation is presented in figure 5.2; it was first presented in Winch and Twigg (1992). The main feature is the avoidance of a position of equilibrium, and the emphasis on continuous changing. It retains the three stages identified in section 5.1, but places them in interactive and recursive relationships to each other, and shows the way in which the successful completion of one phase of implementation generates pressures for *re-evaluation* and a new phase of implementation to begin. If each phase can be considered as a large cycle of implementation, then the small cycles can be seen as the incremental changes within each phase. The process does not revolve around a fixed point, but displays a development through time as re-evaluations build on the experience of *installation and commissioning*, and *consolidation* with the earlier system. This is indicated by the large arrows at the end of each cycle. The overall dynamic can be considered to be one of "organisational learning" in which "feedback from previous experience is used to choose amongst present alternatives", and can be seen as a complement to "rational calculation, by which expectations about future consequences are used to choose amongst current alternatives" (March and Olsen 1988 p 336).

One of the more useful frameworks for understanding organisational learning is that of Argyris and Schön (1978 chap 1). They distinguish between "single loop" learning in which the organisation adapts to the external and internal pressures acting upon it so as to achieve its pre-established objectives, and "double loop" learning in which there is a process of the re-evaluation of norms in the light of the process of adaptation. Double-loop learning, they

Figure 5.2 The Implementation Process



Source: Winch & Twigg (1992)

suggest, is particularly important where the organisation faces conflicting demands, or, what more recent commentators have called paradoxes (e.g. Quinn and Cameron 1988). They also identify the importance of organisational contexts that facilitate "learning to learn" in achieving high quality organisational learning.

Daft and Huber (1987 fig 1) have suggested that the amount of organisational learning required in a given situation is dependent upon the "equivocality of information" which poses problems of interpretation of the data received, and the "amount of information" which poses logistical problems of processing the quantity of data received. The higher the organisation is on these two dimensions, the greater the "information load" it has to bear. This framework can be related back to the typology of technology developed in section 2.2, for it can be suggested that the greater the *complexity* of the new technology, the greater the equivocality of the data regarding the criteria for successful implementation, and the more *systemic* it is, the greater the quantity and range of data requiring to be processed for successful implementation.

This argument implies that *integrating technologies*, which are both complex and systemic, will pose considerable information loads on the organisation. The organisations best suited to cope with learning under such high information loads, argue Daft and Huber (1987 fig 2), are those that are capable of adaptive learning though incremental trial and error decision processes using "rich media" such as interpersonal contact through meetings and teamwork - in other words, those organisations capable of double loop learning. It can, therefore, be suggested that double loop learning is more appropriate for integrating technologies, while single loop learning is more appropriate for the implementation of incremental technologies characterised by both low complexity and a non-systemic nature. How, then, can implementation be organised to facilitate the appropriate kind of learning?

5.3 ORGANISATION FOR IMPLEMENTATION

One of the earliest decisions taken during the evaluation stage is the choice of organisation structure, or *implementation project*, to carry the process through to a successful conclusion. This project may be explicitly conceived as such within the organisation, or it may be a rather grand title for a series of implementation decisions taken on an informal basis by functional managers. While the project organisation may well evolve through the life-cycle of the implementation, the decisions taken on how the evaluation is to be conducted are likely to have a lasting influence upon later activities.

Blackler and Brown (1986) identify three different forms which such *implementation projects* can take. Firstly, they identify "model 0" implementation projects which are characterised by short-term thinking, limited appreciation of organisational issues, and a general sense of muddling through the change. "Model 1" change is characterised by a focus on the technology and the tasks immediately associated with making it work. While they may be strongly project managed, and achieve technical success, such projects tend to show limited awareness of broader organisational issues. It may be called the *technocratic* project organisation. Finally, they identify a "model 2" approach which focuses upon organisational concerns from the initial evaluation stage, and tends to adopt a more participative style of project management, involving end users in the articulation of the design space around the new technology. This is exactly the kind of approach to implementation advocated by those concerned with "human-centred" systems discussed in section 1.2, and is elaborated by Walton (1989). It may be called the *participative* approach.

Perhaps the main feature which distinguishes the *technocratic* and *participative* approaches to implementation project organisation is the stronger role of organisational learning in the latter. The emphasis is upon the review of existing practices, and the development of project

CHOOSING IMPLEMENTATION PROJECT ORGANISATION

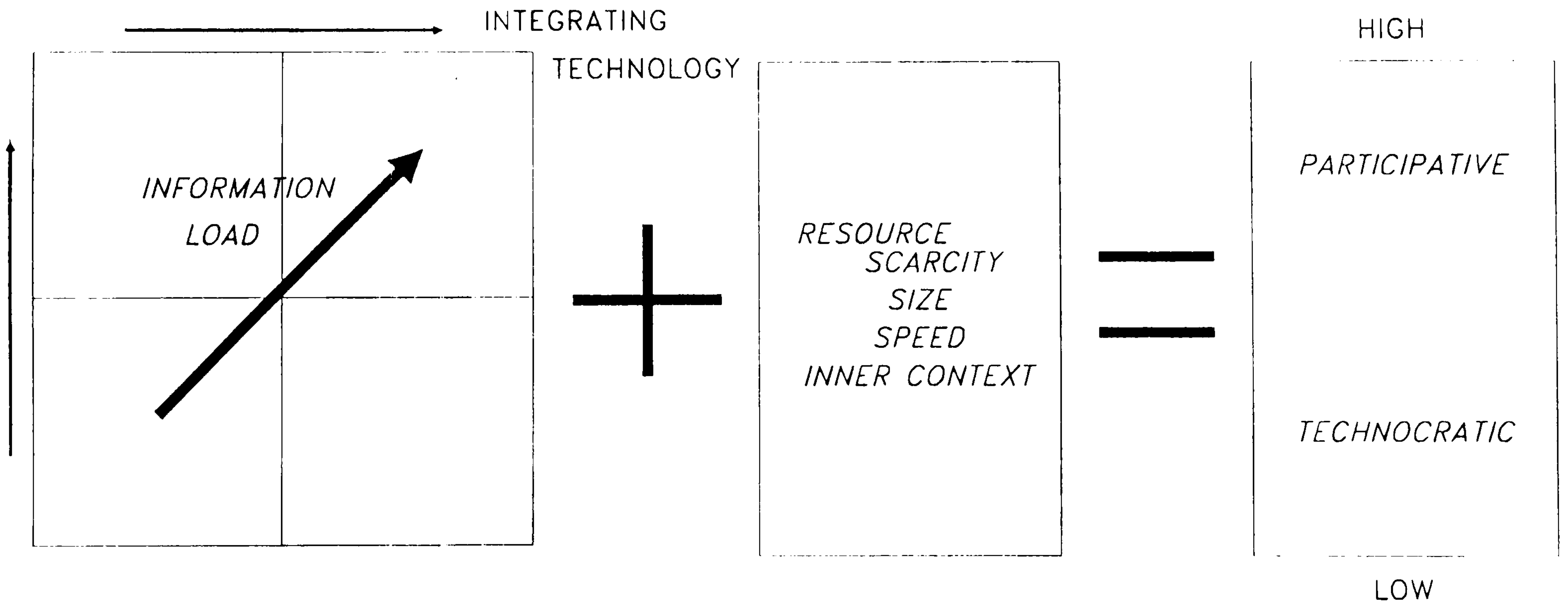


FIGURE 5.3

objectives as implementation proceeds. Participative management is used to involve those affected by the technology in its dimensioning, and a slow project *speed* may be chosen to allow the incremental approach which helps these processes to occur. In terms of the typology of implementation project organisation identified in the previous section, perhaps model 0 implementation can be seen as that where little or no organisational learning takes place, the *technocratic* approach can be thought of as an example of single loop learning, while under the *participative* approach, the project organisation becomes a vehicle for double loop learning.

This implies that an important criterion for the choice of implementation project organisation is the *information load* it faces. There are, however, a number of other important factors. The existing *inner context* will shape the project organisation, particularly the extent of differentiation within the existing structure, the existing level of integration, and the relationship of the new technology to the production strategy. The *size* of the project in financial terms relative to the size of the business overall and other changes taking place will be a factor. In certain situations where the project involves large relative expenditures, there may be a threat to the business' viability should implementation fail. *Resource scarcity* in terms of the availability of skills and capital within the organisation will have a strong influence upon the extent to which the project organisation includes outsiders. Finally, the *speed* with which the implementation is to go ahead - whether it is a "crash programme" or a steady development - will also have an influence.

The relationships between these factors is interactive. For instance, a differentiated *internal context*, and high *speed* are likely to increase the information load through raising the amount and range of data to be processed. Similarly, previous organisational learning will reduce the learning requirements for the present project - returns to experience are significant in the implementation of AMT through learning curve effects. Here, the ability of the organisation to diffuse organisational learning may be crucial (Leonard-Barton 1990) - learning to learn is part of the dynamic. The argument is summarised in figure 5.3, and is presented an heuristic of implementation project organisational choice.

5.4 SUMMARY

The core of the process of implementation has now been elaborated. Firstly, a linear model of implementation stages was derived from the existing literature, and then developed into a dynamic and recursive model of the process of changing inherent in implemention. This model rejected an equilibrium analysis and suggested that implementation is a process of continual changing and learning. The basic features of implementation project organisation were identified and their relative capabilities for organisational learning discussed. As was identified in chapter 2, CAD/CAM is an integrating technology, and so it may be concluded from the above analysis that the achievement of business success in implementation is most likely to be achieved through double loop learning facilitated by a participative implementation project organisation. It is through these requirements for double-loop learning that "CAD/CAM's challenge goes to the core of our conception of the firm" (Adler 1990 p 214)

6

IMPLEMENTING ADVANCED MANUFACTURING TECHNOLOGIES

6.0 INTRODUCTION

The argument so far has developed a conceptual framework which sees the process of implementation of new technologies as one of both organisational and technological change. The argument will now become more focused and review the recent experience of the implementation of integrating technologies before presenting the findings of the research project. It thereby forms the "bridge" between the conceptual framework and the empirical investigation upon which it is deployed. This chapter will follow broadly the structure of the implementation process model elaborate in section 5.1, but it will first review what is presently known about the diffusion of CAD/CAM.

6.1 THE DIFFUSION OF CAD/CAM

In a survey conducted in 1985, New and Myers (1986) found that 66% of "engineering" (including electronics) companies were using CAD or CAM systems, and Bessant (1991 p 168) reports similar figures for 1987. A more recent survey[9] found that 58% of "mechanical engineering" companies were using CAD (Pawar et alia 1991). In a recent survey of 24 mechanical engineering companies who possessed CAD systems[9], Black and Shaw (1991) found that all companies were using the systems for "detail draughting", and around 9 out of 10 were using them for "assembly draughting" (92%) and 2D layouts (88%), and one third had achieved a level of automation through "parametric part generation" (33%). On the other hand, only around one third were using CAD for design analysis applications such as kinematics and

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9) Frustratingly, these authors do not provide a date for their surveys Nor, strangely, does Pawar's team report any findings for NC part programming.

finite element analysis (29%). These figures are broadly supported by Pawar and his colleagues, and in data reported by Bessant. Only 58% of the sample "directly re-use CAD for their manufacturing activities", despite that fact that the sample was restricted to those involved in both design and manufacture. Thus, in terms of the *production information flow* presented in figure 3.2, the predominant use of CAD is at the *draughting stage*, and only one third apply it at the *design stage*, and less than two thirds have a link across to the *planning stage*.

The main benefits achieved from CAD were, in order of response frequency, the ability to re-use design information (92% of responses), reduced design lead times (88%), better productivity (58%), and improved product image (50%). The claim for reduced manufacturing lead time by 46% of companies is impressive in the light of the relatively limited use of direct CAM links, and the 29% claiming better analysis and simulation is a very high proportion of those using CAD at the design stage. 33% of companies were also using the system to create 3D layouts, although it is not clear whether these are wire frame or solid modelling applications (Black and Shaw 1991). Again, Pawar and his colleagues, and Bessant report similar results.

6.2 EVALUATION

The issue of the benefits, or returns of CAD/CAM to the company is the central issue at the evaluation stage, and is strongly shaped by the existing *inner context*. Under the capital budgeting regimes this issue revolves around the "justification" of CAD/CAM - 92% of companies in Black and Shaw's survey prepared financial justifications for their systems. Woods and his colleagues (1985) report that a total of 49% of their sample of 47 CAD/CAM users applied formal techniques, and they note the practice amongst some firms of shortening the pay-back period or raising the discount rate to reduce the perceived risk associated with implementing AMT. Other firms, however, dropped formal techniques when evaluating AMT due to the uncertainties involved. Hayes and Garvin (1982) argue that the misapplication of formal techniques which discount the future can effectively lead to a gradual spiral of disinvestment in capital stocks. For these reasons, Gerwin argues that it is the financial uncertainty associated with the potential benefits of AMT "which is at the heart of the technology selection problem" (1988 p 91).

A number of researchers have criticised the use of such simplistic justification techniques because they do not take into account many of the non-quantifiable benefits of CAD/CAM such as those identified in the previous section. Such justifications as are produced tend to yield more to the demand for corporate rationality than reality (Blumberg and Gerwin 1984 p 117). Senker (1984) found in his survey of 24 systems that many of the justifications prepared by the firms in their survey were wildly inaccurate, while Jaikumar (1984) reports that some managers had completely abandoned using accounting information. Others, such as Primrose and his colleagues (1985) and Kaplan (1986), have tried to develop alternative quantitative methods, but these have yet to diffuse into evaluating firms.

Currie (1989) has explored these issues in some depth. In a set of case studies of the decision to adopt CAD in 20 engineering companies, she reports that only 2 were not obliged to prepare formal justifications, and in both these cases, senior managers were know to be relatively technologically aware. In 11 of the remaining cases, informants expressed reservations about the "soundness" of the information that they themselves had given to those responsible for authorising the decision to adopt. Only 6 of the 20 companies surveyed - all large (>1k employees) - had justified CAD on the basis of "strategic" company-wide benefits; the remainder had deployed "operational" arguments such as productivity savings. She suggests that the predominance of formal justifications are a product of the "accounting culture" that pervades the British engineering industry.

A number of commentators have explored this issue on both sides of the Atlantic. Hayes and

Abernathy (1980) identify the "new management orthodoxy" of financial control, corporate portfolio management, and market-driven behaviour which generates a "pseudo-professional" managerial caste divorced from the realities of innovation and production. As a result, the holding of financial and legal skills, as opposed to technical skills, is, increasingly, the route to the top in the American corporation. The range of issues is too broad to be explored here, for the problems are deeply rooted in the distinctive development of capitalism in the UK and USA. Perhaps the most penetrating analysis of the more immediate issues as they face champions of AMT is that of Johnson and Kaplan (1987) who chart the ways in which the physical measures developed by engineers to control production during the nineteenth century were replaced by financial measures designed to serve the needs of the corporate staffs of the emerging multi-divisional corporations and the external reporting requirements of publicly quoted companies.

The result, they suggest, has been a serious distortion in the information received by production managers who focus their attention on the reduction of production costs as expressed in direct labour cost[10] rather than on tackling the "hidden factory" (Miller and Vollmann 1985) of burgeoning transaction costs which disappear into overhead.

> "By using direct labor to allocate overhead costs to products, cost center managers have their cost-reduction attention solely directed to direct labor savings. With overhead burden rates of 400 to 1000 percent, small savings in direct labor time have large impacts on cost distributions and product costs" (Johnson and Kaplan 1987 p 188).

So far as CAD/CAM and the other integrating technologies are concerned, these distortions are major barriers to adoption, because it is precisely in their ability to save on transaction costs through integrated data base capabilities that many of their benefits lie.

Duchessi and his colleagues (1989), in their survey of 272 MRP/MRP II implementations, report that lack of top management support hampered the achievement of business success.

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[10] [illegible] average, [illegible] UK manufacturing (New [illegible]

Others agree. The traditional "bottom up" strategy for the development of manufacturing technology is no longer adequate for integrating technologies (Carrie and Banerjee 1984). Senker (1984) gives an example of the problems of system incompatibility due to engineering and manufacturing making independent purchase decisions for CAD and CAM respectively. Currie (1989b table 7.1) found that the decision to adopt tended to be taken at higher levels of management if the firm was large (>1k employees), and if the CAD investment was large (£1m+), which suggests that project *size* is a factor. These cases also tended to be those that used "strategic" criteria.

The role of "champions" in the product innovation process is well established (Chakrabarti 1974; Langrish et alia 1972). Winch (1983), Beatty and Gordon (1988), and Gerwin (1984) have noted the importance of innovation champions for successful implementation, and that the organisational position of such champions is crucial. To be effective such champions - who may be dubbed *implementation champions* - must be above the level of engineering and manufacturing individually. Shaw and Macbeth (1986 p 342) found that the innovation champions in their cases were young, relatively inexperienced graduate engineers who reported directly to the technical director or managing director. In both cases they rapidly acquired expert status.

The discussion in Chapter 3 laid stress on the importance of the production strategy for the development of the organisation of production operations. Senker and Beesley found that firms that had a clear idea of how the production planning and control systems they were implementing related to the company's goals tended to be more successful (1985 p.9). Duchessi and his colleagues (1989) report similarly. On the other hand, Rosenthal and Ward report that in "our study of three companies with major integration programmes under way indicates a general lack of clearly articulated strategy, communication difficulty among the technical domains responsible for integration and lack of common purpose" (1986 p 16). Walton (1989 fig 3.4) presents a model of the potential for strategic mismatch between MRP

II system design and corporate decentralisation objectives at Kodak.

Adler (1989b; 1990) provides an overview of some of the issues at this stage derived from his investigation of CAD/CAM implementation in four cases of hydraulic tubing design and nine cases of printed circuit board design. He argues, as do Simmonds and Senker (1989 chap 4), that one of the main problems in developing a successful CAD/CAM strategy appeared to be the lack of familiarity with the technology at senior management levels, and a lack of strategic management capability at middle management levels. Adler characterises the learning process associated with implementation as an "S-Curve"[11] with CAD/CAM presently on the early, flat part of the curve, and argues that "longer-term competitiveness depends upon the organization's ability to shorten the flat parts at both the bottom end and the top end of the S-curve" (1990 p 213).

6.3 INSTALLATION AND COMMISSIONING

Comparing one company's two earlier attempts to implement a CAPM system, with its present successful attempt, Shaw and Macbeth found that for the successful implementation the company had appointed a full-time project leader equipped with micro based project management software. They go on to argue that

> "the work is now being tackled within a coherent strategy for both computing and AMT; user needs have been clearly identified; detailed planning of the implementation has been carried out; users are being educated and trained and are much more involved in the process than previously; a significant amount of effort has been put into tidying up existing procedures and systems and ensuring data accuracy and a close link has been set up with systems suppliers" (1986 p 341).

The project management of the installation and commissioning stage is a vital part of the process, and its organisation is likely to be shaped by the *inner context.* Duchessi and his colleagues (1989) report that nearly two thirds of companies surveyed established a project team. While this made no significant difference to success, stability of team membership did.

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11) S-Curves are a familiar tool to project managers, summarising the shape of the flow of resources through the project. Barrie and Paulson (1992) provide further details.

A survey by Graham and Rosenthal (1986) of FMS implementations found that all eight firms surveyed used some form of team approach and most had specific project managers. However, they felt that the project managers' level of expertise in both manufacturing management and technology was often low in comparison to the requirements of the technology. The teams ranged from 3 to 15 people in size, and those which involved part-time members tended to be less effective. The range of functions covered by the teams was often limited, and only 3 of them included the personnel function. The continuity of membership of the team was an important factor in its success. Overall, the teams tended to be hardware dominated and narrowly technical in their approach.

Rader (n.d.) similarly found the use of specialist teams for CAD implementation: and Hildebrandt (1988) found that in most cases of CAPM implementation he surveyed, project teams were formed. The members of such teams tended to be both advocates of their departmental interests within the team, and advocates of team decisions within the departments. Tyre (1988) found that the use of project teams was associated with the implementation of systemic technologies, but not complex ones. It appears that the project type organisation analysed by Cleland and King (1968) for the management of complex defence contracts has become the established mode of organisation for implementation, at least in the case of integrating technologies. The main questions would appear to be on the conditions for effectiveness of the implementation project teams, and these turn around the many of the issues identified in section 5.3.

Resource scarcity is important in many cases. In a survey of suppliers and users of AMT, the respondents rated the quality of the relationship between the user and vendor as the most important factor influencing implementation outcome (Ettlie 1986; Duchessi et alia 1989). A survey of users of microcomputers for production control in 200 small firms found that half the users had set up a team which included outside consultants and/or representatives of the vendor for implementation, and that only half of the firms rates vendor support as good

(Muhlemann et alia 1984). The evidence from a survey of small firms may, however, be misleading, because they are the least likely to have access to internal resources of skilled personnel. These internal human resources are a function of both IT system skills, and in-house experience in the use of integrative and analytic techniques such as value engineering and group technology.

The level of resources devoted to the project will clearly have an impact on the success of the project (Duchessi et alia 1989). As Ettlie points out (1984), any innovating organisation requires slack resources in terms of cash and people. The role of in-house experience as an element in human resources means that capital and labour are not fully interchangeable in this context. In other words - an organisation rich in cash cannot simply buy in human skills, even if these are freely available in the labour market, which is unlikely to be the case. Not only must the organisation have at least some of the skills in house, but it must have enough to allow them to be released from other duties. This factor is likely to interact with the *speed* of implementation - resource scarcity encouraging slow implementation, and fast implementation consuming a high level of resources.

Leonard-Barton (1990), in a comparative study of 3 MRP II systems and 3 purchasing systems, found that while all implementations achieved business success, there were major differences in the cost and elapsed time of implementation. This was despite the similar nature of the plants involved and the common systems being installed. The main problems that she identifies in the less successful plants are the failure to facilitate organisational learning to cope with the *information load*; *resource scarcity* due to inadequate allocations by senior management; and high *speed* without a full understanding by senior management of the scale of the implementation project.

Webster (1991) provides three interesting cases of failed MRP implementation - none achieved business success, and it is doubtful from the evidence presented that even technical success was achieved. While she presents these failures as a seemingly inevitable consequence of the confrontation between dreams and reality in CAPM implementation, a close reading of the cases reveals a number of more mundane problems. Most notably, all three cases adopted what at best can be described as model 0 project organisations, and were unable to cope with the *information load* inherent in adopting integrating technologies. The scale of the problem in one plant is indicated by the fact that the project manager is described as a "former machinist from the shop floor". Evidence of crippling *resource scarcity* is also apparent in all three, particularly with respect to computing skills.

While there has been considerable debate over the topic of industrial relations and technological change, and a frequent assertion that trade unions, or at least their members, are in some sense, resistant to change, there is little evidence that this is the case. Willman (1986) provides some evidence that strikes over technological change have been largely restricted to three industries - docks; print (especially Fleet Street); and vehicles. Even in vehicles, it is probable that the experience over technological change is more a result of the super-heated industrial relations environment in that industry, rather than a product of rooted resistance to technological change itself. The experience of British Leyland with new body assembly technology for the Metro was one of ready acceptance of change against a background of widespread industrial conflict on other issues (Willman and Winch 1985).

Recent survey and case study data support the contention that trade union involvement in implementation is limited. A survey reported by Daniel (1987) found few problems relating industrial relations and technological change issues, and case studies by Batstone and his colleagues (1986; 1987) give similar results. Simmonds and Senker (1989 chap 8) report a decline in trade union activity around CAD during the eighties, matching the general decline in workplace trade union activity. They identify the main issues that did lead to negotiations as the introduction of shift work, and selection for training. Baldry and Connelly (1986) and McLoughlin (1989) both found limited evidence of union involvement in negotiations over technological change, while a survey by Lintner and his colleagues (1987) found that the presence of trade unions had made little difference to the diffusion of AMT in mechanical engineering.

Training associated with AMT implementation has two main aspects - awareness and technical training for managers, and operator training for users (Stark 1988 chap 10). Simmonds and Senker (1989 chap 5) report widely varying levels of senior management support for training, and that less than a third of companies in their survey of 16 CAD users had provided awareness training, and less than two thirds had provided training for immediate supervisors. Generally, they report a reluctance of senior managers to invest time in appreciating the potential of CAD. On the other hand all had trained users, and had found that, generally, it took 2 to 3 weeks, of formal instruction and on the job training, developed through 4 to 6 months experience to develop proficiency in 2D draughting (ibid chap 7). 3D proficiency and other skills can take a lot longer to develop.

6.4 CONSOLIDATION

Usually, one of the most immediate effects of implementation on the organisation structure is the establishment of a section for managing the system. This task, especially as networked systems are implemented and software applications become more sophisticated, is becoming increasingly demanding. Earl (1989) describes various ways of organising the systems function. Simmonds and Senker (1989 chap 6) have noted the tendency for system responsibility to move from design managers to specialist CAD or systems managers during the eighties, and for the numbers of support staff to grow. Such managers take on the responsibility for the continuing management and development of the system, and effectively becoming the repository of technical expertise on CAD/CAM within their organisations. Usually, they are also responsible for the provision of training once the vendors' responsibilities have been exhausted.

At the broader level, the emerging shape of organisations in the last part of the century is largely a product of the market forces acting upon them, as articulated through the strategy process. The implementation of integrating technologies such as CAD/CAM, itself a product of those market forces, is only one part of the story. It is, therefore, impossible to identify those organisational changes which are solely the result of implementation. It is, however, possible to identify those changes which complement integrating technologies such as CAD/CAM, and, as discussed in chapter 4, to identify those features of organisation design which facilitate the effective use of such technologies. Much of the research that has been done in this area suffers the problems of the "impact approach" that were discussed in section 1.1, and is of limited help because it does not place the outcome of change in the context of the process of change.

Rockart and Short (1991) argue that the dynamic of growing global competition and the increasing capabilities of IT are encouraging the emergence of "networked organisations" in which the "management of interdependence" becomes the key task and IT has a vital "enabling" role. While Galbraith (1977) saw MIS as improving vertical co-ordination through increased information processing capability, in the "networked organisation" IT performs a crucial lateral co-ordination role. The effects are "collapsing the value chain" through inter-functional integration; increased intra-functional integration; the emergence of "groupware" which facilitates IT supported teamworking; the development of decision support systems for senior executives; and a new role for the IT systems management function itself. However, as Rockart and Short themselves note, "no company has yet accomplished the fully networked, large scale integration of functions and systems required to fully manage the product delivery process" (1991 p 208). Moreover, they do not give more than a general indication of how the management of interdependence is actually to be achieved. It seems reasonable to assert that the requisite amount and method of such management is likely to vary between companies, and that, in practice, there is a wide variety of methods to choose from.

Some of these were discussed in chapter 4. In addition to the enabling effect of IT itself, two basic types of structural change were identified - *de-differentiation* and *integration*. The most common form of de-differentiation is *role convergence*, where jobs are redesigned to cover a wider range of tasks. Voss reports a case where "a single group of designers perform all tasks from design, drafting or CAD, NC programming and liaison with manufacturing" (1985 p 322). Similarly, Rader (n.d.) found that German mechanical engineering designers were increasingly doing detail draughting work in addition to design. Buchanan and Boddy (1983 chap 9) found that work roles in an architectural practice blended as both partners and associates, and technicians, started to produce drawings, a job previously carried out by the main grade architects. However, this option is likely to be sensitive to organisation size - Voss describes his case as "smallish", and the architectural practice was also small. The smaller the unit in terms of numbers employed, the more likely is the strategy of de-differentiation discussed in section 4.1 likely to be viable.

If de-differentiation of the organisation structure through the merger of roles and functions is not possible, the alternative is to generate organisational linkage mechanisms. Winch (1983) found that matrix type structures complemented CAD/CAM technology best in organisations where the product market environment encouraged the project orientated organisation of engineering, while capital intensity encouraged the functional organisation of manufacturing. Ettlie and Reifeis (1986) identify a variety of organisational linkage mechanism associated with the technology. Taylor and his colleagues (1986) report the successful establishment of product orientated work groups combining engineering, layout design, and support functions for component design at Zilog Inc. Lee (1988) reports the formation of *cells* combining two previously separate groups of workers in both flexible and enriched jobs. Cells are important because they provide a delineated context in which dedifferentiation can take place. In Galbraith's terms, they handle uncertainty by providing an autonomous unit.

Adler (1988) found that it is the highly differentiated organisations which have the greatest problems in adapting to CAD/CAM. Those with the worst problems organised engineering along strong product/project lines under "myopic" project managers, and manufacturing along functionally organised lines with a strong "fiefdom" mentality. In many businesses, such a configuration had led to a stalemate (ibid p 46). Such *organisational lag* may be caused by a number of factors, but in particular, the existence of opposition to the required organisational innovations may occur. Leonard-Barton (1984) cites the example of an organisation retaining physical data transmission alongside a new electronic transfer (ET) system because of quality control concerns and because designers wanted to retain control over the design process. She concluded that "the perceived need to adhere to old performance and control measures nullifies the relative advantage ET has over current procedures".

Both Willman and Winch (1985), and Jones and Scott (1987) have noted the phenomenon of organisational innovations being made to accommodate the implementation of AMT, and the subsequent abandonment of those innovations. In both cases, particular forms of work organisation and associated payment system were established by the managers and workers associated with the new technology, but then abandoned under pressure from the central personnel function - the new arrangements were perceived as a threat to the integrity of the existing workplace industrial relations system. In the terms of the model of implementation, the organisational changes were not "frozen" into the organisation, and other pressures within the business as a whole, but outside the particular implementing unit, led to their abandonment.

The implications for work organisation and skills of AMT have been the subject of intensive research, with NC/CNC becoming the generic case (Adler and Borys 1989). The overall issues of automation and job design in manufacturing are reviewed by Majchrzak (1988). The discussion here will concentrate on those changes associated more immediately with integrating technologies. Baldry and Connelly, in a study of 8 CAD implementations, found that the systems were being used solely as automatic drawing boards, and that they were "almost classic cases of deskilling" (1986 p 65). However, their work is methodologically weak, and few other researchers agree with them. A review by Ebel and Ulrich (1987) concludes that there has been little impact on skills and employment, while research by Adler (1989) identifies the increasing employment of graduates in design and manufacturing engineering.

In their study of CPICS, a CAPM system, Senker and Beesley (1985) identify the disappearance of the less skilled functions and the upgrading of the more skilled functions. As McLouglin argues (1989), while the manual drawing skills are irrevocably changed with CAD, the design skills required remain unaltered. Ebel and Ulrich (1987) note that it is only the jobs of detail drawing staff and tracers which are affected. Even, here this may not be a result of CAD - Smith (1987 chap 4) notes that tracers had largely disappeared from the aerospace factory he studied over the last 20 years due to changes in drawing and reprographic techniques. There is an important issue here of the disappearance of jobs from engineering predominantly held by women, but it is not one of deskilling in the remaining jobs.

As Osterman (1991) and Adler (1988b) argue, the general picture seems to be one of a net effect of the upgrading of skills along the lines of a shift towards the "intellective skills" identified by Zuboff (1988). Whether this leaves society in the situation that "taking the second industrial revolution as accomplished, the average human being of mediocre attainments or less has nothing to sell that is worth anyone's money to buy" so gloomily predicted by Wiener (1948 p 37) and so trenchantly satirised by Kurt Vonnegut in his novel "Player Piano" is an issue that can only be resolved at the level of national policy.

6.5 SUMMARY

Four main themes then, emerge from the existing literature on the implementation of integrating technologies. Diffusion, while widespread, is far from saturation. A large number of smaller metalworking firms do not possess any form of CAD system, and a large proportion of those that do simply use it as a form of drawing automation to improve productivity. The number of users who are pushing the technology to its limits is relatively few, but they are the large firms in the key competitive sectors of the economy.

The political process around justification is the main issue at the evaluation stage. This dynamic revolves around the procedures to be followed for justification and the inclusion or otherwise of those who will be affected by the change. At the installation and commissioning stage, the project organisation and the level of resources devoted to it emerged as predominant. During consolidation, the management of interdependence moves to the fore, which in the case of CAD/CAM means the co-ordination of the engineering/manufacturing interface. Intra-functional issues associated with job design appear to be relatively less important to the successful implementation of integrating technologies. As Ebel and Ulrich argue, "CAD confined to the design office does not rock the boat. However, the linking of CAD and CAM may well .....prove the crux of the matter" (1987 p 362). It is on this crux that the research that will be presented in the second half of this thesis is focused.

7

RESEARCHING THE IMPLEMENTATION PROCESS

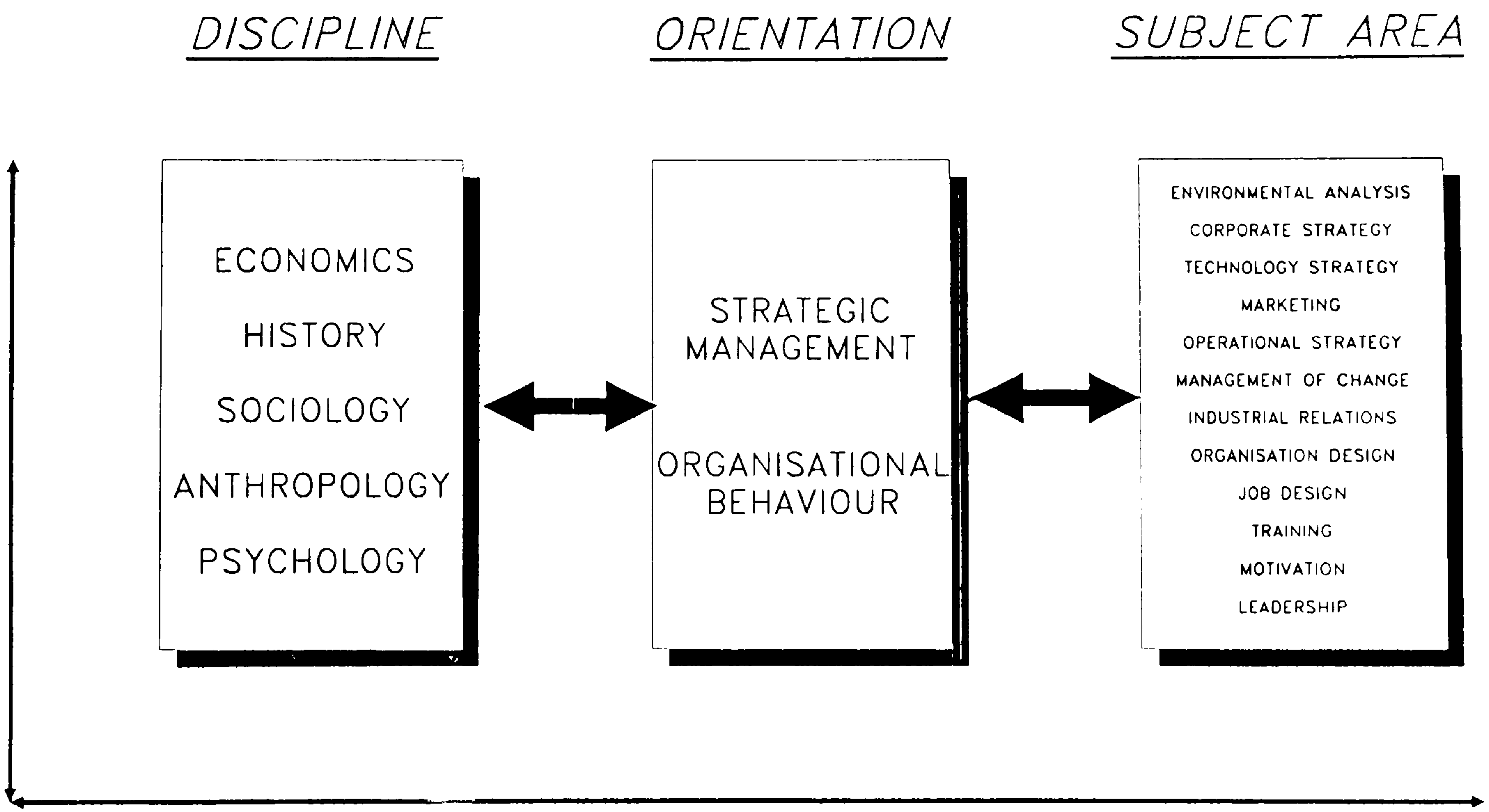
7.0 INTRODUCTION

The preceding chapters have laid out a conceptual framework for the analysis of the implementation of AMT - specifically, the implementation of CAD/CAM systems in the metalworking industries. The argument will now turn to developing the methodology by which it is proposed to deploy the conceptual framework in the case survey organisations. After some general comments on social science research methodology and organisational analysis, the chapter will discuss the rationale for the selection of the case companies and then present the research instrument used during fieldwork. Finally, a brief review of the cases will be given.

7.1 SOCIOLOGICAL THEORY AND ORGANISATIONAL ANALYSIS

In developing a methodology for research into organisations, there are two basic decisions to be made. Firstly, there is the question of the level of analysis - is the concern, for instance, with issues at the level of the national economy, industrial sector, corporation, business unit, department, work group, or individual? The second follows from the first, and is the method of analysis and research methodology to be deployed. Winch (1990) discusses the first issue and outlines the differing relevances of the various social science disciplines for organisational analysis. The argument is summarised in figure 7.1; it is not intended as a strict delineation of discipline boundaries, but as a way of showing their relative strengths. Moving towards the origin on the ordinate, there is an increasing sense of *focus* from the industry as a whole, to the behaviour of individuals. Reciprocally, there is an increasing sense of *context* as each element of the organisation is related to the others around it. Moving towards the origin on

FIGURE 7.1



The Social Sciences and the Study of Management: An Overview

source: Winch (1990)

the abscissa, the perspective changes from a range of issues, to a general sense of orientation in terms of whether the object of study is internal relations within the organisation, often summarised as "organisational behaviour", or external relationships between organisations, often described as "strategic management", and on to the five discipline bases.

The present study is concerned with the management of change at the level of the business unit, and so it would seem most appropriate to take a sociologically orientated approach to the issues. Such an approach can produce important insights into management, and, as John Harvey-Jones points out "one disregards the work of sociologists at one's peril" (1989 p 90). However, it is inadequate on its own. Social scientific research on management topics needs to interact with the relevant contributions from the management disciplines which are not social science based such as law, accountancy, and operational research. In particular, the topic of the implementation of AMT at the organisational level needs to combine the approaches of sociology and operations management[12]. As Voss (1984) argues, "production/operations management" has emerged as a distinctive discipline over the past 15 years which can be clearly distinguished from operational research on the one hand, and production and information systems engineering on the other. Many of the concepts deployed in the framework developed over the last few chapters are derived from the operations management literature as the sociological literature has consistently failed to gain precision in its formulations of concepts such as environment and technology.

The second choice has long been the subject of intense debate within sociology, and has two dimensions (Burrell and Morgan 1979). The first is that of "assumptions about the nature of society". It is conventional in sociological analysis to distinguish between those approaches which see society as the embodiment of human activity, and those which present society as a coercive and socialising force beyond human control (Berger and Pullberg 1965). Thus, "one

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12) At the level of the work group and individual, more anthropologically and psychologically orientated methods may well be more relevant.

views action as the derivative of system; whilst the other views system as the derivative of action" (Dawe 1970 p 217). As Burrell and Morgan (1979) argue, this distinction is central to the development of sociological theories of organisation. The tension between the two perspectives has much of the character of Goethe's debate between Faust and the Gospel. Faust rejects the notion that "In the beginning was the Word" (St. John chapter 1, verse 1), and writes that "In the beginning was the Deed" (1949 p 71), for God did not create Man, but Man created God. In more secular terms, the issue is whether people create society, or society creates people.

Faust resolved the dilemma through a pact with the Devil. Others have gone less far, and tried to show the ways in which sociologists are faced with a dynamic and interactive paradox, rather than a choice. Marx and Weber both explored this dynamic, though their acolytes have often forgotten the essentially dialectical character of the interaction. More recently Berger and Luckmann (1967) have shown the way in which reality is socially constructed, while the work of Giddens (1979; 1984) represents a major attempt to develop a theory of "structuration" which dynamically investigates the interaction between structure and action in modern societies. Van de Ven and Poole (1988) argue strongly that such an approach is essential for understanding how organisations change. As is clear from the preceding chapters, it is this position, conceptualised as the dynamic between structure and process in organisations, which is adopted in this thesis. Organisations are here seen as simultaneously the product of human processes of action and institutionalised structural constraints upon that action.

The second dimension is that of "assumptions about the nature of social science". Here, the options are "subjectivist" approaches relying on interpretative techniques and "objectivist" techniques relying on more "positivist" methods of enquiry deploying more or less explicitly formulated hypotheses. In his review of interpretative techniques, which he calls "qualitative", Fletcher is damning: "As a method it is certainly vital and attractive. But more than that it is easy....In the trivializing of man and the social conditions the [interpretative] method degenerates into a voyeurist's phantasy" (1974 pp 143/4). He goes on to advocate what Burrell and Morgan would call "radical structuralism".

While Fletcher's comments may be too harsh, there are two main problems with interpretative techniques. Firstly, they remove the responsibility from the researcher to see the whole that the actors in the situation cannot see - if they could see it there would be no point in doing the research. By attempting to see things through the actors' perspective, the sense of context of those actors' activities is inevitably lost. Secondly, the approach is naive in its assumption that the subjects of research are somehow independent of prior sociological knowledge. The problem is what Giddens calls the inherently reflexive character of sociological enquiry (1990 chap 1), which might be more succinctly described as the Porter Effect[13]. Most of the informants have been formally trained as managers, and some have MBAs. They have, therefore, already been exposed to the basic concepts which the researcher uses in enquiry. A methodology aimed at discovering the actors' own interpretations of the situation is meaningless when those interpretations have already been shaped by theoretical concepts shared with the researcher prior to fieldwork.

The "sociological paradigm" adopted here, then, may be described as an "objectivist" one which rejects the dichotomy between the "problem of order" and "problem of action" perspectives. Instead it emphasises the dynamic process of structuration as the creative destruction of order through action.

7.2 STUDYING ORGANISATIONS

As Bryman (1989) shows, there is a wide variety of methodologies available to sociologists researching organisations. They range from case study work, to survey work. Both have their strengths and weaknesses. In favour of case study methodologies is the rich detail of process

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[13] In two cases copies of Michael Porter's work could be seen on informants' office bookcases.

that is available from skilful researchers; in favour of the survey is the sense of the typicality of the findings which can be of crucial importance for more policy orientated work. Yin (1989 chap 2) advocates case studies as crucial ways of building theories.

Some of case study techniques are explicitly derived from anthropology and have been deployed most effectively in the study of payments systems and work group behaviour. In the US, the Chicago studies of Roy (eg 1952) and Burawoy (1979) are seminal, while in the UK the Manchester studies (Cunnison 1982), particularly those of Lupton (1963) and Cunnison (1966) remain vital reading. More recently, an impressive amount of work, which may be called the Bristol studies, has tried to capture the "fluency of peoples' lives" (Beynon 1975 p 14) through non-participant case studies (eg Nicholls and Beynon 1977; Smith 1987). However, this work has largely failed to develop the rigour of method and analysis which makes the more anthropologically orientated work so valuable (Emmett and Morgan 1982). Other case study methodologies have ranged from the largely covert (Dalton 1959), to buying the case study company (Foster 1969). Pettigrew (1990) has articulated the argument for longitudinal case studies of organisational change which are both processual and contextualist in character. The strength of this type of disciplined qualitative work is attested by his work on ICI.

Perhaps the main problem with the case study approach is that of typicality. For instance, Whipp and Clark (1986), and Willman and Winch (1985) have both given us detailed case studies of what is now Rover, but they can tell us little about the British car industry in general because of the acknowledged idiosyncrasies of the company studied. They are not even particularly complementary for building up a picture of Rover itself because they are studies of different divisions at different points in time. Perhaps the most radical demonstration of the limitations of single case research is by Burawoy (1985 chap 3) who attempts to build a model of "hegemonic regimes" of production in advanced capitalism largely on the basis of two studies (his own and Lupton's) conducted 20 years apart in two different countries. His account is unconvincing.

At the quantitative end of the spectrum are those studies which develop operationalisations of conceptual frameworks to test formal hypothesis of the relationship between organisational variables. Although one of the most influential studies of this type is the Aston work (eg Hickson et alia 1968; Pugh et alia 1969), this approach is particularly common in the USA (eg Blau et alia 1976; Collins 1988). It can produce valuable data on correlations between key variables, but even at its best it produces relationships between measures that are difficult, if not impossible, to interpret (Starbuk 1982).

As might be expected from the advocacy of a dialectical approach, a methodology which "triangulates" (Denzin 1970 part 12) on the problem at hand by deploying both qualitative and quantitative techniques is advocated here. The basic options are the deployment of quantitative techniques in a case study setting in a process of "organisational assessment" (Van de Ven and Ferry 1980), or the collection of enough case studies to allow a meaningful frequency counts across the cases in what might be called a *case survey*. The importance of the latter approach is that is has been responsible for some of the most influential contributions to organisational analysis - Woodward, Lawrence and Lorsch, and Kanter have all used varieties of case survey analysis across 10 or more cases with seminal results.

What is advocated here, then is a *case survey* methodology in which the essence of the method is *pattern recognition* across cases, and the unit of analysis is the production departments of the business, which are defined here as those responsible for engineering design, the drawing office, production planning and control, and actual manufacturing. The aim is to combine some of the strengths of both the case study and survey approaches with a well defined sample of cases. The basic field work approach is the case study, but the aim, from the start is to achieve quantitative outputs. This is distinguished from Yin's (1989) "case survey" in that it is not a meta-analysis of existing cases, but follows a survey rather than "replication logic" in its formulation.

7.3 THE CASE SURVEY

The sample firms to be studied was taken by a process of "planned opportunism" (Pettigrew 1990) through the mobilisation of personal networks. In this I am very grateful to Clive Reynolds of the Department of Engineering at the University of Warwick for some valuable contacts. Four of the firms, MN, MI, MC and ML, were those studied by an Imperial College team 8 years earlier, the results of which are reported in Winch (1983). Two of the cases, MJ and MO, were selected for study in greater depth involving a larger number of interviews and a more intensive dialogue between informants and the researcher. This work was carried out by David Twigg. The organisational time-spans covered by the research were from the time of the first evaluation of CAD to the present. In most cases, informants who had been involved in decisions up to ten years previously were still available for interview.

The basic criteria for case selection were an existing CAD installation, and membership of the "metalworking" industrial sector. Metalworking was chosen because it accounts for the largest single proportion of CAD use - the mechanical engineering sector accounted for some 40% of CAD installations in Europe in 1987 (Bessant 1991, figure 7.1). The importance of this criterion is that all the firms surveyed have similar *production information* and *materials flows*. The production information flows all include engineering design, and are, therefore distinguished from industries such as pharmaceuticals and chemicals where R&D is much more important, and textiles and steel which have no design process within their production information flows. The materials flows consist almost entirely of the cutting and forming of metal, and the subsequent assembly of components thereby created. They are therefore distinguished from industries which are based upon the transformation of fluids and powders, or solely the assembly of components such as construction.

None of the companies include significant electronic, as opposed to electrical, elements in their production processes. Where electronic components, such as avionics, are included in the final product, they are universally bought in. In terms of Porter and Millar's (1985) framework, therefore, the "information intensity" of the value chain in all the case companies is high, while the "information content" of the products is relatively low. In methodological terms, the case survey sample controls for IT based product innovation to allow a clear focus on the issues around process innovation. In this respect, the research is distinct from other work, such as that of Adler, Currie, and Senker, where electronics companies were included in the cases. It also concentrates upon mature industries, and so the sort of young, dynamic organisation of the kind studied by Dodgson (1991) was not encountered.

7.4 THE RESEARCH INSTRUMENT

The case survey methodology requires consistency in method between cases, and the standardised collection of some key items of data. It was, therefore, decided to use a more structured research instrument than is normal in case study research. A copy is attached at appendix A. It was developed from an earlier version of chapters 3 and 6 (Winch 1988). The instrument formed the basis of interviews with key informants in the case companies which were conducted along the lines recommended by Buchanan and his colleagues (1988). The aim was to interview the managers responsible for the manufacturing and engineering departments, and the management of the system itself. Additional interviews took place based upon advice from the earlier informants. A total of 97 informants were interviewed in 15 companies between the autumn of 1988 and the end of 1990. Each set of interviews, together with supporting documentary data, was written up as a case study and returned to each informant for validation. Their comments were incorporated in a second version of the case study which formed the basis for the survey analysis presented here. In at least one case, the feedback case has been used on an internal management development programme.

A feedback session, to which representatives from all the case companies were invited, was held at London Business School in May 1990. Some of the key findings - mainly from chapter 13 - were presented and discussed in plenary and workshop sessions. Additionally, in the depth case studies carried out by David Twigg, a continuing dialogue has been maintained during fieldwork as various versions of the implementation workbook (Twigg and Voss, 1992) have been tried out in the case companies.

Section A of the instrument is aimed at establishing the *outer context* of the case firm. Sections B,C, and D are then focused on various aspects of the *inner context.* Section B deploys conventional manufacturing strategy measures to identify the main features of the manufacturing strategy; the way in which the concept of a *production strategy* was developed from these measures will be explained in chapter 8. Section C focused more on the *choice of technology* for manufacturing operations, and the criteria against which that technology is managed as part of the *production mission.* Section D provides a wealth of data on the production information and materials flows and the organisation structure. Flow charts for both materials and production information were developed for each company, as well as organisation charts at the business level, and the manufacturing and engineering departmental levels. Later questions in this section collected data on the character of transaction processes between engineering and manufacturing. The data from these sections of the research instrument are discussed extensively in chapters 8, 9, and 13.

Sections E and F turn to the implementation process. Section E, after establishing the history and present dimensions of the CAD/CAM system, explores the organisation of the *evaluation,* and *installation and commissioning* processes. Section F is more concerned with outcomes from the process in term of both *technical* and *business success,* and finishes with some more general questions to allow the informant to explore issues not already covered in the interview. The data from these sections forms the basis for chapters 10, 11, and 12.

In many interviews, extensive additional notes were taken as the discussion developed - the research instrument was seen as a sketch for the interview, not a comprehensive design. Interviews typically lasted 90 minutes, and were supported by tours of factories, lunch time discussions, collection of documentation, and follow up telephone conversations for clarification of points. All data were collected on a confidential basis both within and between cases. For this reason, information which might reveal the identity of the cases is not used in the following chapters.

7.5 SUMMARY OF THE CASES

Summary information on each of the 15 cases is presented in table 7.1. They were located in all parts of the Kingdom except Wales, and most are household names. Collectively, the corporations of which these companies are part represent much of the UK's industrial base. Most of the companies have been manufacturing on the site(s) visited since before 1918, and only MH and MM have manufacturing operations which are situated on sites that have been established since 1945. The former factory showed all the signs of a branch plant established under regional aid, and has been closed since fieldwork ended.

At the start of the research, two cases were independent companies; for one, the year of 1989 was the 200th anniversary of such independence. In four cases the site studied was a cost centre, while the rest were profit centres as part of multi-divisional corporations. In the vehicle companies things are a little more complicated because the engineering departments worked as cost centres, serving factories operating as profit centres within the business. The status of the survey companies at the start of fieldwork is summarised in figure 7.1; the overall business status of the vehicle companies is given. Four are the privatised off-spring of nationalised industries. All but two were UK owned in 1988 - the odd ones out having been recently acquired by EC and US companies. However, three of the companies changed status while the research was under way which halved the number of independent companies and shifted ownership in all cases away from the UK. MH and MI were unbundled from a larger profit centre during fieldwork, and MH became a separate profit centre while MI remained a cost centre as part of a larger, multinational joint venture.

TABLE 7.1
THE CASES

COMPANY CODE	INDUSTRIAL SECTOR	OWNERSHIP	STATUS	UNIT SIZE
MA	Building Components	UK	PC	500
MB	Mechanical Engineering	Ind	PC	914
MC	Electrical Engineering	UK	PC	1230
MD	Hydraulic Components	UK	PC	176
ME	Aerospace	UK	PC	4500
MF	Vehicle Components	EC	CC	800
MG	Shipbuilding	UK	PC	12000
MH	Heavy Engineering	UK	CC	1210
MI	Heavy Engineering	UK	CC	2200
MJ	Vehicles	Ind	PC	12000
MK	Aerospace Components	UK	PC	1400
ML	Vehicles	UK	PC	38000
MM	Vehicle Components	UK	PC	2500
MN	Mechanical Engineering	US	PC	1100
MO	Vehicle Components	UK	CC	4000

Unit size is given as the number of people employed on the site visited, except for the two vehicle companies where the dispersed nature of production makes this measure meaningless, and total size is given. All the plants except one fall into the medium (500+) or large (1000+) size categories except MD. This company shares its site with 2 others from the same corporation which were unbundled from a single company in the mid eighties; it was much larger when it first implemented CAD. All the companies make intermediate or capital goods except the two vehicle companies.[14] None made light consumer goods. The cases can, therefore be taken as fairly typical of larger firms in the UK mechanical engineering, electrical engineering, and transport industries. They are also similar to the aerospace firms studied by Adler, the metalworking firms studied by Currie, and the mechanical engineering and vehicle companies studied by Simmonds and Senker.

7.4 SUMMARY

The methodological approach selected for investigation of the conceptual framework is that of the *case survey* which has the strength of combining the richness of data on organisational processes available from qualitative case study research with the greater typicality possible with more quantitative survey work. The sample of cases was selected from one broadly defined industrial sector in such a way that key variables were controlled. Most importantly, the basic character of the production information and materials flows, the information intensity of the value chain, and information content of the product were controlled. This controlled sample allows the exploration of commonalities and contingent variabilities between the cases. The sample is fairly typical of the metalworking sector of the UK economy, and the extent to which the findings are applicable to other sectors can be explored by others because of the detailed presentation of the context of implementation in following chapters.

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14) There are problems of definition here - defence goods are not strictly capital goods because they are not used productively, and the dominance of the vehicles market by the company car means that the vehicles producers can probably be treated as capital goods producers in some respects.

8

THE STRATEGIC MANAGEMENT OF PRODUCTION

8.0 INTRODUCTION

The presentation of the findings from the case survey will follow the framework developed in the preceding chapters. To begin, this chapter will present and assess the picture of the strategic management of traditional metalworking production as the economy began to emerge from recession in the latter part of the eighties. It will thereby present the *context* of the implementation of CAD/CAM. In line with Pettigrew's distinction, the *outer context* will be discussed first, before moving onto the *inner context* as defined by the *production mission*, and the nature of transactions within the information and materials flows. The relationship of these to the organisation structure of the case study firms will be discussed in the following chapter. Throughout the following chapters, unattributed quotations are taken from interviews with managers in the company concerned.

8.1 THE OUTER CONTEXT

The general picture which emerges from the sample is of buoyant companies enjoying good profits in rising world markets. The level of confidence amongst the managers interviewed was almost palpably greater than when four of the cases were researched in the early eighties. Most of the businesses had been severely battered during the recession, and had emerged after considerable reductions in size, and major re-organisations. For some, survival itself had been in doubt. However, effort directed towards taking out costs, improving quality, and focusing activity had paid dividends. Four of the companies claimed to be in the top three in their particular world market niches, while most believed that they had areas of competitive advantage which would take them through the nineties.

All but one of the sample was profitable, and five were making healthy profits. The informants were asked (Q A4) about their company's gross revenue over the previous two years (effectively 1987/1988). The responses are shown in table 8.1, and provide a self-reported measure of performance[15]. It is worth noting the five most profitable ones - MB, MD, MJ,

TABLE 8.1
PROFITABILITY

COMPANY CODE	PROFIT LEVEL
MA	break even
MB	high profit
MC	small profit
MD	high profit
ME	small profit
MF	small profit
MG	small profit
MH	small profit
MI	small profit
MJ	high profit
MK	high profit
ML	small profit
MM	small profit
MN	high profit
MO	small profit

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15) Bryman (1989 p 237) reports research which concludes that self reported measures are reasonably accurate

MK, and MN - four of them will appear more than once as examples of well managed metalworking companies, while the fifth, MD, has a distinctive and sustainable competitive advantage. The issue of the sources of profitability will be addressed in the conclusions.

Most are selling in international markets to diversified customer bases in at least one of their product lines. In these markets, demand was generally rising, but this was also attracting increased competition in many cases. One of the two companies which serve only a national market is in defence, while the other is a tied plant of a vehicle manufacturer. Both of these, obviously, face undiversified (<4 customers) markets. One company is experiencing a falling market demand in its defence related product line, while demand for its commercial lines is rising. No company reported falling competition. Changes in national and global politics while the research was under way meant that four of the companies might soon face dramatic falls in demand. One - not a defence company - believed, according to one informant, that it was facing a "cliff edge" in 1991 due to political instability in China and India, and policy changes in the UK.

8.2 THE PRODUCTION STRATEGY

Two main ways of exploring the *production strategy* were used. Firstly, following Hill (1985 chap 2), informants were asked to identify the "order winning criteria" for up to three product lines (Q B3). This yielded 29 (non-independent) observations of the most important order winning criterion for a product line. Although developed as a framework for the analysis of manufacturing strategy, closer inspection reveals that many of the criteria he proposes are, in fact, attributes of the product design, and hence the responsibility of engineering rather than manufacturing. If the lower half of the list ("rate of new product introduction"; the "product design" categories; and the "other" category which was specified by the informants who chose it as "technical service") is classified as engineering criteria, the result is that pure manufacturing criteria tend to be twice as important as engineering criteria in winning orders (69% vs 31%). Price and delivery criteria were the most frequently mentioned (24% of product lines each), while quality criteria came close behind (21%).

The second approach tackled the issue of nature of the contract with the customer. Question B1 identified the nature of the market transaction with the customer through conventional manufacturing strategy questions for the three most important product lines at each case survey company. 32% of the 29 product lines identified were "made to forecast" - these were mainly the vehicle and vehicle component companies. 52% of product lines were "designed to customer order", while the balance were either "manufactured" or "assembled to customer order". Only two companies, MA and MD, mixed "make to stock" and "design to order" manufacturing strategies. However, the "designed to customer order category" hides a number of different forms of contract with the customer. It was, therefore, decided to develop a new classification scheme which was more sensitive to the actual production strategies of the case companies. The conventional manufacturing strategy approach identifies where the contract with the customer enters the *materials flow*; building on the analysis in chapter 3, the new typology offered here identifies where the customer enters the *production information flow*.

Only three of the companies sell all their output direct to the final customer through a distribution network - the two vehicle companies and one of the mechanical engineering companies. Here, production is on a *make to forecast* (MtF) basis, and the contract with the customer occurs after the production information flow, and indeed, the materials flow, have been completed. One group of intermediate goods companies is that which manufactures components for other final assemblers. These component companies tend to build on a *make to order* (MtO/F) basis, where the order takes the form of a contract against the customers' forward schedule. Each order may include an element of customisation of the standard product through "variant design". Some capital goods companies build or assemble to specific orders which take the form of individual contracts, for which an amount of customisation, or "contract design" may be done. Again, this is essentially a *make to order* (MtO/C) process. In both cases, the contract with the customer enters the production information flow at the planning stage.

It is the limitation of customer specific engineering design work to customisation that distinguishes the make to order companies from the *design to order* (DtO) companies. They tender on a basic design, which then undergoes significant development to meet the needs of the particular customer. In these cases, the contract is placed towards the end of the design stage. The final category is that of the defence companies, where the customer in the form of the responsible procurement agencies is heavily involved in developing the concept design, usually on a separate contract from the contract to build. They have, therefore, been dubbed the *concept to order* (CtO) companies, where the contract with the customer is made virtually at the start of the production information flow. The categorisation of production strategies in terms of where the customer enters the production information flow for the most important product line in each case is given in table 8.2.

8.3 THE CHOICE OF PROCESS

To identify the choice of process, the most senior manufacturing manager interviewed was asked to describe the production processes. An immense variety of ways of transforming metal were identified, and most companies were undertaking major investment programmes on the shop floor. Raw materials in sheet, plate, rod, bar, and billet form are formed by pressing, cutting, rolling, forging, bending, extrusion, or casting. Some go on to form welded fabrications; all go on to be machined by various techniques to form components. In two of the volume component manufacturers, machining is organised entirely on a group technology basis. Two of the component companies, MA and MD have no assembly operations, restricting their activities to metal forming and fabrication; both of them are particularly interesting in their use of CAD/CAM which will be discussed later. In all the other cases components go on to form sub-assemblies, sometimes after heat treatment, before going for final assembly on the assembly line or station, or fitting in the erecting shop or construction hall.

TABLE 8.2
INFORMATION AND MATERIALS FLOWS

COMPANY CODE	PRODUCTION STRATEGY	INFORMATION FLOW	MATERIAL FLOW	COUPLING COMMIT
MA	MtF	Tender	High Volume	-
MB	MtF	Development	Low Volume	-
MC	DtO	Tender	Low Volume	Sequential
MD	MtO/F	Tender	High Volume	-
ME	CtO	Procurement	Low Volume	-
MF	MtO/F	Development	High Volume	-
MG	CtO	Procurement	Low Volume	-
MH	DtO	Tender	Low Volume	Sequential
MI	DtO	Tender	Low Volume	Sequential
MJ	MtF	Development	High Volume	Iterative
MK	DtO	Tender	Low Volume	Iterative
ML	MtF	Development	High Volume	Iterative
MM	MtO/F	Development	High Volume	Iterative
MN	MtO/C	Development	Low Volume	Iterative
MO	MtO	Development	High Volume	Iterative

No site visited encompassed the entire materials flow from metal forming to final assembly or fitting. Two companies have their own foundries on site, while most handle their own sheet and plate cutting and preparation. In one of the vehicle companies pressing is carried out on a separate site, while the other is presently acquiring its own remotely located pressing capability. Many make extensive use of bought out components such as forgings and sub-assemblies, and nearly half are concerned with manufacturing components for other final assemblers. None were significantly involved in production technologies other than metalworking such as electronics or the processing of liquids or powders. The extent to which bought out components and sub-assemblies are used varied considerably, and depended upon a variety of factors related to the production strategy in terms of policies regarding make or buy, and corporate strategy in terms of vertical integration. Some companies, also "bought in" work to utilise spare capacity - in one company, where the latest product line had not yet been productionised, extensive reliance was placed on this manufacturing strategy.

8.4 THE MATERIALS FLOW

The materials flow for each of the cases was charted as a process flow diagram in a simple input/output form from sketches made during interviews (Q. D3) As will be clear from the discussion of process choice above, at anything more than the most general level of description, the materials flows were fairly idiosyncratic to the case under study. However, informants were also asked to classify the materials flow for each product line in terms of Woodward's (1966) typology (Q. C2). "One-off", or jobbing, production predominated with 39% of product lines, while 23% of products were produced on a "flow line" base. The balance was evenly split between "small" and "large batch" production (19% each). Although there was some variation within companies - companies with flow line production might also produce some large batches, and predominantly one-off production companies might also produce some products or components in small batches, only MA mixed large batch/flow line production with small batch/one off production technology. This is a special case in that the one-off production is for an, as yet, relatively unimportant new product. This suggests the two groups can be considered separately as generic *low volume* (<100 off) and *high volume* materials flows. The results for the most important product line in each case are given in table 8.2.

The above discussion is summarised up in figure 8.1, showing the correlation between relationship to the customer as defined by the production strategy and the materials flow. Taking the 29 product lines, it can be seen that design to order/concept to order, and low volume production are highly correlated, as are high volume production with make to order and make to forecast. Because each case can be unambiguously allocated along each of the two dimensions, the table can be reproduced by case with come confidence. This is shown in figure 8.2. The situation of the two anomalous firms - both are with low volume on a make to order or make to stock basis - is interesting. At this point suffice it to say that they are two of the five most profitable companies and both in the top three in their respective world markets.

Hill (1985 S.3.3) has suggested that "line" produced goods tend to compete on price as the order winning criterion, while "jobbing" goods tend to compete on design, quality, and delivery. However, the evidence from these 29 product lines is that while only 1 out the seven flow product lines competed on price as one of the top three order winning criteria, 5 out of the 12 jobbing product lines so did. What appears to be happening is that in many markets price is always the main criterion, and that some of the volume manufacturers are finding that their customers are prepared to pay for reliability of delivery and performance, and quality of design. For instance, ML "tried to avoid" price competition, and has positioned its vehicles in the upper quartile of each market segment in a classical differentiation strategy. These findings are in line with Porter's (1980) analysis of competitive advantage which shows that cost leadership (price competition), differentiation and focus (non-price competition) strategies are available in all industries.

When this issue was probed more deeply, informants from design to order firms argued that engineering competence was becoming more of a market entry criterion, and that price and delivery were becoming more important. For instance, an informant in aerospace components argued that a few years ago, quality and engineering capability used to be the order winning criteria, but now all the remaining competition are competent in those areas , and that price and reliability of delivery are the criteria now. In heavy engineering, an informant argued that the key market entry criterion is product integrity with a very good record for reliability in service, and that the order winning criteria are speed of delivery and price.

8.5 THE PRODUCTION INFORMATION FLOW

The production information flows were similarly described in input/output form. However, here, three distinctive patterns could be discerned amongst the flows. These are what might be called the *tender route* where the business puts considerable engineering effort into tendering to the customer for each contract. This accounts for six of the cases, and an example is given in figure 8.3. Here, the distinctive tender loop with the customer prior to the placing of an order can be seen before the bulk of the engineering design work is done. A second distinctive flow might be called the *procurement route* is illustrated in figure 8.4 - the two companies displaying this flow were the two defence companies. The distinctive feature here is the separation of the customer's "design order" which leads to project definition from its "build order" which leads to the full engineering definition prior to the detailing processes of layout and model building.

The third type of flow identified is the *development route*, which is illustrated in figure 8.5, where the company develops a product, or at least a generic product type, before seeking specific contracts. The product development process may involve considerable consultation with potential customers, and individual contracts can involve customising the generic product, but the actual contract with the customer does not involve a major engineering effort. Very often prototypes are built as part of the development programme, while this is rare for the other two routes - amongst these, only ME used prototypes as part its production information flow. The categorisation of the cases is summarised in table 8.2.

THE PRODUCTION STRATEGY AND THE MATERIALS FLOW

(PRODUCT LINES)

	low volume	*high volume*
design to order/ concept to order	15	0
make to order/ make to forecast	2	12

n = 29

FIGURE 8.1

THE PRODUCTION STRATEGY AND THE MATERIALS FLOW

(CASES)

	low volume	*high volume*
design to order/ concept to order	MH MI MK MC MG ME	
make to order/ make to forecast	MN MB	MJ MM MF MA MD MO ML

n = 15

FIGURE 8.2

MI - TENDER ROUTE PRODUCTION INFORMATION FLOW

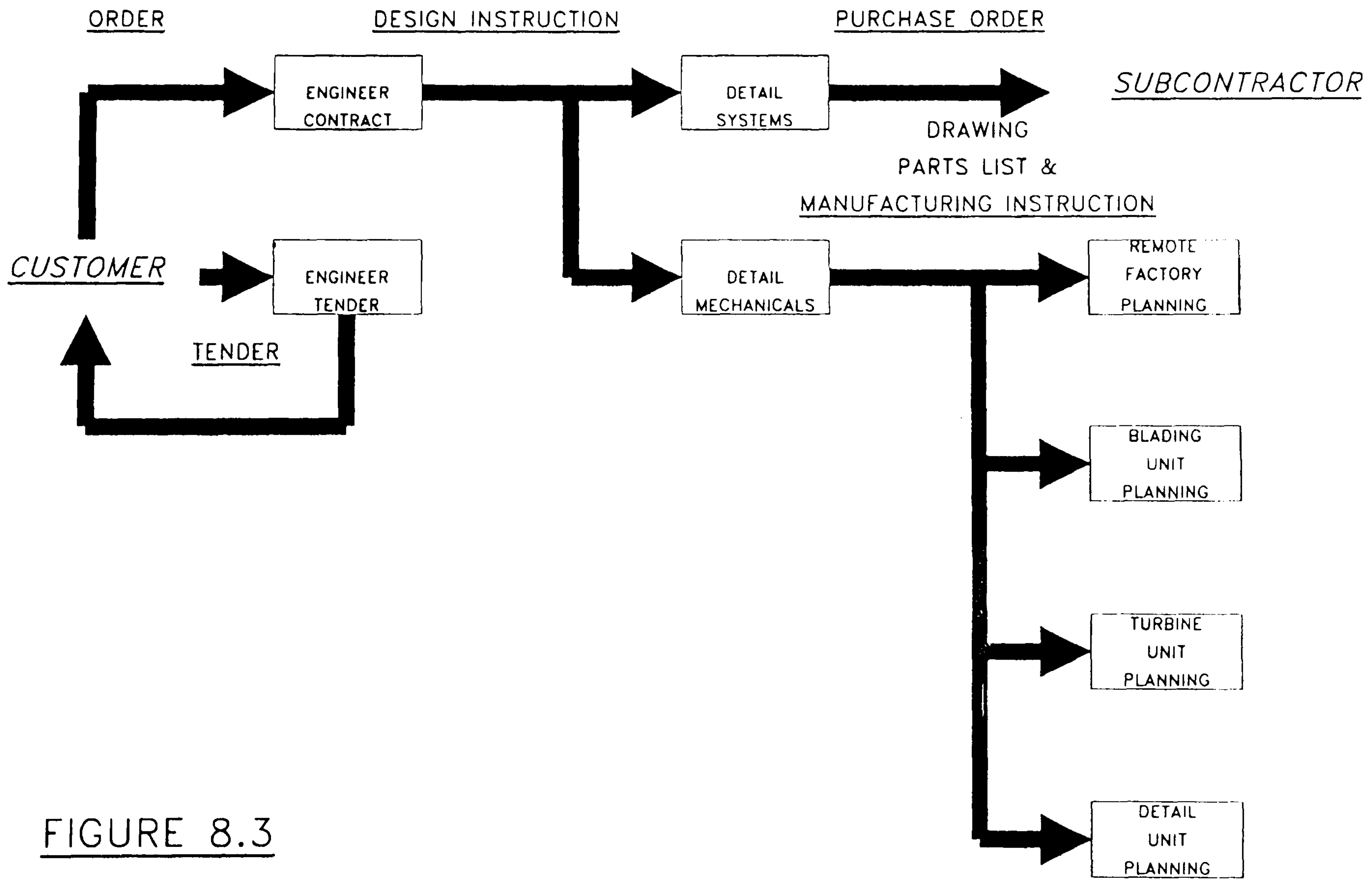


FIGURE 8.3

MG – PROCUREMENT ROUTE PRODUCTION INFORMATION FLOW

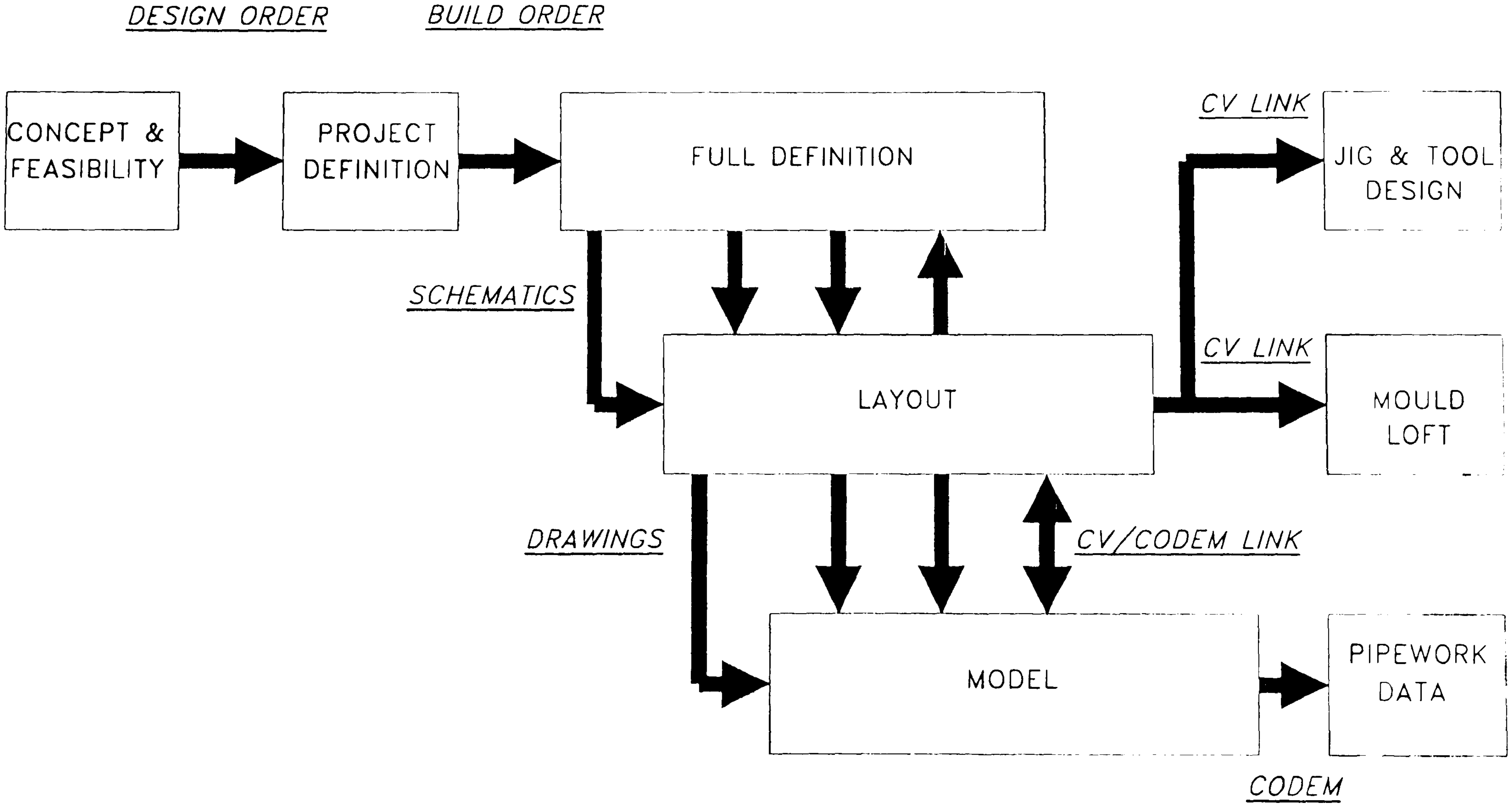


FIGURE 8.4

As might be expected, the different production information flows are associated with particular relationships to the customer as defined by the production strategy. All four of the design to order companies have tender route flows, and the distinctive nature of the concept to order companies in defence with their procurement route flows has already been identified. The other two companies with a tender route are the two component companies identified above which restrict themselves to metal forming, and tender on their customers' designs. As neither has had a significant design capability in the past, it is difficult for them to develop their own products. Both are actively using CAD to change this situation. The remaining companies - all make to forecast/make to order companies - used the development route. These relationships are presented in figure 8.6.

8.6 TRANSACTIONS: THE ENGINEERING/MANUFACTURING INTERFACE

The concept of transactions within the information and materials flows as the binding agent between the flows themselves and the associated organisational structures and processes was developed in chapter 3. The discussion in chapter 4 focused the argument on the key transaction within production information flow at the interface between engineering and manufacturing, or the engineering/manufacturing interface. At least so far as CAD/CAM is concerned, this information transaction is the most important. The three main variables which affect the character of transactions were identified as *direction*, *intensity*, and *coupling* in section 3.4.

At the engineering/manufacturing interface, the *direction* of the main data flow is, by definition, from engineering to manufacturing; the main variable is the destination in manufacturing to which the information flows. This is largely contingent on the materials flow. In the *low volume* companies, the information flow goes through production engineering and then forward to production management on the shop floor in a relatively tightly coupled flow, as is shown in figures 8.3 to 8.5. None of these has a separate toolroom apart from the

MB – DEVELOPMENT ROUTE PRODUCTION INFORMATION FLOW

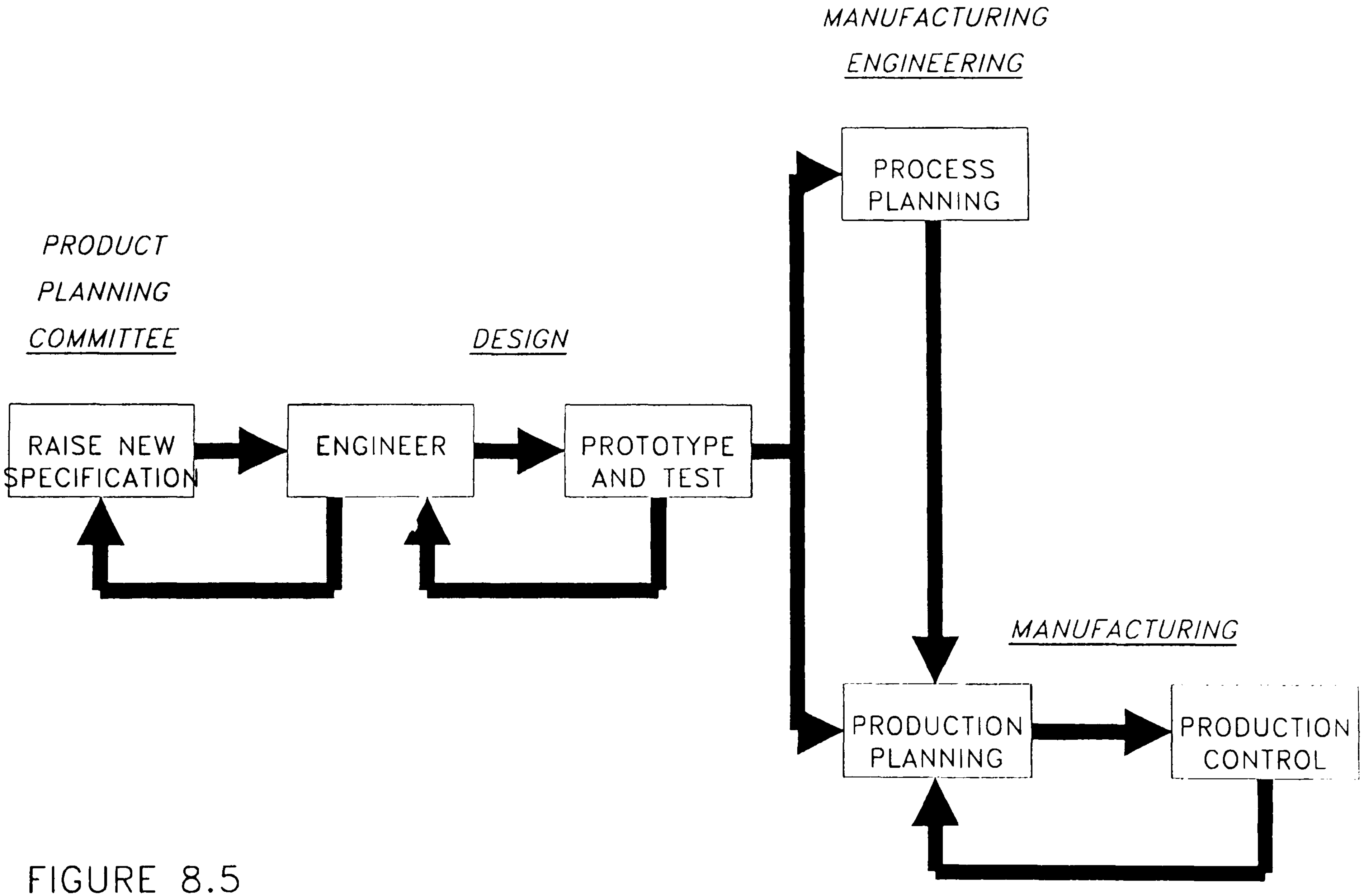


FIGURE 8.5

THE PRODUCTION STRATEGY AND THE PRODUCTION INFORMATION FLOW

TENDER	*PROCUREMENT*	*DEVELOPMENT*	
MC MH MK MI	ME MG		*DESIGN TO ORDER/ CONCEPT TO ORDER*
MA MD		ML MO MB MJ MF MM MN	*MAKE TO ORDER/ MAKE TO FORECAST*

Figure 8.6

MM – PRODUCTION INFORMATION FLOW

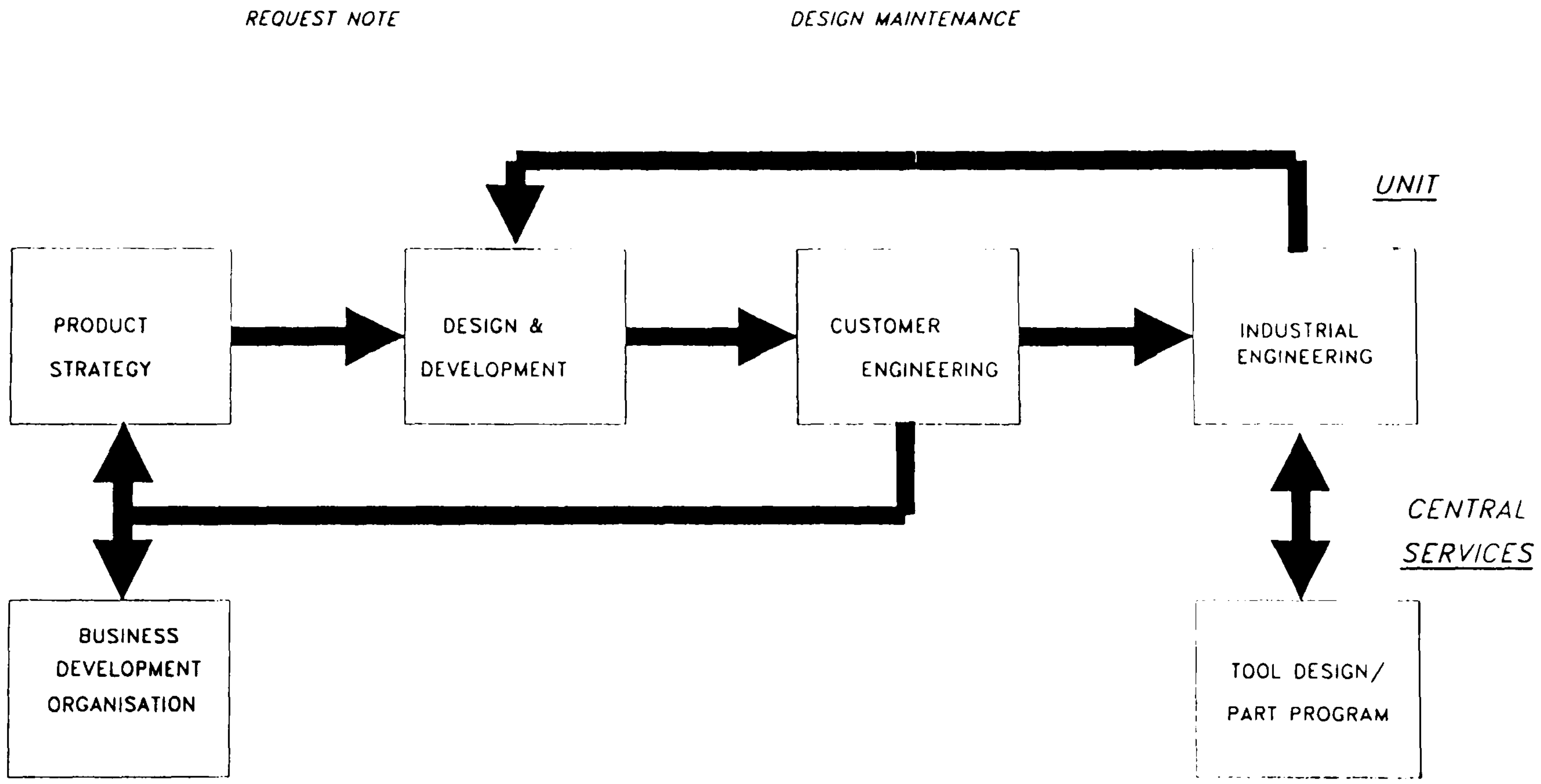


FIGURE 8.7

concept to order companies. Here, tooling mainly takes the form of assembly jigs rather than tools for component manufacture. In all of the *high volume* companies, on the other hand, the production engineering function includes a large tool design capability, and the flow passes from there to the tool room as shown in figure 8.7. In this type of production information flow, production management is relatively decoupled from production engineering. The organisational consequences of this relatively loose coupling will be explored in the next chapter. Typically, the *high volume* companies have little or no CNC machining on the shop floor, and so the part programming section works for the tool room as well. As tool manufacture is usually a one-off process, this lends a significant degree of convergence to the two types of flow, so far as the engineering/manufacturing interface is concerned.

In order to measure the *intensity* of information flows between engineering and manufacturing, informants were asked how frequently information passed between the two functions (Q. D5). All those who answered this question replied that information was exchanged on a daily basis, and that this exchange was usually informal. Clearly, this could mean no more than a quick phone call, and tells us little about the quality of the exchange. More important is the nature of the interdependence, or *coupling*, between the two functions.

In order to address this issue, informants were asked to assess their company in terms of the typology of coupling developed in section 4.4 (Q. D4). Pooled coupling is, by definition, not relevant to information flows between functions. No particular pattern could be discerned between those identifying sequential flows, and those identifying reciprocal flows, and some informants stressed that what happened depended on the particular situation. From the discussion of the production information flow in section 3.4, it might be expected that a clearer distinction of interdependence would have been found. The explanation for this lack of distinction almost certainly lies in convergence between the two types of production information flow due to the role of tooling in the high volume companies.

More telling was the picture that emerged of what the production information flow, in the opinion of informants, ought to look like. Informants often spontaneously volunteered different pictures of what happened in practice and what they would like to see happen at the engineering/manufacturing interface. The ideal can be defined as the *coupling commitment*. An opinion was not obtained in every case, but, those that were obtained revealed an interesting pattern. Informants from three different companies stated that while, in practice, the flow is mainly reciprocal in nature, the ideal situation would be a sequential flow. These were all the design to order companies with tender information flows and low volume materials flows. Those companies with development information flows expressed a strong preference for sequential flows for variant or contract design, but preferred more iterative information flows for new product development.

Only MN identified itself as normally having an iterative information flow, while and MJ and ML claim to have achieved it on their latest product development programmes. MK and MO have the explicit aim of achieving an iterative flow from their present position of a reciprocal flow, while MM claimed that iterative flows were what were supposed to happen, even if practice did not always achieve this goal. It appears that the main difference is between those companies which rely largely on sequential flows where possible, and move to reciprocal flows more or less formally as required, and those companies, who as a matter of policy are aiming for iterative flows. The latter group includes three of the most profitable companies. The overall results are presented in table 8.2.

The perception of the need for iterative flows is a response to a variety of internal and external pressures. In the vehicle companies the aim is to reduce product development lead times, and ML claim to have reduced the time for their latest project to the industry average of four years. In MM, a history of failure of product development initiatives had stimulated a radical approach to current projects. At MK, the aim of reducing costs by 30% over 18 months had given the mandate for a significant change in product development methods. A particular

A SUMMARY MODEL

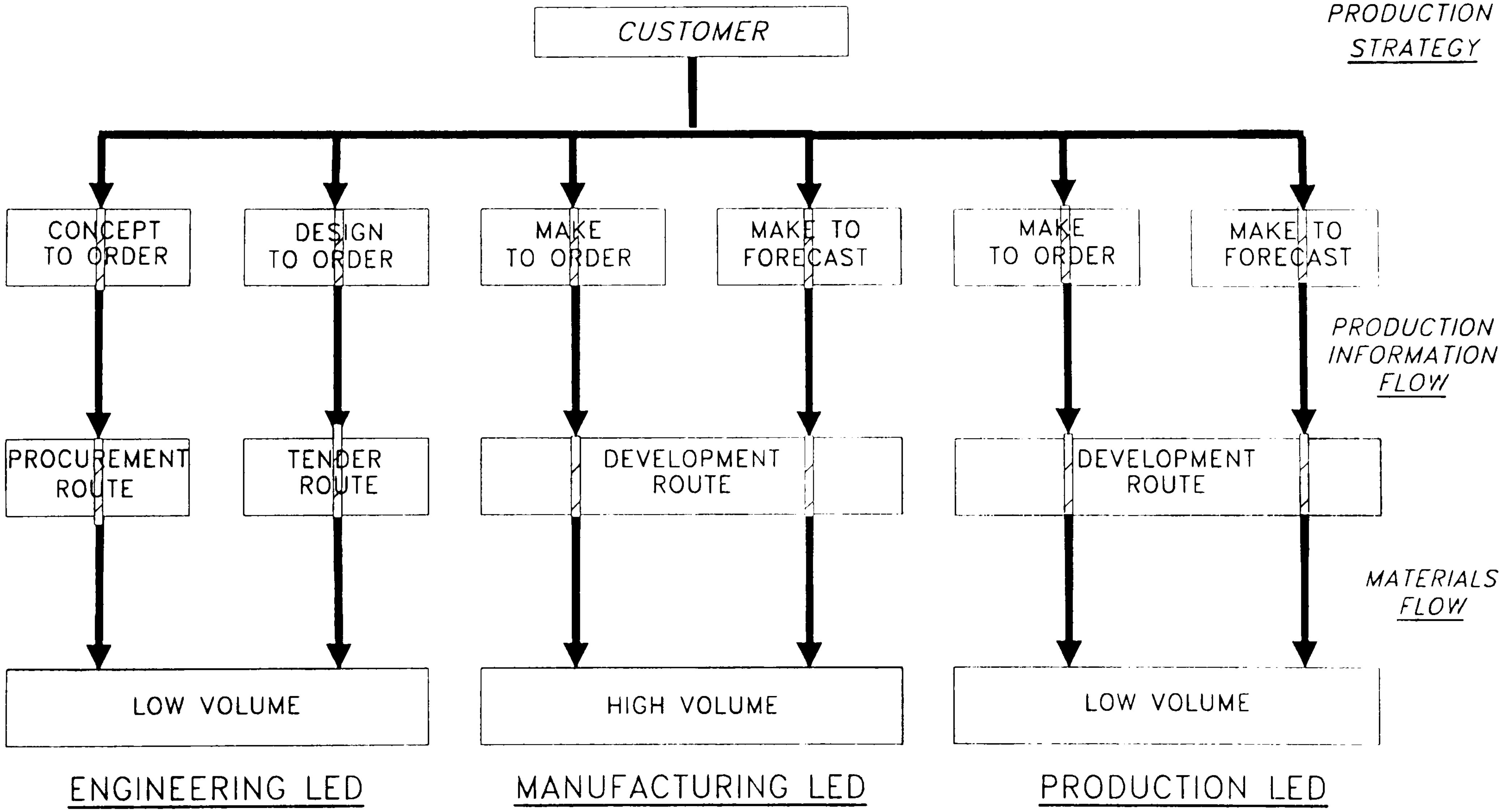


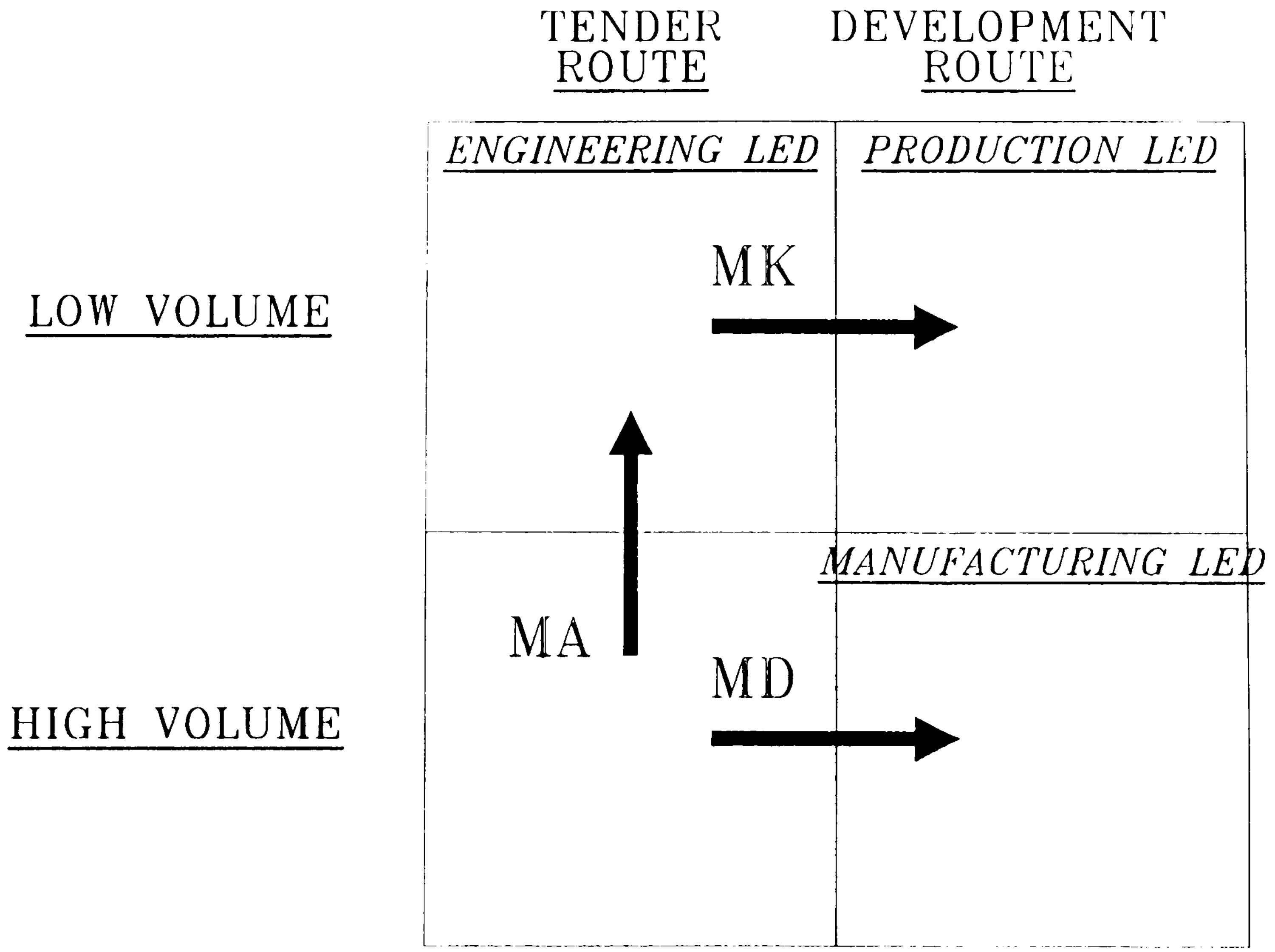
FIGURE 8.8

target for this company is the reduction of the number of very expensive and slow engineering change orders (ECO) by getting manufacturing input to the design before it is signed off and hence liable to ECO procedures. For MN, the business strategy of being a follower in developments in product technology meant that product development lead times needed to be very quick to respond to competitors' initiatives - over the last 12 years they have reduced product development times from 18 months to 6 months.

What these six companies have in common is relatively frequent product initiatives. In contrast, many of the other companies have long product development cycles and very few product initiatives. In the *concept to order* companies, product development cycles are long, and infrequent - the decade is a more appropriate period for counting major product initiatives than the year or month. Both of them have had only one major product initiative in the last 10 years. In the three *design to order* companies committed to sequential flows, product technology development is so evolutionary that it is sometimes difficult to identify specific development projects. Under such circumstances, coming to an awareness of the benefits of iterative coupling, and its implementation may well be much more difficult.

8.7 THE GENERIC PRODUCTION MISSIONS

The *production mission* was defined in chapter 3 as the way the *production technology* is organised to meet the *production strategy*. The evidence on the elements of the production mission presented here, the production strategy, the choice of technology, and the associated information and materials flows, allows the identification of a set of generic production missions, which is summarised in figure 8.8. The clearest distinction is around the nature of the main materials flow in defined in terms of volume. As Woodward (1966) showed, the key distinction is between those that produce on a one-off/small batch, or low volume basis, and those that produce on a large batch/flow, or high volume basis. However, it is also clear from the above discussion that this distinction based upon the materials flow is of limited use.



THE CHANGING PRODUCTION MISSION

Figure 8.9

because the production information flow needs also to be considered. The four types of production strategy, defined in terms of where the contract for sale enters the production information flow, yield three distinctive types of production information flow. The procurement and tender routes lead to materials flows of a low volume nature. Make to forecast companies go on from the development route to choose materials flows based on high volume production.

Within the low volume mission there is an important source of convergence. The concept to order/procurement route companies are facing two distinct pressures. Firstly, their main customer, the state, wants to move from a "cost plus" relationship to a "prime contractor" role where they take on responsibility for subcontracted activities. Secondly, the "peace dividend" means that they need to seek alternative product and markets; this is affecting MG particularly seriously. The two heavy engineering companies, MH and MI, made this shift to a design to order/tender route consequent upon the collapse of the home market, and the necessity to seek new markets abroad some years ago. It seems likely that both ME and MG will be obliged to follow this route over the next few years, and as will be discussed in the next chapter, they have both been making significant changes to their organisation structures in a response to these pressures.

This suggests that two distinct production missions can be confidently identified. The *engineering led* mission is characterised by a design to order production strategy, flexible process technology, a tender route information flow, and a low volume materials flow. The *manufacturing led* mission, on the other hand is characterised by a make to order production strategy, relatively dedicated process technologies, a development route production information flow, and a high volume materials flow. It is likely that the production departments will have distinctive relationships to their marketing departments, articulated through the production and marketing strategies, although this question was not pursued in the research.

However, a hybrid mission could also be identified at MN and MB, which combines a development route information flow with a low volume materials flow. MB, in particular, has recently been implementing a policy of reducing batch size in a move towards lean production. They are both mechanical engineering companies which successfully compete in global markets. The history of both these companies suggests that they may represent an emergent type of generic production mission which be described, for reasons that will be explored in chapter 12, as a *production led* mission, and is also summarised in figure 8.8. The fascinating question for the next decade is whether the development of lean materials flows will push enough *manufacturing led* companies into low volume production, and the process of modularisation of designs will push enough *engineering led* companies into the development route to make the *production led* mission the predominant one.

As with all typologies, the cases which do not fit are particularly interesting. Two of the tender route companies, MA and MD, are only just starting to develop an engineering capability to increase the value which is added within their operations. Presently, they are both volume producers with make to forecast and make to order strategies respectively. MA's business strategy is to move towards a design to order strategy with a tender route and the low volume production of "engineered" products. MD, aims to move more towards a development route as it shifts to "black box" design for its customers. In both cases, the implementation of CAD/CAM systems are seen as central to these shifts in strategy. They are, therefore, moving towards *engineering led* and *manufacturing led* production missions respectively in the search for a greater share of value added. MK was also making a strategic shift from an engineering led to a jointly led production mission at the time of fieldwork, which will be discussed further in the next chapter. These developments are illustrated in figure 8.9.

8.8 SUMMARY

Starting with the outer context, this chapter has explored some major elements of structure and process in the metalworking industries along the lines of the production model presented in figure 3.3. The process by which the business enacts the environment through the production strategy was identified before the choice of manufacturing technology was discussed. The ways in which this choice structures the materials and information flows was then reviewed before three generic production missions were derived. These generic types will form the basis for much of the following discussion of implementation, but first, the ways in which these information and materials flows influence the structure of the organisation will be explored in the next chapter.

9

ORGANISATION DESIGN FOR METALWORKING PRODUCTION

9.0 INTRODUCTION

The production strategy combined with the choice of process leads to the three generic production missions identified in the previous chapter. This chapter will address the issue of the relationship between the production mission with its attendant flows of information and materials, and the design of associated organisation structures, using the conceptual framework developed in sections 3.4 and 3.5. The relationship between production technology and organisation design has been long disputed, but most observers appear to agree that there is an observable relationship between the work flows within the organisation, and the design of the organisational elements most closely related to those flows (Mintzberg 1979 chap 14).

A perennial question of organisation design is whether to structure by *function* or *product*. Functional organisation, it is argued, allows the maximum utilisation of resources such as expensive machinery and scarce skills. Product organisation on the other hand, greatly eases co-ordination of the transactions within the information and materials flows. Functional organisation makes co-ordination difficult, while product organisation threatens the efficient use of resources[16] (Mintzberg 1979 chap 7) One way of attempting to resolve this dilemma is a *matrix* structure (Galbraith 1977 chap 10; Mintzberg 1979 chap 7) where operational managers report to both functional and product orientated senior managers. The benefits of this approach in metalworking production are discussed in Winch (1983), while it has long been important in organisations where geography is a major design contingency (Gulick 1937).

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16) See the discussion of Printer Inc in Lorsch and Lawrence (1972)

MK BUSINESS ORGANIGRAMME

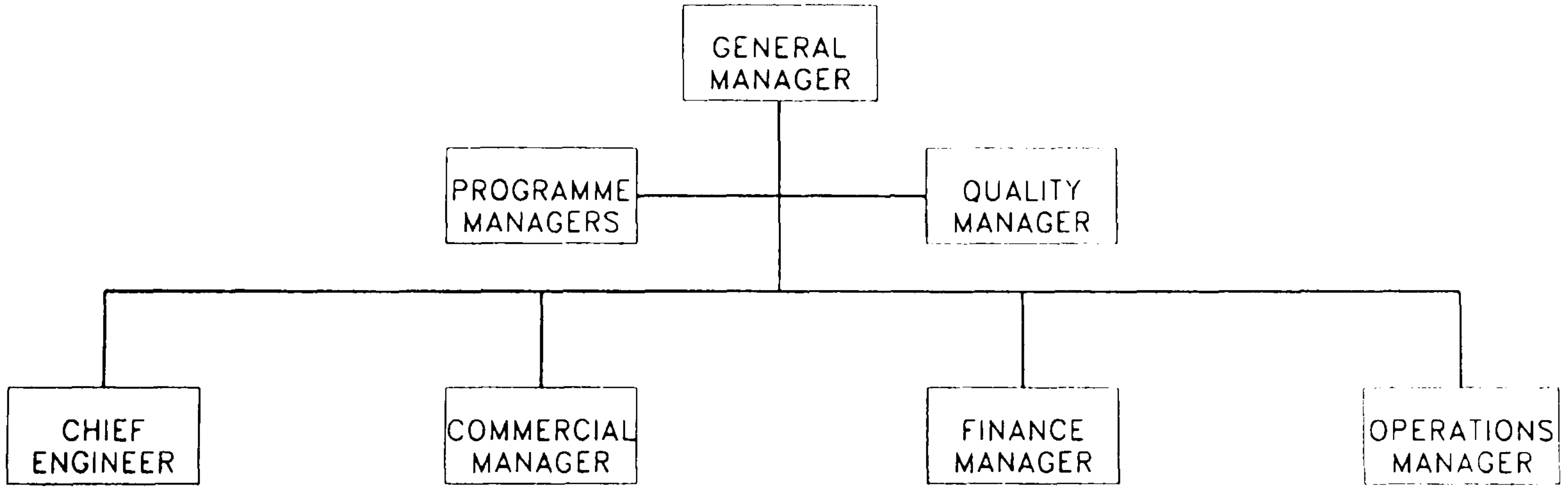

FIGURE 9.1

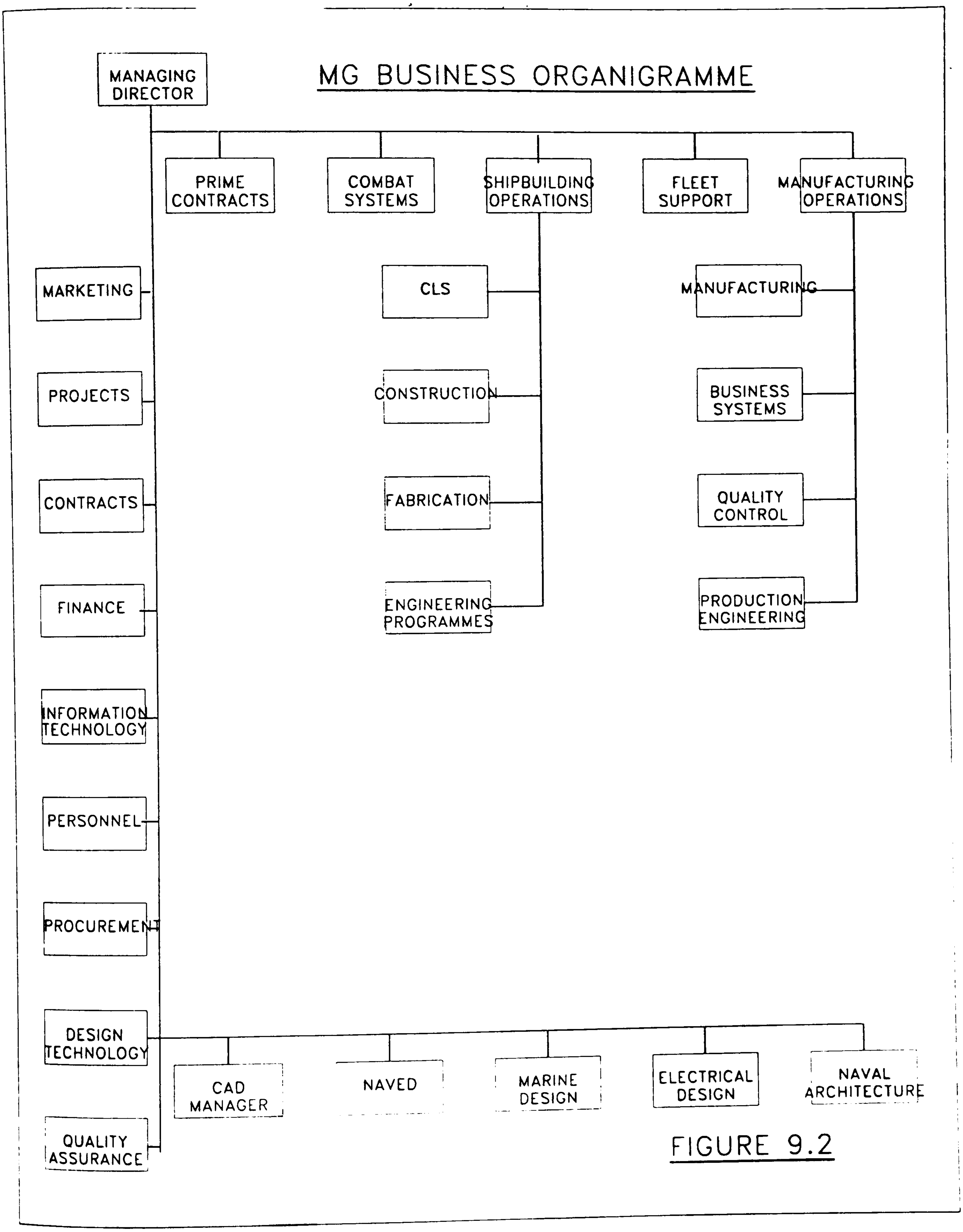
MG BUSINESS ORGANIGRAMME
MANAGING DIRECTOR
PRIME CONTRACTS
COMBAT SYSTEMS
SHIPBUILDING OPERATIONS
FLEET SUPPORT
MANUFACTURING OPERATIONS
CLS
CONSTRUCTION
FABRICATION
ENGINEERING PROGRAMMES
MANUFACTURING
BUSINESS SYSTEMS
QUALITY CONTROL
PRODUCTION ENGINEERING
MARKETING
PROJECTS
CONTRACTS
FINANCE
INFORMATION TECHNOLOGY
PERSONNEL
PROCUREMENT
DESIGN TECHNOLOGY
QUALITY ASSURANCE
CAD MANAGER
NAVED
MARINE DESIGN
ELECTRICAL DESIGN
NAVAL ARCHITECTURE

FIGURE 9.2

9.1 THE DESIGN OF THE BUSINESS

The predominant organisational form of the overall business amongst the case study firms is *functional.* Taking the managers reporting to the Managing Director or General Manager, the most common configuration is into the four primary functions - engineering, commercial, manufacturing, and financial (cf Kimball, cited Urwick 1937 p 58). Four of the firms studied have this arrangement, including three of the four most profitable ones - MK, MN, and MD. The fourth is MM. An example of this basic functional structure is given in figure 9.1, which also shows the managers who are typically in support to the main four functions in a line and staff arrangement. These support functions will be discussed later.

In two cases, two of the functions are merged - engineering and manufacturing in the case of another highly profitable business, MB, and engineering and commercial in the case of MA. In the latter case, the engineering capability upon which the company originally built its reputation atrophied over the years after the war once its patent had expired. The company is now making a considerable effort to re-establish an engineering capability to gain the value added in engineering design. This initiative is being led by the Marketing Director, and the engineering capability has been established as a separate Design Division alongside the other product divisions within the marketing function. These then buy manufacturing services from manufacturing. The Manufacturing Director argued that "manufacturing is a service to marketing...the company is very much marketing led". At MB, the arrangement seems to be traditional within the firm, perhaps because of the relative simplicity of its product.

Two companies have differentiated engineering functions. At MI and MC, the distinction is between engineering and product development, and can be explained in historical terms. In the first case, a merger which took place as fieldwork was under way led to the promotion of the Engineering Director who had covered both functions to the corporate level. The two Chief Engineers now report to the Managing Director directly. This arrangement was described as transitional while the implications of the merger are worked through. In the second case, the separation of the functions is also fairly recent, and is consequent on the arrival of a new Engineering Director from outside the company. According to one informant, the separate role of Product Development Director was established to avoid overloading the new Engineering Director in his early days. The present Product Development Director will soon retire, and the post is then expected to lapse.

At ML, in an inversion of the departmental titles used at MI and MC, a similar differentiation had existed between Product Development, and Design and Concept Engineering. However, the Director of the latter has recently resigned, and so the two functions were merged under one Director in August 1989. This move was described by one informant as a great step forward, as the two previous Directors were "warring" on the Board. So, it seems as if a unitary engineering function is the norm in metalworking industries, and that attempts to separate completely the product development and engineering design functions are unstable.

Three firms have expanded commercial functions. At MI, a Construction Director is responsible for the erection of the product on the customer's site. The importance of this role is indicated by the fact that the remarkable halving of product delivery lead times achieved during the seventies from 9 years to 4.5 years came more from reducing site construction times than design and manufacture lead times. At ME, the importance of providing in service support to the product led to the establishment of a Customer Support Director, in addition to both a Commercial Director, and a Sales and Marketing Director. Thus expanded commercial functions seem to be related to the needs of the market in terms of the amount of support required by the customer at its own site. At ML, two Commercial Directors look after the two distinctive product lines inherited from a merger.

MF has a differentiated manufacturing function, which again is the result of a recent history. Since the take-over in 1987, the technical function has been merged into a Product

Development Group, and the commercial functions have also been brought together. However, the manufacturing operations of the constituent parts of the business have not been combined. This is partly geographical - the two divisions are UK and continental based. However, the main reasons seem to be that the products presently in production were all developed prior to the merger, and the elements of design for manufacture in them means that they cannot be transferred between factories. Until the new technical function, which as one informant put it, "reflects the goals of five years' time", develops a common product range, few synergies can be reaped within the operational function.

Similar forces appear to be at work in the differentiation of ML's manufacturing operations into three profit centres. In two cases these are geographical groupings, but the third division represents a separate product group which has only recently ceased to operate as a completely separate company within the group. The Product Development Director reports separately to the Board as a cost centre, and has now taken responsibility for the engineering function of the third product group.

One of the companies, MO, has a *product* structure, with its UK operations grouped into four main product divisions, all located on the same site. A group of off-site component manufacturing plants also reports direct to the Managing Director. Within the product division studied, the organisation design is functional, but with a proliferation of commercial functions - strategic planning, OPT and customer liaison, original equipment sales and marketing, and aftermarket sales which all report separately to the divisional Director. The four divisions are supported by a centralised Engineering Services and Corporate Quality department responsible for research and development, and overall quality assurance.

There is some evidence from the cases that such divisionalised structures are unstable. Where the divisions are successful and capable of independent existence, they tend to be formed into separate businesses within the corporation - MD is the result of such an unbundling. Where one or more of the divisions is unsuccessful, or ceases to be identified as a part of the "core business", they can be targets for closure or sale, as happened at MN. At MC, the business was divided into four product divisions between 1981 and 1986 - the Large Machines, Medium Machines, Steel Products, and Site Divisions. The Steel Products Division combined all the factory feeder departments such as the fabrication and press shops, while the Site Division was responsible for site installation of the product. The period was described by one informant as a "total disaster". It had led to a rapid rise in transaction costs between divisions, and a fragmentation of the technical function, as engineers were allocated to the separate divisions.

MK is moving towards a *matrix* organisation, but only one company - MG - presently has one, which is shown in figure 9.2. The changes were fully implemented by early 1989 in response to privatisation, the Ministry of Defence's shift towards a prime contractor system of procurement where one company takes the entire responsibility for the defence project, and more general changes in the market. Business Centres have been established which trade with each other. For instance, Manufacturing has to tender to Shipbuilding for the supply of components, and is free to seek work outside the business. As in ME, the provision of in-service support to the product has led to the establishment of a separate function. Prime Contracts was established to tender as a prime contractor to the Ministry of Defence. These Business Centres are supported by nine Service Areas, some managed by Board Directors. Although the Service Areas contain many of the traditional staff functions, they also include important elements of the primary functions, and the Business Centres are a mix of functional and product groupings.

MN had a matrix organisation until the mid eighties, as reported in Winch (1983). The matrix organisation had originally evolved in response to the problem of increasing responsiveness to the customer by combining the commercial and technical functions into three product based divisions, and gaining economies of scale in manufacturing by putting the workload of the

MK TECHNICAL FUNCTION ORGANIGRAMME

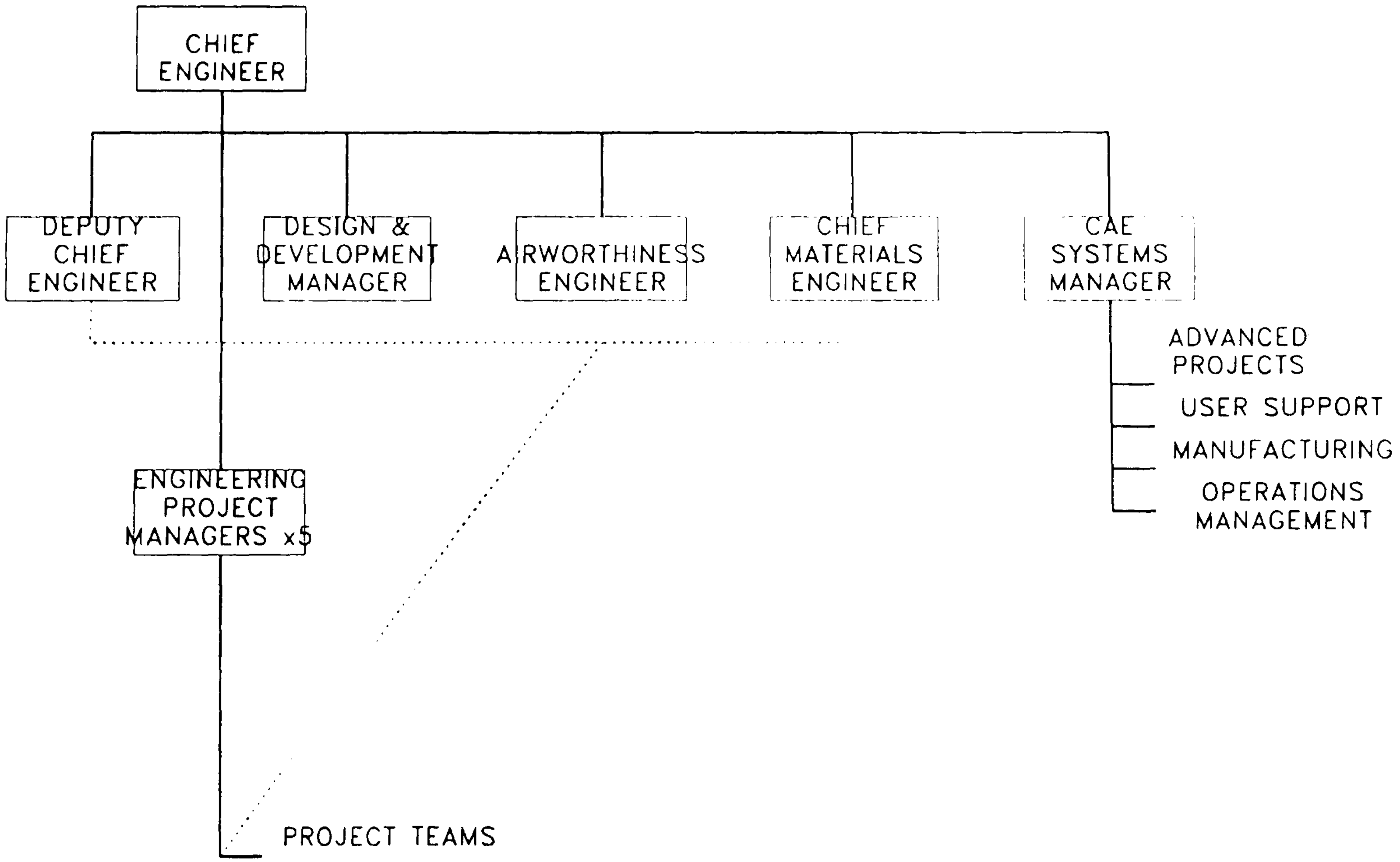

FIGURE 9.3

three divisions through the same factory. The sustained growth of the company meant that each division could justify its own manufacturing facilities, and the emphasis shifted back towards product organisation. This development was formalised in 1985 by the formation of self-contained businesses from the product groupings. The process was completed in 1989 when the case study division was sold to a US corporation. The business now has a simple functional structure.

It seems, therefore, that matrix organisations are only adopted when neither functional or divisional organisation designs are workable. However, matrix organisations are often unstable with a tendency to revert to functional forms (Kingdon 1973), and the case of MN shows that the opportunity to revert to a functional organisation was taken as soon as it could be. It remains to be seen how long MG sticks with its new structure, as it is unclear what benefits its gains from differentiating out the nine separate Service Areas. While some Service Areas are conventional "staff" functions, others, such as Design Technology, Marketing, Finance, Contracts, and Procurement, are usually part of the primary functions. No rationale for this arrangement was offered by the informants interviewed.

The remaining case, MH was formed into a new profit centre during the course of the research by combining half of another division's engineering function with the factory for which it has always designed. The result at the time of fieldwork was an organisation design with a relatively large span of control for the Managing Director of seven managers, three of whom are responsible for various manufacturing functions. It seemed likely at the time of fieldwork that this structure would be rationalised towards the primary functional structure fairly rapidly, but in the event the factory was closed.

In the opinion of Sheldon (cited Urwick 1937), staff functions are responsible for developing plans and standards. This role appears to explain the emergence of most specialist staff functions. The importance of a having a coherent human resource policy across the business means that most of the companies have Personnel in a staff function. However, the manager responsible is, usually, clearly inferior in status to the managers or directors of the primary functions. Only ML and MA have a Personnel Director - both are high volume companies, and the former has a long history of industrial relations problems. At MO, the personnel function is devolved to the product divisions, while at MG it forms one of the Service Areas.

The importance of standards is clear in that five of the functionally organised companies have a Quality Manager or Quality Director reporting to the Managing Director in a staff role. At MO, there is a Corporate Quality function above the product divisions, while at MG it is one of the Service Areas. Two companies pull out information technology as a specialist staff function, while again at MG it is one of the Service Areas. The role of these functions will be discussed in chapter 12.

Perhaps the most interesting example of a specialist staff function responsible for planning is the emergence of *programme management*. Programme management is distinguished from *project management*, because the latter typically operates within the primary functions, while the former operates at the business level and co-ordinates between the primary functions. This role is identified by a direct reporting relationship to the Managing Director. The distinction is clearest at MK, where the newly re-organised engineering function contains five Project Managers who report to the Chief Engineer. At the same time, at team of Programme Managers reports direct to the General Manager. This is a new status - their earlier role was described by one informant as being little more than a progress chaser, and the direct reporting relationship to the top is intended to give them added authority.

At ME, a similar elevation in the status of the Programme Director was made during the recent re-organisation, with a brief to cover both Engineering and the Supplies Division (manufacturing). Previously, the Programme Manager had reported to the Engineering Director; again, he is supported by a Chief Designer who manages a team of project managers and reports to the Engineering Director. At MG, a Project Director was appointed for the first time during the formation of the matrix organisation, taking over a role previously handled by the Technical Director. While all three of these programme posts were formed during 1988 or 1989, MI has had a programme management function called, somewhat confusingly, the Project Management Department reporting to the Managing Director for a number of years.

A similar distinction exists at ML. A directorate of three Vehicle Directors is responsible for the management of a vehicle from the initial conception right through the product life cycle and the development of derivatives on a "cradle to grave" basis. While they report within Product Engineering, their scope of authority ranges across the entire company, and they include manufacturing and commercial people within their teams. There is also a group of Project Directors who are responsible for new product initiatives to the Vehicle Directors. This is the type of role described by Clark and Fujimoto as the "heavyweight product manager" (1991 chap 9).

In addition to these two layers of functionally based project management, and business based programme management, MH and MG both have *projects divisions*, the latter is identified on figure 9.2 as Prime Contracts. These operate as separate profit centres within the business as prime contractors which tender on a "turn-key" basis for contracts. At ME, the projects division is established on a joint venture basis with a major manufacturer of information technology. As well as managing the procurement of the company's basic product, project divisions also co-ordinate the work of subcontractors responsible for specialist items such as power sources and electronic systems. They thereby encompass the entire value chain, and has a similar role to that of project managers in the construction industry. These three levels are summarised to table 9.1. MC does work for a project company in the same group, MI normally works for MH's projects division.

At ME, MG, and MA, the transactions between the engineering and manufacturing functions take place on an internal market basis, where manufacturing services are "bought". In all three cases, these developments only took place in the two years prior to fieldwork. It is, therefore, too soon to evaluate the effects of this choice of transaction governance structure. However, the experience of MC with internal market transaction governance, albeit organised on a different basis, does not augur well. While such an arrangement, at least in the case of the two defence contractors, ME and MG, does allow manufacturing to obtain work from other companies on a subcontractor basis to sustain factory loading, the high levels of asset specificity inherent in the production technologies of shipbuilding and aerospace, and the frequency of transactions, suggest that a unified transaction governance structure would be normally favoured (Williamson 1985 chap 3).

THE HIERARCHY OF PROJECT MANAGEMENT

Functional Level: *Project Management*

Designated leaders of project teams within individual functions or between functions. They may or may not report to a *programme manager* as well as to their functional managers. Their task is usually to achieve internally set operational performance targets.

Business Level: *Programme Management*

Responsible for the overall co-ordination of project activities within the business. Clear non-functional authority, usually specified by direct reporting to the managing director. Their task is to ensure that the business' commitments on project delivery are met. They are the interface with the client, which may be an independent business or a *projects division*.

Inter-Business Level: *Projects Division*

Responsible for the overall procurement of the product on a "turn-key" basis. Separate profit centre status, relying on market transactions for the supply of all goods and services. Their objective is to ensure that all the client's requirements are met.

Table 9.1

9.2 THE DESIGN OF THE ENGINEERING FUNCTION

Within the overall business, the two primary functions that are of most relevance to the production information flow are technical and manufacturing. Turning first to the technical, or engineering department, a very different story from that at the business level can be found - the *matrix* form is predominant. Headed by managers with titles such as Chief Engineer, Engineering Director, and Technical Director, five of the cases have matrix organisations for their technical functions - MN, MK, ME, MM, and ML. Typically in such an arrangement, the technical staff form a pool of expertise which is allocated to the various design projects as a team. The engineering discipline heads are responsible for the supply and development of high quality technical skills, while project managers are responsible for deploying those skills on a particular product development initiative. This distinction is made clear at ME with the Chief Designer responsible for project management, and the Chief Engineer responsible for technical excellence while both report to the Engineering Director. An example of this kind of arrangement is given in figure 9.3. Support services such as computing tend to report separately to the head of the technical function.

Three of the cases, MF, MC, and MO, organise the engineering function around *product* groups, while one of the vehicle producers, MJ, organises around vehicle elements such as body, power and train, and so on. Here, the distinctive feature of organisation design is that all the engineering disciplines required for the work are contained within a product group. Within the product group, technical staff are then often deployed functionally. None of the four with this type of organisation design normally favour a design team approach within the product groups.

Bertodo (1988;1989) has shown the way in which his company has flattened the organisation of its engineering function over the last few years. The number of levels in the hierarchy was reduced from 7 to 4, spans of control were broadened from between 2 and 5 subordinates to between 8 and 10, and staff were grouped into four broad bands from 11 grades. The company had found itself with a large number of engineers in managerial grades who had few managerial skills. The reduction of the number of management positions by 70% returned

MN MANUFACTURING ORGANIGRAMME

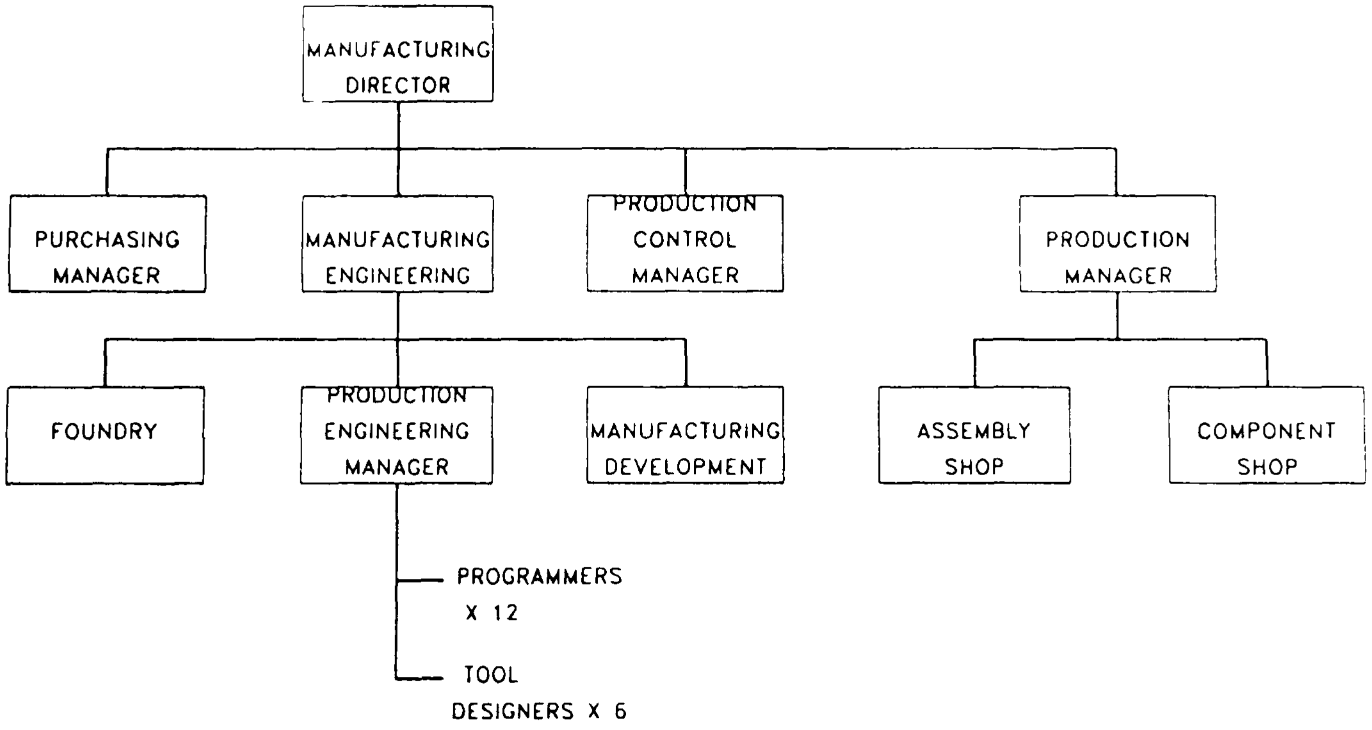

FIGURE 9.4

these engineers to technical work where, in the opinion of Bertodo, their skills are best deployed. Both of the vehicle companies studied displayed this trend. Bertodo's example is from a company with a matrix organisation in the design function, but even with a product-type grouping as at MJ, similar ends were achieved by a re-organisation in 1988. The effect of implementing a matrix type structure is usually to flatten the organisation, although none of the other companies with matrix organisation articulated their aims in these terms. This may be because they are all smaller than ML and MJ.

Bertodo also emphasises the differentiation of the more developmental aspects of engineering into a separate advanced engineering section. Again, both vehicle companies displayed this trend, with the establishment of Advanced Engineering, or Advanced Technology sections. This trend towards a clearer differentiation between the development of new technologies and the mainstream engineering design process deploying largely existing technologies was discernable in other companies as well. MO established a Concept Engineering section within the case study division in 1989, while the establishment of Design Technology as a Service Area at MG also appears to be in line this trend. ME also has a specialist Advanced Engineering section.

Another three cases organise their technical departments on *functional* lines. MI and MH both retain the traditional discipline based engineering groups, which feed a separate drawing office. The drawing office in turn tends to be functionally split. Within MG, which is illustrated in figure 9.2, the drawing office - identified as Engineering Programmes on the organigramme - is organised on a project basis, having moved from a traditional discipline basis two years ago. The distinctive feature of the engineering function at MG is that the drawing office reports to manufacturing rather than engineering - an arrangement which is, I was informed, traditional in shipbuilding. The design function - identified as Design Technology - is organised on a functional basis and reports as a Service Area. It is notable that these three companies are those with the longest concept to delivery lead times, which is a function of very large cost and size of each individual unit of production.

In two of the smaller companies, MB and MD, the engineering function includes both engineering design, and prototype and test in the former case, and quality assurance in the latter. At MA, the technical department - Design Services - is completely undifferentiated These examples can be called *unified* organisation. These features are most probably explained by the relatively small size of the engineering departments in these three cases - less than a dozen staff in each case.

At MJ, the new product development process has been separated out completely from the development work on the existing two product lines. A special cell - New Vehicle Concepts - was established in 1985 with a direct reporting link to the Board. The aim is to provide a multi-disciplinary environment for exploring conceptual designs in a CAD environment. It works with a core of permanent staff which can be more than doubled by secondees from various other departments. The idea is innovative, but has run into boundary problems with the mainstream engineering departments because of a perception of its favoured status, and the issue of when to hand the concept over to the rest of engineering for further development.

If the pattern of organisation design is related to the production mission types identified in the last chapter, the most notable finding is that the *manufacturing led* firms tend to favour either the *product group* or *matrix* form of organisation. The *engineering led* firms, on the other hand tend to favour the *functional* or *matrix* forms - MC is the exception here. No manufacturing led firm has a *functional* form. The two *production led* firms both have highly integrated forms - *unified* and *matrix*. It is also clear that four of the five firms with matrix organisations are also committed to the development of iteratively coupled production information flows between engineering and manufacturing. The odd one out is ME. The other two committed to iterative coupling have product group organisation.

9.3 THE DESIGN OF THE MANUFACTURING FUNCTION

Turning now to the manufacturing function, we find a very different pattern of organisation. Managed by men[17] with titles such as Manufacturing Director, Operations Director and Supplies Division Director, the organisational form tends to be a functional one. Typically, it is differentiated into what might be considered the four primary manufacturing functions - *manufacturing engineering, production, production control,* and *purchasing.* Figure 9.4 shows such a *functional* organisation. Most of the cases have variations on this theme - sometimes production control is not separately identified, in other cases site services also come under manufacturing. In the nine cases with a toolroom, these also report to manufacturing, except at MA which has a separate business manufacturing specialist production machinery within the group.

There are two main development in the organisation of manufacturing - the emergence of "unit" organisation in production, and associated changes in manufacturing engineering. Units are distinguished from group technology cells in that they are organisational rather than technical entities. In the two vehicle component cases, the units consist of a number of group technology cells as well as more conventional arrangements. Their importance for the argument here its that many of the manufacturing engineering functions are being devolved down to the units.

Manufacturing engineering is mainly responsible for the stage three tasks in the production information flow shown in figure 3.1. It is, essentially, the interface between the engineering process which produces the design in the form of drawings, specifications, and schedules, and the manufacturing process which transforms it into a product. It translates the language of

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[17] Although none of the most senior manufacturing managers are women, the toolroom at ME and one of the units at MI are run by women. None of the technical function managers amongst the cases, so far as I am aware, are women

MO MANUFACTURING ORGANIGRAMME

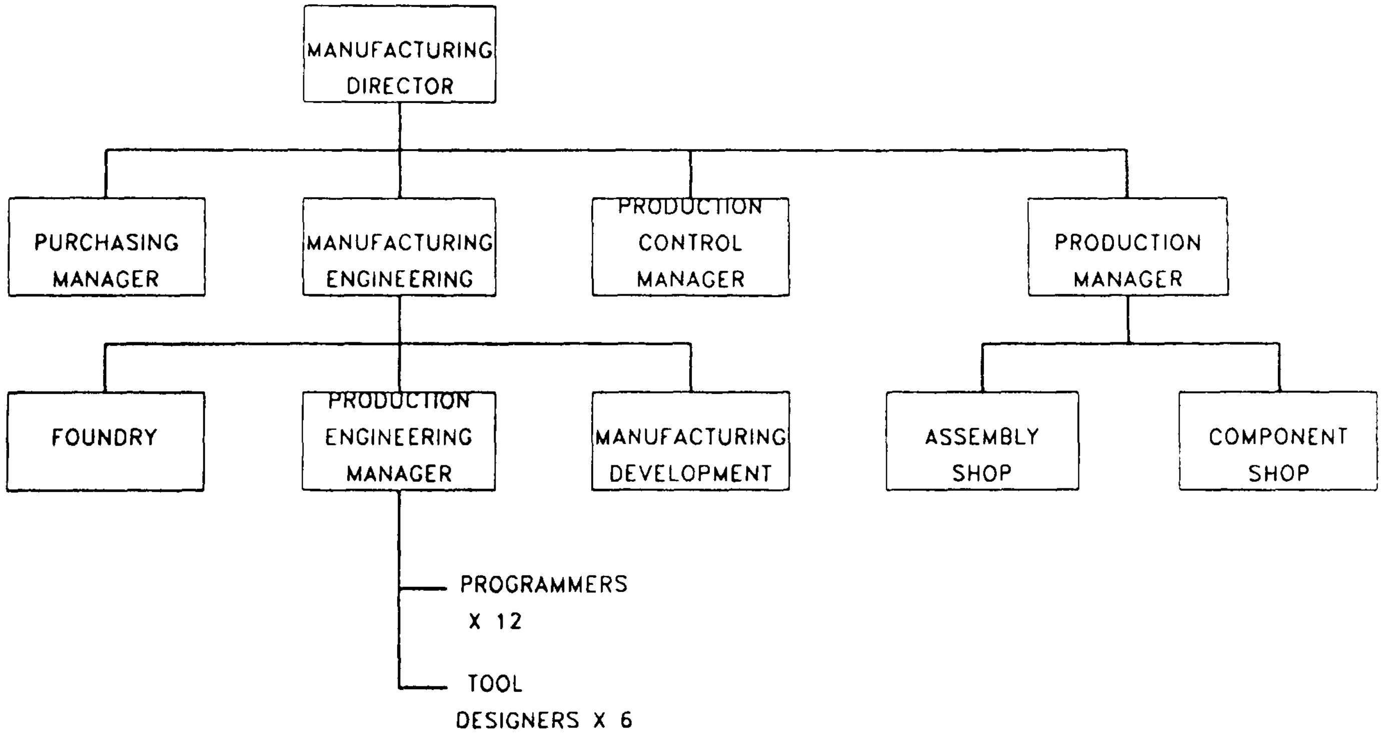

FIGURE 9.5

design into the language of production, taking a two dimensional representation and specifying the means by which it is to be converted into a three dimensional artifact. Its growth has been one of the most notable features of the development of the organisation of metalworking production and is central to the contemporary implementation of Taylor's conception of scientific management. Smith (1987 chap 4) provides a useful description of some of the occupations in manufacturing engineering.

The main tasks usually carried out by *manufacturing engineering* are *production engineering* which covers the design of jigs and tools, the planning of process routes, and the programming of NC machine tools; *industrial engineering* covering method and work study; *manufacturing systems engineering*, responsible for design of production technology and the layout of the plant; and *production planning*. The importance of each of these tasks varies considerably with the nature of the materials flow. For instance, the high volume producers have little need for NC programming and process planning, but have large manufacturing systems engineering and tool design capabilities. In low volume production, where the machine tool stock is general purpose, there is usually little requirement for tool design, but a large need for NC programming and process planning.

In high volume production, the implementation of unit organisation has been associated with the drawing of a clear distinction between production and manufacturing system engineering on the one hand, and industrial engineering and production planning on the other. MM, MF, and ML have all developed since 1986 what, at ML, is called the Manufacturing Engineering section which reports separately within manufacturing and includes the first two tasks, and Conformance Engineering which includes the latter two tasks and reports to the operations managers for the units that they cover. An example of what can be called this *manufacturing planning* form of organisation is shown in figure 9.5. As one informant put it, Manufacturing Engineers are "future orientated", while the Conformance Engineers are "present orientated". MJ's single manufacturing engineering department is strongly differentiated along these same lines. At MO, these functions, somewhat confusingly called Industrial Engineering, actually report within the engineering function, which is called Product Engineering, rather than manufacturing.

Three of the cases - MI, ME, and MG - have no central manufacturing engineering capability. Here again, the factory has recently been organised into units, and each unit manager has all the staff which he or she requires to complete the unit's pre-production and production tasks, including manufacturing engineering and production control. This form of organisation is presently being implemented at MC. An example of the unit organisation of the manufacturing function is given in figure 9.7. What these four companies have in common is that they are all one-off production companies. Only one such company had not moved in this direction at the time of fieldwork.

In all three cases, the implementation of what can be called *unit* organisation is fairly recent, and has tended to be fraught. At MG, the implementation of the unit structure began in 1986 with the establishment of the Machining Unit. It involved the break up of a large production engineering capability, and now each unit has its own process planners and NC programmers, as required, within a Methods and Tooling Office. However, it was decided to retain a centralised Jig and Tool design and manufacture function to spread its costs across as many activities as possible. A separate Manufacturing Technology department reports to the General Manager Materiel, which is responsible for advising units on the purchase of new machine tools and the development of computer systems such as a tool management system. At MI, the three units were established in 1988. Since then, turnover amongst production engineers has been relatively high; according to one informant, this is due to the uncertainties inherent in the break up of the central production engineering function.

An obvious problem with the *unit* organisation is that of co-ordination between the units along the materials flow. It is probably no co-incidence, therefore, that these companies have all

ML MANUFACTURING ORGANIGRAMME

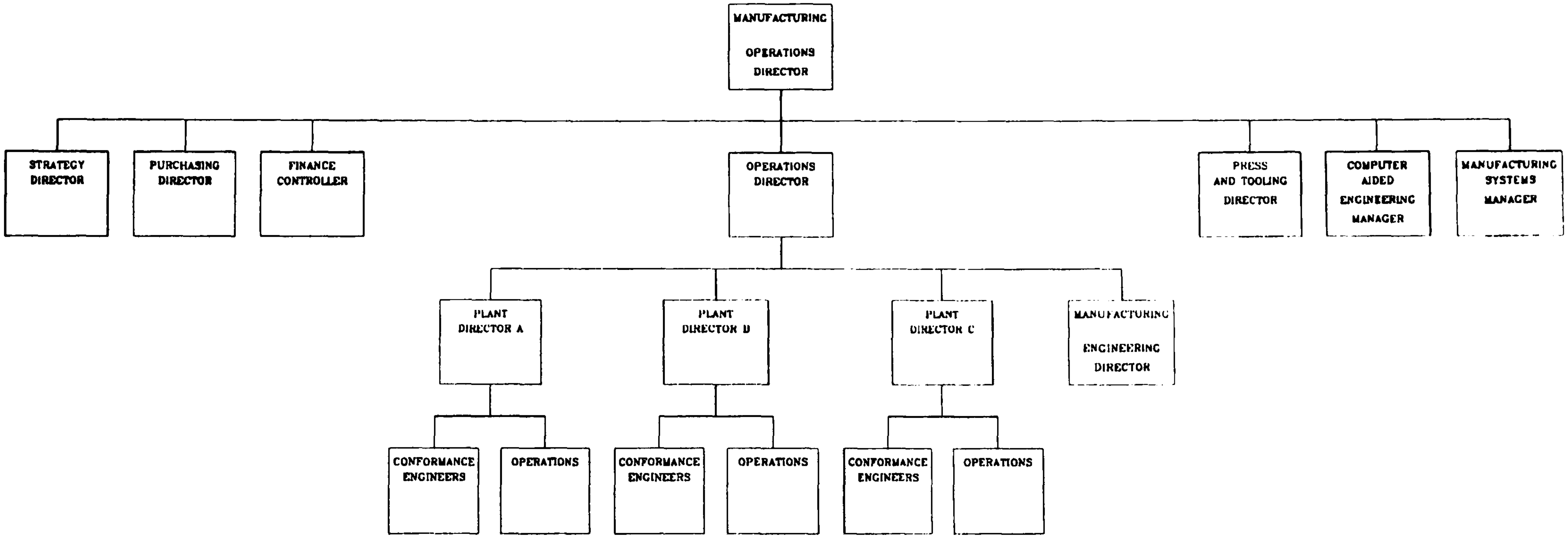

Figure 9.5

ME MANUFACTURING ORGANIGRAMME

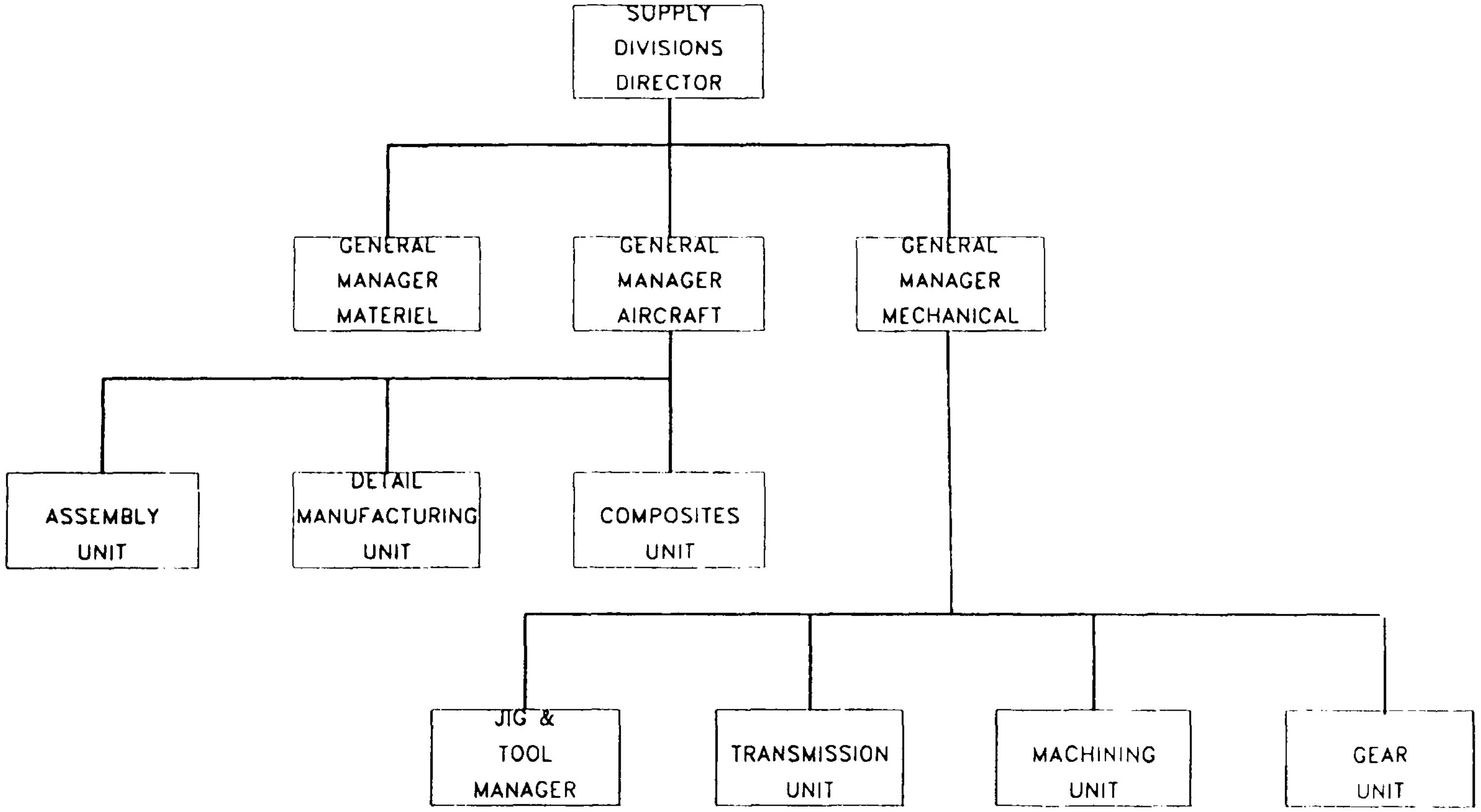

FIGURE 9.6

implemented *programme management*. Co-ordination is to be achieved, it seems, at the level of the business, rather than within manufacturing. Informants also expressed concern regarding the career prospects of production engineers, and the loss of the sharing of expertise within a centralised office. These complaints may just be symptoms of resistance to change, but is remains to be seen whether the *unit* organisation of one-off production is a success. A further implication for the co-ordination of the engineering/manufacturing interface will be discussed later.

At the small batch company, MK, the possibility of moving towards a unit form of organisation was evaluated. It was rejected on the grounds that it, according to one informant, "would have been suicide". The factory is organised into a number of "cells" on either product or group technology lines, but a central production engineering function was retained for a number of reasons. Firstly, plant tends to be common across the product cells, and so there are economies of expertise in developing common approaches. Secondly, much of the work is at the leading edge of technology, which includes a number of very sophisticated machining centres, and a centralised grouping can learn faster and share a developing expertise better than a fragmented one. Thirdly, there is a danger of the proliferation of approaches. Fourthly, it is felt that the status of production engineers needs lifting. The use of the term "manufacturing systems engineering" to describe their work is one way of doing this; another is to acknowledge them as a group with a definite expertise allied as closely as possible with product engineering. Fifthly, an overall function is required to allocate work to the different product cells.

During 1991, the production engineers at MK are to become one of the disciplines within engineering's matrix structure which was described in section 9.3. Co-ordination with the factory is to be retained through the industrial engineers, who also report to the Chief Production Engineer. They are to be devolved down to the manufacturing cells. As well as the conventional industrial engineering tasks, they are to become responsible for making minor adjustments to process plans, and to "chip away" at process optimisation. To support these developments in manufacturing engineering, multi-skilling within both groups is being encouraged through a training and career development programme.

Relating these developments back to the generic production missions identified in the previous chapter, interesting differences can again be found. *Manufacturing led* companies have been increasingly implementing a *manufacturing planning* type of manufacturing organisation design consisting of unit organisation in production with their own industrial engineers and production planners to look after daily matters, and centralised manufacturing engineering organisation for future projects. Otherwise, they favour functional organisation. In the *engineering led* companies, the diffusion of *unit* organisation with all manufacturing engineering devolved to the unit managers has been equally rapid and meant the breakup of traditional centralised manufacturing engineering functions. The *production led* mission companies both favour traditional *functional* manufacturing engineering departments. It is also clear that those companies who expressed a commitment to *sequential coupling* are implementing *unit* type organisations, while those committed to *iterative coupling* are implementing *manufacturing planning* type organisations or staying with functional organisation.

9.4 SUMMARY

A notable feature of the organisation design of the case study companies is the sheer stability of structure at the business level. The line and staff arrangement around the four primary functions of engineering, commercial, manufacturing, and financial would be recognisable to any commentator over the last sixty years. In the few cases where companies have deviated from this traditional design, there are good reasons to believe that the resulting structures are unstable. The only long term stable feature which departs from the traditional model seems to be the differentiation of the commercial function to meet requirements of the market for installation and product support in service.

TABLE 9.2
THE ORGANISATION OF ENGINEERING AND MANUFACTURING

COMPANY	MISSION	ENGINEERING ORGANISATION	MATERIAL FLOW	MANUFACTURING ORGANISATION
MA	MtO/C	UNIFIED	Large Batch	FUNCT
MB	MtF	UNIFIED	Small Batch	FUNCT
MC	DtO	PRODUCT	One-Off	FUNCT
MD	MtO/F	UNIFIED	Large Batch	FUNCT
ME	CtO	MATRIX	One-Off	UNIT
MF	MtO/F	PRODUCT	Large Batch	MANPLAN
MG	CtO	FUNCTION	One-Off	UNIT
MH	DtO	FUNCTION	One-Off	FUNCT
MI	DtO	FUNCTION	One-Off	UNIT
MJ	MtF	PRODUCT	Flow	MANPLAN
MK	DtO	MATRIX	Small Batch	FUNCT
ML	MtF	MATRIX	Flow	MANPLAN
MM	MtO/F	MATRIX	Flow	MANPLAN
MN	MtO/C	MATRIX	Small Batch	FUNCT
MO	MtO	PRODUCT	Large Batch	MANPLAN

However, this stability at the business level provides a basis for considerable change elsewhere. In the staff functions, new demands from the market for time, cost and quality improvements is encouraging the formation of new staff services to enhance co-ordination between the primary functions, particularly regarding quality and delivery lead times. The most recent example of this phenomenon amongst the case study companies is the emergence of *programme management* as a response to market demands for improved lead time performance.

Perhaps most radically, the organisation of engineering has been undergoing considerable change. The shift towards matrix organisation from a traditional one of discipline based design offices feeding a separate drawing office is both marked and recent. The shift has occurred across all types of company, and appears to be driven by a concern to both improve the effectiveness of the design process within engineering, and to improve co-ordination across the engineering/manufacturing interface. These concerns affect all the case survey companies to a greater or lesser degree, and it seems possible that the matrix will emerge as the dominant form of engineering organisation design in the metalworking industries. In this case, a desire for changes in the coupling within the production information flow is leading to changes in organisation design.

In manufacturing, change has been less marked, but is none the less significant. In the large batch/flow companies the traditional functional organisation of manufacturing engineering has been split into *manufacturing planning* and *manufacturing support* tasks. The former tends to be concerned with future projects, and relates closely to engineering, while the latter is concerned with present production, and has been devolved down to the factory units for which it works. Again, this differentiation is a fairly recent development. In the one off production companies, the trend is in the other direction with the abandonment of a centralised manufacturing engineering capability, and a devolution down to self-contained factory *units*. Here is a clear example of the manufacturing mission influencing the organisation design of manufacturing. These developments in the organisation of the engineering and manufacturing functions are summarised in table 9.2.

The evidence presented here provides some support for Kanter's contention that the "innovating organization .... has a quasi-free market sandwiched between two hierarchies" (1985 p 176). She argues that stability at the top and the bottom is necessary for the development of integrative and innovative processes in the middle ranks. While this certainly appears to be true so far as the top of the organisation is concerned, the implementation of CAD/CAM is profoundly affecting the ways in which the lower parts of the organisation work as well in ways which will be explored over the next four chapters.

10

ADOPTING CAD/CAM

10.0 INTRODUCTION

Now that the *outer* and *inner context* of the implementation of CAD/CAM systems in the case survey firms has been assessed, the argument can turn to the *process of change*. The next three chapters will follow the stages of implementation identified in section 5.1 from adoption, to installation and commissioning, and then to consolidation, and review the experience of the 15 firms with implementing their systems. However, before that is done, it will be useful to describe the *content of change* in terms of the type of CAD/CAM systems being implemented in each company, in order to provide a basis for the descriptions and analysis that follow.

10.1 THE CONTENT OF CHANGE

The basic principles of CAD/CAM technology were discussed in section 2.3; this section will discuss the systems actually implemented by the case companies which are presented in table 10.1. With the exception of Radan's Radcraft at MD, they are the market leaders in CAD systems over the last decade or so. The McDonnell Douglas GDS system is not well known in metalworking, but is a market leader in the construction industry. The range of systems covered by the cases, then, is fairly typical of those that were installed in many medium and large sized metalworking companies in the UK during the eighties. For much of the period, Computervision's CADDS has offered the state of the art. However, in terms of functionality, IBM's CATIA and McDonnell Douglas' Unigraphics II now appear to be ahead. In 1989, ME compared the two and found them to be broadly equal in functionality, while MK compared CATIA and CADDS4X and found the former superior, especially in terms of its solid

TABLE 10.1

SYSTEM IMPLEMENTATION

COMPANY CODE	PRESENT SYSTEM	DATE	FIRST SYSTEM	DATE	PART PROGRAMMING
MA	GDS	1988	-	-	-
MB	UNIGRAPH	1987	-	-	UNIGRAPHICS
MC	MEDUSA	1986	CADDS3	1982	GNC/APT400
MD	RADCRAFT	1980	-	-	-
ME**	CADAM/ SYSTRID	1980	AD2000	1978	ANVIL 5000 /WESTRID
MF	CADDS4X	1985	CADDS3	1980	MDSI
MG**	CADDS4X	1984	-	-	COMPACT II/ HEWLETT PACKARD
MH	CADDS4X	1985	CADDS3	1982	GNC/TUDRIP
MI	CADDS4X	1983	CADDS3	1982	CVNC/APT
MJ*	CADDS4X	1982	CADDS3	1981	CVNC
MK*	CATIA	1989	CADDS4X/3	1980	NC VISION/APT
ML*	CADDS4X	1984	CADAM	1979	CVNC
MM*	CADDS4X	1985	CADDS3	1982	NC VISION/APT
MN*	UNIGRAPH	1977	-	-	UNIGRAPHICS /COMPACT II
MO	MEDUSA	1986	UNIGRAPH	1979	HEWLETT PACKARD

* = CAD/CAM link for part programming
** = link for surface modelling only

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modelling and relational data base capabilities. Computervision's Medusa offers an attractive package for less demanding applications, while IBM's CADAM, a leading system in the seventies, is obsolescent.

Twelve of the case companies - see table 10.1 - first implemented a CAD system in the five years between 1978 and 1982. Nine from ten of Currie's sample of large firms also implemented during this period (1989b table 1). The only one of the case study firms which implemented during this earlier period, but was not large (>1000 employees) at the time of fieldwork is MD which was much larger at the time of first implemention - during the unbundling described in section 7.5, MD got the CAD system. The systems implemented during this period might be considered first generation draughting systems - they were obsolescent by the mid eighties, but provided a base on which to develop the second generation of modelling systems - a process most easily seen in the shift from CADAM to CATIA. Early users of CADAM, such as ML and ME, complemented it with specialist 3D surface modelling packages developed by aerospace companies which also ran on IBM hardware - NMG and SYSTRID respectively.

In most cases, the implementation of alphanumeric CAM systems was earlier than that of the CAD systems, and had been evolving during the seventies. As can be seen from table 10.1, all but two of the companies have both CAD and CAM systems. However, as might be expected from the diversity of CAM systems in relation to the CAD systems, they are not all fully integrated. In other words, not all the case survey firms had achieved *technical success*. Various criteria may be proposed for such success, but the existence of a direct graphics link for data transactions between the CAD system, and the CAM system for the programming of NC machine tools for the manufacture of prismatic parts seems to be an appropriate one.

The NC machining of turned parts tends to be a relatively simple to program because it poses an essentially 2D problem, and can be relatively effectively handled using non-interactive packages such as APT and Compact II. Perhaps because of this, some widely used interactive CAM packages were reported to be not very good for turned parts. MN, for instance, has deliberately chosen not to use its Unigraphics system for programming NC turning for these reasons. The incentive to use interactive CAM systems for programming NC turning is not great. Moreover, not all company's materials flows have a significant requirement for turned parts, and so such a test would not be generalisable. So this criterion is rejected on the grounds of technical underdevelopment and lack of generalisability.

The establishment of a CAD/CAM link for tool design poses few technical problems. Both tasks employ the same graphics images, and CAD software can be used for tool design as easily as it can be used for detail draughting. These links are not without problems, but they are largely organisational. For instance, at MM, the tool designers tend to redraw the component rather than pick up the engineering drawing directly because the engineering drawing contains too much data which takes a considerable time to suppress.[18] A second problem is more technical in that much tooling is for semi-finished parts, while the engineering drawing is for the finished parts. So this criterion is rejected on the grounds that it is technically undemanding, and not generalisable because most low volume materials flows have little requirement for tooling.

One of the most successful and straightforward applications of CAD has been for the design of electrical circuits, due to their simple two dimensional nature. At MG, a VAX mini-computer has been used to develop a proprietary electrical CAD system known as ELECTRICAD. This can be used to create and automatically check wiring diagrams. From the data base thereby generated, the complete drawings for wiring looms can be created. An ELECTRICAM package is then used in the loom shop to laser mark the wires for identification purposes. In the next stage of development it is planned to link this data base with the circuit testing machinery. At MG, the EDB (electrical data base) system, running on the CV hardware, has been under internal development since 1985. Wiring schematics are prepared directly on the screens from the specification, and then used to create cabling and commissioning diagrams. Data extraction for parts lists can already be carried out, and the production of a full bill of materials is planned. MN has also written its own package, running

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18) This problem could be solved if engineering layered their drawings

on the same VAX as the Unigraphics system. At MC, specifications developed using proprietary programs running on GEC mini-computers are merged with graphics from the CAD library on the Medusa system. However, there are few CAM opportunities with electrical manufacturing, because it is largely an assembly, rather than a machining process. The relatively undemanding and limited nature of electrical CAD applications suggest that it is not a good basis for assessing the degree of technical success.

It might be considered that pipework would also be a very favourable application for CAD[19]. However, the inherently three dimensional nature and sheer complexity of pipe systems has caused problems for the case companies. At MH and MI, the inability of the software to cope with falls, pulled bends and site welds was only one of many problems. Moreover, both subcontract pipework manufacture, and therefore have no opportunity to reap downstream manufacturing benefits from an integrated CAM system. The only company which does not subcontract most of its pipework manufacture, MG, only uses the CAD system for validating pipe runs digitised off a 1:5 scale model with a computer controlled camera. The technique was derived from the engineering construction industry for the design of process plant. While this data is used directly to program NC pipe bending machines, the pipe runs are laid out on the model by manually fitting colour coded plastic wire. The reason is that the pipe runs, and particularly their inter-relationships in highly confined spaces, are too complex to be handled on the computer.

The existence of a direct link for data transactions within the production information flow for the bulk of prismatic parts would appear to be the most appropriate measure for technical success, therefore, on the grounds that is it technically demanding, a significant potential application in most companies, and generalisable across the cases. On this criterion only five of the companies could be said to have integrated CAD/CAM systems in that the bulk of prismatic work goes through the system as a direct data transfer. Two other companies have

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19) Adler chose this application for one of his set of cases, the other is electronic circuit boards

achieved that goal only for surface modelling applications, leaving the bulk of their transfers to IGES or manual transaction. This appears to be due to the fact that the tool paths follow the designed surface, and the benefits that accrue from a successful data transfer are so large that it repays considerable extra effort and in-house development of the system. The classic example of this application is the machining of body dies in the vehicle industry, and much of ML's experimental work in the seventies was around this problem. The remaining companies rely on either data transfer through IGES links between their incompatible systems, or still use paper transfers in the form of drawings, although MB and MC are close to *technical success.*

This situation is summarised in table 10.1; technically successful companies are identified with a single asterisk, while those that have achieved surface modelling links are marked with a double asterisk. It is notable that none of the former are *engineering led* companies. The data for ML shows body engineering only. Figure 10.1 gives the example of ME's production information flow to show the diversity of links between the CAD and CAM systems. In the cases of MA and MD, it can be argued that there is no need, technically, for such a link. Neither have any NC machine tools in manufacturing or the toolroom for reasons to do with the nature of their high volume materials flows, although this may soon change at MD as they try to do more finishing work to increase value added on the components they manufacture. In the other cases, the reasons for the lack of technical success lie in the implementation process, and it is to this that we will now turn.

10.2 THE EVALUATION PROCESS

As was discussed in Chapter 5, the evaluation process starts with the awareness of the *performance gap*, which prompts an evaluation of the possibilities, before a formal application for funds is made through the justification. The awareness of a performance gap regarding the potential of CAD and CAM grew amongst the case companies during the latter part of the

ME – PRODUCTION INFORMATION FLOW

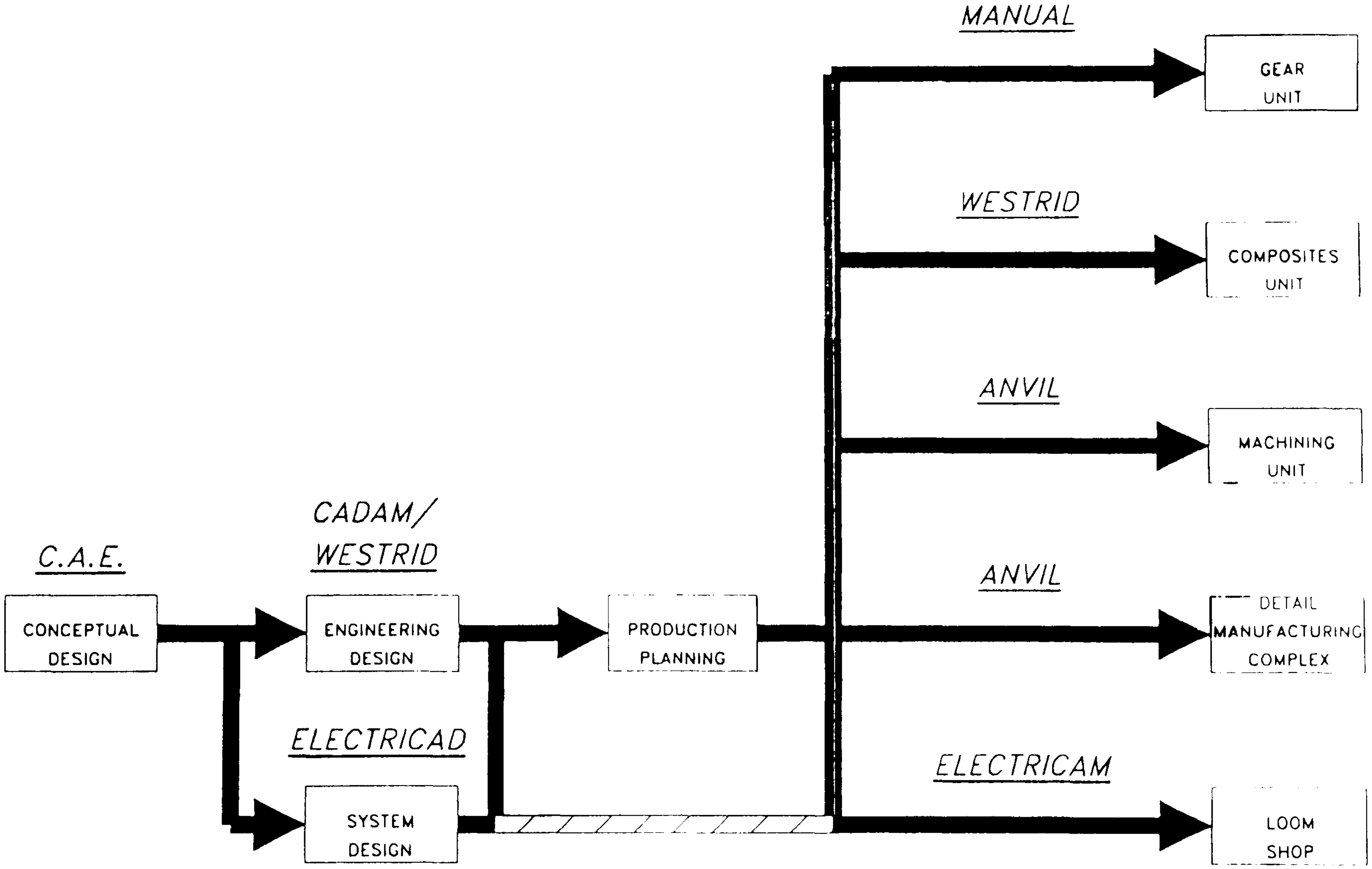

FIGURE 10.1

seventies. On the one hand, the use of main frame and mini computers for alpha-numeric CAE applications had been growing for some thirty years. On the other, the diffusion of NC machine tools during the seventies had encouraged the implementation of alpha-numeric part programming packages such as APT, which also ran on minis. By 1977, US companies were heavily marketing the new interactive graphics CAD systems in the UK (Arnold 1983); an effort focused mainly on the large companies (Currie 1989) of the sort covered in this research, and awareness spread.

Most of the case study companies set up informal *task forces* to look at the possibilities in the late seventies - this is summarised in table 10.2. First off the mark amongst these cases was MN, which set up a *task force* under the Technical Director in December 1976, prompted by an article in a trade magazine describing the system of a major competitor. Presentations from Computervision and Applicon and a trip to the US to see working systems sponsored by these vendors failed to impress. Only a visit to the company's US subsidiary where they were using the CAM part of Unigraphics - Uniapt - convinced them of the benefits. This resulted in one of the earliest installations in metalworking in the country in March 1977.

By 1980, most of the case companies were looking at the potential. ML had been experimenting at departmental level with 3D surface modelling packages for much of the seventies before deciding on NMG in 1978, and had a very early graphics package for press tool design, but did not commit itself to CADAM until 1980. Other parts of the company were, at the same time, implementing CADDS 3. The approach at ME was more formal. A trial system was installed in 1978, and in 1980 a CAD Steering Committee of senior managers was established, under which a task force, or Working Group, of functional specialists evaluated the options. At MC, a comprehensive review of most elements of the production information flow was carried out which produced a series of far sighted documents in 1979/80 which covered interfaces with manufacturing and bill of materials documentation. They even considered writing their own CAD/CAM system.

TABLE 10.2
THE ORGANISATION OF EVALUATION

COMPANY	TASK FORCE	MANUF INC	DP INC	CONSULT USED	IMPL CHAMP
MA	-	-	-	*	*
MB	*	*	*	*	*
MC	*	*	*	*	*
MD	*	-	-	*	*
ME	*	*	*	*	*
MF	*	-	-	-	*
MG	*	-	-	-	*
MH	-	-	-	-	-
MI	*	*	*	-	-
MJ	*	*	*	*	*
MK	-	-	*	*	*
ML	*	*	*	-	*
MM	*	*	*	*	*
MN	*	*	*	-	*
MO	*	*	-	-	*

A number of the case companies have been through complete re-evaluations of their CAD/CAM systems, and ME had just embarked on its third evaluation at the time of fieldwork. This was usually prompted by the perceived obsolescence of the existing system's hardware or software, or a desire to expand greatly the size of the system. Those companies that re-evaluated in the mid eighties also relied upon a *task force* approach, with the exception of MD, which relied upon a single functional manager. The *performance gap* tended to work in a much stronger way with re-evaluation - managers had a clearer sense of the both the potential of CAD/CAM systems in particular, and information technology in general, coupled with an intimate knowledge of the limitations and frustrations of their own system.

For MC, the obsolescence of CADDS3, and hence the necessity to upgrade to CADDS4X prompted an evaluation of requirements and a hard look at the level of functionality required. The realisation that they did not need a 3D modelling capability for designing electrical machines led to the decision to opt for Medusa. At MK and MD, awareness of the greater functionality of workstations against terminals encouraged a complete review. MO wanted to expand the system to the other two product divisions, and so went back to a basic appraisal of their requirements. Similarly, at ME, the first re-appraisal was prompted by the decision to make a major investment and to expand greatly the system, while the second is rooted in the realisation that both CADAM and SYSTRID are obsolescent; indeed, the latter was described by one informant as "terminally ill". At ML, the use of CADAM in body engineering and Computervision equipment elsewhere in the company meant that re-evaluation was likely to lead to the scrapping of one system, and body engineering switched to CADDS4X in 1984.

The *task forces* varied in composition, and few included all three of the main interest groups who could be involved in such a process - engineering, manufacturing, and data processing. The findings are summarised in table 10.2. At MA and MD, only the engineering function was involved in evaluation. The evaluation task forces at MF, MI and MG did not include manufacturing. At MO, MI and MF the task force did not include data processing, while at ME, on the other hand, it was led by the data processing function. MK can be considered a special case because of the role of the corporate centre in championing innovation. In the remaining cases, data processing tended to act in an advisory role, while retaining the right to sign off the final justification. Figure 10.2 compares those cases where all three concerned functions were included in evaluation and the achievement of technical success. It suggests that the inclusion of all three is a necessary, but not sufficient, condition for technical success.

		TECHNICAL SUCCESS	
		Y	*N*
TRI-FUNCTIONAL REPRESENTATION	*Y*	MJ ML MM MN	MB MC ME MI MO
	N	MK	MD MA MF MG MH

Figure 10.2

Senior management at director level was usually very supportive - in many cases the implementation champion was a director, and in the rest senior management provided support and drive. The case of MK where the corporate centre encouraged the company to adopt the innovation was exceptional, but at MG as well, which was then nationalised, there was strong championing from the centre. Only at MH and MI was there, apparently, little top management support for the task force's work.

These task forces appraised the long term viability of vendors, benchmarked the functionality of the systems, visited demonstration sites, which included MN, and carried out in-house trials. Only at MM was concern for compatibility with the systems of dominant customers expressed. The impression gained from informants is of a learning process during which system potential, business requirements, and investment criteria were articulated and re-articulated until a case could be made. This case was then distilled into a justification to meet capital budgeting procedure requirements. Six of the companies involved outside consultants in the evaluation process. While in case of MD and MB, this was explicitly to fill a gap in internal computing expertise, ME and MC already possessed strong engineering computing skills. In the first case involvement seems to have been political, and in the latter, the choice to evaluate manufacturing systems as well seems to have required additional skills. MK and MM relied upon the same strong corporate Technical Services function.

The re-evaluators tended to display a much stronger concern with interfacing the system with other business systems. The existence of manufacturing and business systems on an IBM platform elsewhere in the organisation was crucial in the ME and MK re-evaluations, while at MO, compatibility with systems in other divisions throughout the world was considered important. At ML, compatibility with the CAD/CAM systems used outside body engineering was a critical factor. Clearly, compatibility with the obsolescent system is also a consideration. MO was greatly aided in changing systems because they were able to purchase interface software from another metalworking company. At MC, the compatibility of Medusa with

CADDS3 was critical, while the amount of development work done with MD by Radan encouraged them to stay with that system. At ME, during both re-evaluations, the IBM policy for business systems was critical in selecting IBM CAD/CAM systems. Only MK has switched to a non-compatible system, and will retain a working Computervision CADDS4X system to allow access to old files.

In most of the cases, informants could identify and name an *implementation champion* who could be credited with pushing the implementation through - the results are summarised in table 10.2. In ME, MB, MN, ML, MJ and MF this person was the head of the technical function. In MA, MD, MM, and MC he was the head of the department which was to use CAD. In the former case the evaluation task force usually reported to this person; in the latter it was led by this person. Neither MH nor MI could identify such a champion. Winch (1983) suggested that the position of the implementation champion within the organisational hierarchy might be crucial to his or her effectiveness. At MN, the Technical Director also had an oversight over manufacturing due to the matrix organisation, which is illustrated in figure 4 of Winch (1983), while at MB, the Manufacturing Director is also responsible for engineering. At MK, MO, and MG, the champion was at corporate level.

Of the twelve companies first implementing during the earlier period identified in section 10.1, only three reported that they had evaluated CAD/CAM mainly on the basis of what one informant called "island productivity" in draughting - ME, MF, and MM. At MH and MI, the system was justified on its potential to reduce the cost of rectification during construction of pipework fouls by using the system's promised three dimensional clash detection capabilities - for MH, rectification accounted for 7% of site work at the time. It is not clear what MD expected from their system, despite the fact that one of the informants was the original innovation champion. MK's system was installed as part of an initiative at the corporate level to try out CAD - as one informant put it, the "money was put up to get us on the band wagon". They were chosen as a pilot site, and the system was funded by head office.

A detailed review of the evaluations made at three companies shows the breadth of the cases made. While draughting productivity features strongly, many other factors were also taken into account. This does provide evidence for the predominance of draughting productivity justifications in the evaluation of CAD discussed in section 6.2, but it also suggests that management decision making was less crude than sometimes suggested for a number of reasons. Firstly, the first generation systems were actually sold on the basis that they would increase drawing office productivity, so it is not unreasonable that managers, who usually lacked any actual experience of working systems, should emphasise this criterion. Secondly, they were implemented in the depths of the worst recession since 1945 and serious doubts about the future in many of the companies; cost savings were strategically paramount. Thirdly, some companies were aware of non-cost benefits and deployed them in evaluations, even if they could not articulate them clearly as a basis for justifications.

Turning to the later implementors after 1984, who moved straight to second generation modelling systems, we find a different story. Of these, only MA, implementing in 1988, relied entirely upon draughting productivity. However, as there is little opportunity for them to take advantage of downstream links or enhanced functionality due to the nature of the product, this is hardly surprising. At MG, implementing in 1984, the initiative was taken up at corporate level which provided guidelines for justification, and gave figures for the expected productivity savings, which moved beyond island productivity and included the downstream benefits for NC programming productivity, as well as improved build quality and design integrity. Their decision was supported by an agreement with the Ministry of Defence to fund the system as an agreed element of overhead. At MB, implementing in 1987, downstream benefits for NC programming productivity, product development lead time improvements, and product data integrity were emphasised. The decision was made in a climate of, as one informant - a main board director - put it, "when, not if" CAD should be purchased, and the payback period was lengthened to 3.5 years.

The most revealing evidence of a change in attitudes comes from those who went through the whole evaluation process again from 1984 onwards, which suggests a strong *organisational learning* effect as organisations became better at using their systems. MC justified its shift from CADDS3 to Medusa in 1986 on the basis of reduced maintenance costs, increased functionality, and improved draughting productivity. At MO, however, the shift to Medusa in 1986 was justified on the ability of the system to control the mass of data within the production information flow, to eliminate bottlenecks within that flow, to facilitate design modifications, and to improve the quality of drawings going to the customer. MD also re-evaluated in 1988, and chose a completely new Radcraft system. The main criterion used here was compatibility with "design led" business strategy that had just been drawn up by external consultants. The Board argued that a pre-requisite of such a strategy was CAD, and significant support came from the marketing function who found that customers appreciated the quality of the tender drawings from the old system, and the speed of tender turnaround. No specific justification for funds was prepared.

The re-implementation at MK was justified on the grounds of the greater functionality of CATIA over CADDS4X, particularly with respect to the interface with CAPM and CAE software, and its solid modelling and relational data base capabilities. There are three aspects to the evaluation. Firstly, the compatibility with the COPICS system in manufacturing would allow the direct transfer of bills of materials, in a significant step towards a CIM system. Secondly, the cost of ECOs in the aerospace industry is very high, and so the system is expected to provide support for a simultaneous engineering approach which reduces the needs for such procedures. This is a major issue for many companies - Miller and Vollman (1985) report that the number of ECOs in Japanese electronics factories is only two thirds of that in US factories and they make them further in advance. Thirdly, the solid modelling and engineering analysis capabilities are expected to reduce product development lead times and improve design quality. For instance, the weight of the product is critical in aerospace, and the new system has already proven its ability to help engineers to take out weight from designs.

The evidence is, then, that there has been a shift away from simple reliance on draughting productivity at stage two of the production information flow, a trend which seems to have gained momentum during the latter part of the decade.[20] This might be explained in a number of ways. Firstly, the rapid slide down the cost/performance curve that CAD/CAM shares with other information technologies means that the real cost of investment has dropped significantly. Secondly, the greater functionality of the second generation systems, especially CATIA and Unigraphics II, offers proven non-cost benefits that were merely promised by the first generation systems. Thirdly, improved business performance during the later part of the decade has generated a greater willingness to make capital investments. It is noteworthy that three of the late implementing and re-implementing companies which appear to have moved furthest from justification on island productivity grounds - MD, MB and MK - are also three of the five most profitable cases. A fourth, MN, spent the period investing heavily in CAPM systems, and advanced machining and materials handling technology. Fourthly, there is now much greater demonstrable evidence for the non-cost benefits of CAD/CAM. In the late seventies there was only a handful of fully operational systems in the country; the level of uncertainty regarding benefits was so high that it is hardly surprising that implementation champions fell back on whatever "hard" justifications they could find.

Another factor, however, also distinguishes those companies that contented themselves with a justification based upon draughting performance, either in terms of productivity or rectification cost savings, and those who considered the requirements of both engineering and manufacturing. Two groups can be identified - those who evaluated CAD and CAM separately, and those who evaluated CAD/CAM systems. Into the second category go MG, MC, MO, MB, MN, MK, and MM, and into the first go MH and MI, ME, MF, MA, ML, MJ

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20) Currie's data on firms for this later period does not, however, support this contention, although the two firms she found that did not use a "cost benefit case" did implement during the later period

and MD. The last two had no downstream applications to consider, but what distinguishes the rest of this group is either the lack of an innovation champion, or the identification of the innovation champion strongly with one function. MO, MG, MM, and MK all benefited from a corporate overview, while MN and MB had key directors bridging the two functions. MC benefited from extensive external advice from consultants. It seems as if a business level view is necessary to prevent justifications being based on an island productivity basis.

10.3 THE POLITICS OF IMPLEMENTATION

The review in chapter 6 discussed the extent to which the evaluation of integrating technologies could be seen as a political process of negotiation. The evidence from these cases is that there are three main dyads of negotiation around CAD/CAM - the relationship between the implementors in the implementing departments and senior management; the relationship between engineering and manufacturing; and the relationship between engineering and the IT function. In practice, these are inter-twined, but each has a distinctive dynamic. The many typologies of the dependencies that generate power relations are reviewed by Mintzberg (1983), but the one presented by Handy (1985) of "resource power", "position power", "expert power" and "personal power" can effectively aid the exploration of these three dyads.

The previous section identified the extent of an accounting culture amongst the cases surveyed, but such a culture can be seen more broadly as the expression of the power relationship between implementors and senior staff at the business and corporate level. Senior managers rarely exercise power over their staff nakedly, but more frequently through rules for how things should be done and through the generation of shared goals and commitments in the generation of "simultaneous loose-tight properties" (Peters and Waterman 1983). Armstrong (1988) has explored the tendency to rely on tight controls in terms of the lack of "trust" placed in engineers by senior managers.

In the case of ML, the procedure for the justification of the CADAM system involved the preparation of "Fin Caps". These were prepared by the manager(s) concerned, and then taken over by a finance manager who prepared a quantified assessment on both a DCF and payback basis. The justification then went to group level for approval before being signed off by the Managing Director. Although an extensive unquantified case could also be put forward, the Fin Cap had to be quantitatively viable and pay back within 2 years. Such a case need not always have been productivity based, but where most other benefits such as design integrity and reduced lead times only pay back over the life of a four or five year product development project, they are difficult to deploy effectively within the timescale specified. The financial manager assigned to prepare the detailed Fin Cap was the key to a successful justification -if this manager believed that the case was not viable, it went no further.

There is a strong sense here of the financial manager acting as a gatekeeper to those who could authorise the resources required to make the investment. This was not necessarily a crude imposition of a financial logic, and could include considerable dialogue between the implementor and the financial manager. For instance, in one case, the champion of the CADAM system, when applying to expand the system, was asked for evidence that ML were behind the competition - that there was a *performance gap*. His researches showed that ML were actually ahead of the competition and an argument that this was a competitive advantage that should be sustained was developed and carried successfully. However, the nature of the *resource power* over these champions, transmitted by financial managers exercising *position power* is clear.

This pattern of sophisticated evaluations of CAD/CAM by engineers being squeezed into narrow quantitative rules established by accountants was common amongst the case survey firms. For instance, at MN, productivity gains were not a significant motive for evaluation, yet the actual justification was made on a straightforward productivity basis. However, in some cases the relationship was reversed. At MA, the Board had pressed for CAD to be evaluated for some five years, but the manager concerned had used his *position power* and failed to act. It was not until he was replaced by a manager whose brief explicitly included implementation that evaluation commenced. At MG, the corporate centre developed detailed rules by which CAD/CAM was to be justified.

The resource dependency of implementors on senior management, which is maintained through the rules established by the finance department shapes the implementation process in many ways. However, these issues did not greatly exercise implementors - from discussions with informants, justification was largely seen as frustrating, but part of the accepted way of doing things. In Lukes' (1974) terms it has almost receded to the "third dimension" of power in which the agenda is set in such a way that issues do not emerge as a source of conflict. The other two dyads of negotiation, however, were firmly in the "first dimension" of overt conflict in many of the case survey companies.

The relationship between implementors in engineering, and the IT function within the organisation was often fraught. Typically, the justification procedure included the obligation for the IT function to sign off the justification to ensure that it was technically viable. The problems mainly revolved around policies of hardware platform standardisation developed at either the business or corporate level. These policies were often developed for data processing requirements and did not take into account the different requirements of engineering and manufacturing IT applications. The differences are symbolised by the frequent preference by data processing functions for IBM and compatible hardware, while engineering and manufacturing typically prefer DEC's VAX hardware.

At ME, an AD 2000 system on DEC hardware was installed an built up to five screens by 1979 for 2D draughting and 3D layout work on flight controls. On this experience, a decision was made to investigate a substantial CAD investment and a CAD Steering Committee of senior managers was set up to oversee the activities of a Working Group consisting of middle ranking specialist managers. The Working Group proposed the development of the AD 2000 system on a decentralised network of VAX minicomputers. This did not find favour with the Steering Committee which then commissioned an international firm of external consultants. The report recommended the implementation of CADAM on a centralised IBM system for 2D work, leaving the existing system for 3D work only. The issue was that the business systems were already on an IBM mainframe which is was hoped to expand, and CADAM was already in widespread use within the aerospace industry. By 1985, the AD 2000 system had, in the opinion of one informant, been "squeezed" out by the IBM lobby.

In 1985, the Detail Manufacturing Complex - effectively an FMS - was implemented with the aim of improving the efficiency of sheet metal working. It was controlled by a VAX, and DEC recommended ANVIL 4000, a development of AD 2000, for part programming. There was "a lot of opposition" to this suggestion, but manufacturing won the day for two reasons. Firstly, the CADAM part programming capability was easily demonstrated to be inadequate compared to ANVIL. The social shaping of CADAM as a tool for increasing drawing office productivity in the aerospace industry had led to the inclusion of some "quick and dirty algorithms" which meant that the integrity of the drawing geometry was adequate for draughting, but questionable for more demanding part programming purposes. It proved to be quicker to recreate the geometry than check the drawing office's output. Secondly, the greater computer literacy of manufacturing compared to engineering allowed them to mount a more effective case against the demands of the IT function to stay with IBM.

Similar tensions arose at MB, where the IT function advocated ICL hardware in the interests of compatibility with the business and CAPM systems. Engineering advocated DEC hardware supporting Unigraphics. Again, consultants were deployed, but this time on the side of engineering. Informants from engineering were keen to emphasise that the system was engineering's and completely within their control. At MK, the decision to switch to CATIA met with considerable opposition from the corporate level, where a Computervision[21] policy was in operation. Six months of "continual battle" during which head office made attempts to undermine the evaluation on the grounds of "subjectivity" were necessary before the authorisation was

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[21] By then owned by Prime.

received. The result is that head office is now reviewing its own policies. At MD resistance to the corporate policy of standardising on Medusa during the re-evaluation was only possible because they already had the Radan system. At ML, the champion of the CADAM system left the company to work for IBM when the policy of standardisation on Computervision was implemented.

The main issue here would appear to be that of *expert power*. IT functions, whether at corporate or business level, see themselves as the guardians of hardware and software expertise, and use this to develop strong positions within the organisation. When this is challenged by users who are acting on different criteria for evaluation, conflicts arise. The issue of hardware and software compatibility is fundamental as systems become more integrated. Many organisations are addressing the problem of how to balance the needs of user departments for specialist applications and the needs of the business for integrated systems in an attempt to mitigate this power struggle in ways which will be explored in section 12.2.

The third dyad is symptomatic of a more general problem in many metalworking organisations - the sometimes tense relationship between engineering and manufacturing. This tension usually has its roots in the financial control system - rarely are engineering and manufacturing in the same cost centre, and in many cases they are in separate profit centres. At ML, for instance, where Product Engineering is a cost centre, and, therefore, effectively an overhead on the manufacturing profit centres, conflicts were reported to be endemic. These conflicts affect evaluation because many of the benefits of CAD/CAM are effectively a cost to engineering which reap greater benefits to manufacturing. The ability to receive data by electronic transfer direct from the product data base is of enormous labour saving benefit to part programmers and tool designers, yet may not offer any productivity returns to engineering. Engineering, however, bears most of the cost of implementing the system.

At MI, engineering and manufacturing are independent cost centres in a context where the corporate culture is one of the radical decentralisation of decision making. As a result the business were described as being run by the "barons" of the various functions. Although the evaluation task force included both functions, the Engineering Director made it clear that, on a scale of one to ten with manufacturing positioned at one and engineering at ten, if the benefits to engineering fell below eight, then the justification was not likely to gain approval. In other cases, such as MH and MF, the result of these tensions was that manufacturing was completely ignored in the evaluation process.

The problem here appears to be one of a battle for ascendency between peers. Their resource dependency is mutually based upon senior management who have, wittingly or not, set up organisational resource allocation and control procedures which put the two at loggerheads. These struggles were noticeably worse in the *engineering led* companies with their ethos of "engineering excellence". Although the metaphor of "the wall" between engineering and manufacturing is current in many firms, the influence of Gorbachov has been much stronger in the *manufacturing led* companies. In the *production led* companies, the nations have long been unified. This struggle permeates many of the problems with installation and consolidation that will be discussed in the following two chapters.

10.5 SUMMARY

The evidence here is evaluation is an iterative process of negotiation within the organisation, and that broadly based task forces to ensure effective coalition building, implementation champions to drive the process through, and top level support to smooth conflicts and provide resources are necessary but not sufficient conditions for effective implementation. It also appears that *engineering led* companies find it most difficult to achieve these conditions, while *production led* companies find it easiest. The point is perhaps most clearly made by the cases of MH and MI which are the furthest from technical success of all. Although their task force was broadly based, neither had identifiable implementation champions or top level support. However, evaluation is only the start of the process, and once the decision to adopt has been taken, maintaining momentum requires effective project management.

11

ACHIEVING TECHNICAL SUCCESS

The previous chapter showed the way in which the process of the evaluation of AMT is a political process which sets the terms under which *installation and commissioning*, and *consolidation* will take place, and the criteria of technical and business success by which those stages of the implementation process will be judged. This chapter will, firstly, examine the ways in which the case companies have installed and commissioned their CAD/CAM systems, building upon the organisational mechanisms used for evaluation. It will then go on to look at the organisational changes which are immediately consequent upon the installation in terms of the management of the system. This will then be related to broader issues regarding the successful management of information technology in manufacturing organisations.

11.1 THE INSTALLATION PROCESS

To manage the installation process, most companies tended to rely on the members of the *task force* who had done the initial groundwork in evaluation. In three cases - MC, MF, and MG, this group was upgraded to a full time *project team.* A further four companies also appointed a specialist project manager - MO, MG, MB, and MK. In MH and MI, no specialist group or persons was given responsibility for installation, and it fell to functional managers who also had other responsibilities. There was also a tendency for the scope of the installation group to widen. At MG the installation project team included representatives from manufacturing where the evaluation task force had not done so. Initially MG's installation team included representatives from each of the three main disciplines from both the drawing office and design engineering. It was the first ever multi-disciplinary team within the company. When it was felt appropriate, the lofting function was also included, but not the mainstream manufacturing people. At MB, on the other hand, the installation team narrowed in scope after data processing dropped out because the evaluation had not opted for the ICL hardware which provides a platform for the manufacturing and business systems. The organisation of the installation process is summarised in table 11.1.

On the engineering side, achieving technical success with CAD has been relatively smooth. The physical installation of the hardware did not pose any significant problems, and few failed to produce reliable drawings fairly quickly. The main exception to this is the pipework package at MH and MI. Here a number of problems were experienced. First, it took six months to change the CADDS 3 package from AUSI to BSI specifications, and then it still did not produce useable drawings. CADDS4X is an improvement, in that it can create a three dimensional model and detect clashes, but it still cannot be used to effectively produce isometric drawings. The system's output has to be edited, which takes a lot of time, and the relationship between the computer model and its representation in the drawing is then lost. The expansion of the system at MI in 1986 also ran into problems when Computervision's new workstation based version of CADDS4X proved to be bugged. As one informant put it, the company "suffered long and hard" while CV debugged the system.

The story at the CAM end is less happy. Many CAM installations, based on alpha-numeric software, took place earlier than CAD. This, coupled with problems of achieving technical success across the CAD/CAM interface, and failures to involve manufacturing in the evaluation or installation processes created a number of serious and long lasting problems.

Software for the programming of NC and CNC machine tools was widely available by the mid seventies. Running on batch processing mini-computers without a graphical interface, such systems were usually slow and laborious. However, a number of users built up considerable expertise with such systems, and some production engineers were reluctant to lose that expertise and switch to the unknown quantity of interactive graphical CAM systems which were often bugged and underdeveloped. As can be seen from table 10.1, a number of users, including companies which otherwise rate highly on the scale of technical integration, are still using older, alpha-numeric systems alongside the more modern interactive graphics.

At MC, GNC had only just been installed at the time of fieldwork; it had relied on APT 4000 for many years which had been considerably developed in-house in association with the consultants who had helped it with the CAD evaluation during the late seventies. In 1975, MH commissioned the writing of TUDRIP from Kongsberg for programming NC controlled multiple drills; the system was also used for programming a CNC flame cutter. In 1984, GNC was installed for the programming of the growing number of CNC machine tools and the flame cutters. However, TUDRIP was retained for the drills, and has been developed to the point that it now provides virtually automatic programming, plus internal quality checks. However, the vendors are no longer prepared to support it, and the future is in some doubt.

Manufacturing Operations at MG had long been using Compact II when the CV system was installed. There was considerable resistance to the use of Computervision's NC Vision from the production engineers. This was partly due to the cost and other implications of replacing a considerable existing investment in post processors, but also due to the part programmers' lack of confidence in the ability of the CV software to produce reliable part programs. According to one informant, the dispute became quite bitter as the part programmers tried to convince the proponents of CV of the inadequacy of its CAM software. When it became available, CVNC was also evaluated and pronounced inadequate. An attempt was then made write an interface with Compact II, but the nature of the CADDS4X 3D model undermined this approach.

Programs for the machining of cam rings are automatically part programmed using an in-house development of APT at MM. While this software is accessed through the CV systems' Instaviews, it runs on the corporate main frame, which also performs the post processing for NC Vision. This arrangement is presently under review, as it had been provided free to the user companies until

1989. At MN and MK, is has been found easier to program NC lathes - a relatively simple task compared to machine tools for prismatic parts - using non-graphical programs. At MN, this is the result of a policy decision that CAD/CAM is about prismatic parts, while at MK, according to one informant, NC Vision never really got to grips with turning.

The decision to continue to use what might be considered outmoded CAM systems alongside more modern techniques, then, can be traced to a number of factors. Firstly, a considerable amount of money and expertise has been invested in them, particularly the post processors, and in two cases, virtually automatic programming has been achieved for some tasks - the greater flexibility of the general purpose computers which support such systems has facilitated the writing of such programs. Secondly, the technical limitations of many of the earlier interactive graphic CAM packages discouraged implementation. Thirdly, the relatively simple task of programming lathes and drills - they are both 2D problems - has meant that the limitations of not having interactive graphics has been significantly reduced. However, as might be expected, there are also organisational issues which will be addressed later in this section.

The companies using alpha-numeric part programming do so alongside interactive graphics systems for activities which might be considered to lie a little outside the mainstream of the production information flow, or for specialised applications. However, as table 10.1 illustrates, five cases have installed technically incompatible CAD and CAM systems for their mainstream activities. These are then either interfaced using IGES or direct translators, or, effectively, not interfaced at all. The case of MK is relatively simple. It has recently implemented CATIA for CAD work, but, because of the lag of around 18 months between the completion of design and the start of production, the production engineers are still working on designs produced on the CADDS4X system. The new CAM system will be installed as part of a later phase of implementation.

In the other cases, however, the incompatibility represents longer term implementation problems -

the problems at ME were discussed in section 10.3. The manufacturing plant at MF has a full CADDS4X installation, but it is not used for part programming. As the re-equipment of the factory took place during the mid eighties a number of CNC machine tools were installed for production work in group technology cells. However, it became apparent that Computervision's offer was not appropriate. In particular, it quoted a high price for post processors and a 6 month delivery. MF turned to MDSI who offered post-processors at one twentieth of the price, and on a 2 day delivery. Therefore, a Texas microcomputer running MDSI software was installed in 1985. A graphics interface was then written as part of a Teaching Company scheme with a local College.

The problems with production part programming at MG have already been described. Relations with the toolroom - also part of Manufacturing Operations - have been only a little better. It uses CADDS4X for tool design, but the EDM wire erosion machines used for tool manufacture come with Hewlett Packard part programming facilities, and the interface between the two is through a particularly tortuous IGES link using a main frame which is owned by a completely separate business division of the corporation which shares the site. A direct interface using an microcomputer is presently under development. MO have a similar problem - although tool design is carried out on the Medusa system, the AGIE wire erosion machine is again programmed using a Hewlett Packard system; data transfer is by manual drawing "walked over" to the toolroom.

MH was only established as a single, independent unit during fieldwork. Prior to this, the factory and the design office were separate divisions within the same company. This relative independence was reinforced by the distance between the two - a three hour journey including one hour by air. The factory had gone its own way without any reference to CAD developments across the water. The installation of a CV terminal in the factory has been evaluated, but this in no way solved the main problem of the transmission of design data between the two systems, a problem that is presently handled by the Post Office. Only after fieldwork had finished was an experimental transfer of design data made to a new multi-spindle drill. This is not programmed using TUDRIP or GNC, but by software developed by the local University.

Even where engineering and manufacturing possess compatible systems, problems still arise in achieving technical success in the CAD/CAM link. MK had achieved a CAD/CAM link with a trial part by 1981 which was taken right through to machining with a domestically written post-processor. However, in 1982, it upgraded to CADDS4, which proved to be so bugged that the CAD/CAM link became completely inoperable. It was not until the upgrade to CADDS4X in 1984 that the problems were completely resolved. By 1989, some 95% of prismatic work was machined on NC machine tools and programmed using NC Vision. Evaluation and development work with Computervision on CVNC has been halted by the decision to replace the system with CATIA.

At MI, there has never been anything more than an experimental link between CADDS4X and CVNC. While the satellite factory has had NC Vision since 1982, it was not until 1985 that CVNC was installed at the main site. It proved, in the words of one informant, "almost too hostile to drive". By 1989, the output of part programs from the production engineers was so inadequate that work was being subcontracted out. The poor user-friendliness of CVNC has taken the blame for this state of affairs, although one informant suggested that organisational issues which will be identified below were at the root of the problem. As a stop-gap, a PC based system - Supercam - was being justified the time of fieldwork. In January 1990, a major Teaching Company scheme with a local University started with the brief to examine the whole issue of the engineering/manufacturing interface for the manufacture of a major component.

At MB, there is a strong intention to implement a full link to CAM, but this had not occurred at the time of fieldwork. The problem is purely organisational. As a company who had implemented only the year before fieldwork began, it was still learning how to use the system. It had run into a classical "Catch 22" of needing the system to cope with a high workload, but not having the slack resource to take time out from immediate concerns to learn how to use the system. The installation of the system coincided with the installation of a large number of CNC machine tools, and the choice was between manually writing the part programs to get those running, or learning how to use the CAM capabilities. The major productivity gains from accessing the design data base were not yet available because engineering were only creating that data base for new product initiatives, not the ones presently being manufactured.

In section 9.3, the implementation of the *unit* organisation of manufacturing was identified in the one-off materials flow cases. This development, it appears, can pose a threat to the maintenance of a CAD/CAM link. At MI, the implementation of the Unit structure at the satellite factory has meant that tool design is now done manually. In the central production engineering department, the 6 terminals were allocated as required to tool design and part programming. Now, three of the Units have been given 2 terminals each, but this has meant the fragmentation of the spare capacity that was used for tool design, and the present system is not capable of supporting any more terminals. The problems at the main factory have already been described above, and one informant put the disruptions down to bad management of the Unit re-organisation and a loss of morale amongst production engineers, with the CVNC system merely acting as a scapegoat. At ME and MG, no such problems have arisen, but neither has been conspicuously successful in the past in achieving a CAD/CAM link, and it is unlikely that the loss of a central capability will help in this respect. The *unit* form of organisation seems to make it more difficult to develop a common policy across the engineering/manufacturing interface.

The five companies that have achieved technical success on the criterion defined in section 10.1 have a number of features in common. Firstly, the original evaluation covered both engineering and manufacturing benefits of both a cost and non-cost kind; secondly, CAD and CAM were evaluated jointly, rather than as separate systems; thirdly, the evaluation task force included representatives from manufacturing; and fourthly, two of them had implementation champions promoting the evaluation at a level above the individual engineering and manufacturing functions. If the corporate involvement at MM is included, this count rises to three. The only other case to meet these four criteria is MB, whose problems, as described above, are very much learning curve ones.

Two other companies have achieved partial links for surface modelling applications only. At MG, most of the above criteria were met, apart from the rather crucial one of including manufacturing in the evaluation team. The result of this was that it only considered the downstream benefits for the Mould Shop, which is part of Shipbuilding Operations, where the plates are cut for the hull. The programs for the CNC flame cutters are directly derived from the 3D model by the lofters, who were included in the installation team. However, the interests of Manufacturing Operations were apparently ignored, and this appears to be behind the resistance put up to CV based part programming.

At ME, the achievement of a surface modelling link for the design and machining of mould tools appears to be much more of an informal affair, and to have received little senior management support. The organisation of the system management function, which will be discussed in section 12.2, appears to have been a help. The replacement of aluminium fabrications by fibreglass mouldings opened up the opportunity for a CAD/CAM link. The surface of the component is defined mathematically as a series of discrete sections. A complete surface is then "skinned" across the sections using a domestic development of SYSTRID known as WESTRID. This 3D model is than loaded into CADAM for the design of internal components by the design team, and the planar elements of mould tools by the tool room. Both the component surface in WESTRID and the planar tool elements in CADAM are then merged into ANVIL for the design of the complete tool as a combination of planar and surfaced elements. The rough cut part program for the 3 axis miller is then written in ANVIL, while the final cut is again written in WESTRID.

The situation at MF is, perhaps, a classical example of what happens when a group is not included in an organisational change. Manufacturing engineering was, apparently, not even consulted on the choice of system, and all manufacturing based informants displayed a distinct lack of enthusiasm for it. The sentiment is that with a cheaper, simpler system, they could have done much more. The system had, effectively, been left behind when the engineering function was centralised at the main site leaving only a rump in the shape of Residential Engineering to give technical support to the factory. The problems of "ownership" of the system were made more difficult initially because the system was actually managed by the Residential Engineering function. One indication of the lack of support for the system is that the CAD System Administrator has the lowest status of any of the system managers amongst these cases, and has no independent budget or authority. The result is that the system is little used for jig and tool design, and, as described above, not at all for part programming. The most successful applications have been plant layout and annotating drawings for invitations to tender to component suppliers.

Although manufacturing were involved in the initial evaluation at MI, the lack of an implementation champion at a senior level appears to have seriously hampered progress. Indeed, some informants hinted that the then Engineering Director was downright obstructive to a broadly based justification, as discussed in section 10.3. This attitude seems to be rooted in the corporate culture of a radical decentralisation of decision making to cost centres which the case shares with MH and MC. The problems of implementation at MH have already been indicated, at it seems likely that the ten year delay before MC actually installed a linked CAD/CAM system despite an early awareness of the benefits is linked to this culture.

11.2 MANAGING THE IMPLEMENTATION PROJECT

The project management styles for each implementation are identified in table 11.1, which refers to the most recent major implemention, and draws upon the scheme developed in section 5.3. The classification draws mainly on the answers to questions in section E of the research instrument, but also relies upon a more general sense of how informants articulated the issues around implementation management. The pattern is notable for the rarity of *participative* approaches, those companies which appear to have relied upon a *model 0* approach, and the bare majority who can be considered to have had a *technocratic* approach.

MA and MD faced a low *information load*. MD was re-implementing a package with which it had

TABLE 11.1
THE ORGANISATION OF INSTALLATION

COMPANY	PROJECT ORG	MANUF INC	DP INC	PROJECT MANAGER	PM STYLE
MA	-	-	-	-	0
MB	TF	*	-	*	T
MC	PT	*	*	*	T
MD	-	-	-	-	0
ME	TF	*	*	*	T
MF	PT	-	-	*	0
MG	PT	*	-	*	T
MH	-	-	-	-	0
MI	-	-	-	-	0
MJ	PT	*	*	*	T
MK	TF	-	*	*	P
ML	PT	*	*	*	T
MM	TF	*	-	-	T
MN	TF	*	*	*	T
MO	TF	*	*	*	T

notes: TF = task force   T = technocratic
PM = project team   P = participative

previously been happy on a total of three workstations, and had no CAD/CAM linkages to worry about. Similarly, MA were implementing simple, well-established system for architectural engineering design consisting of two workstations. Relatively little organisational learning was required in each case. The same cannot be said for the other three companies with *model 0* implementations. At MF, installation was a "real drive in job; [its] amazing we got away with it as we did". Despite this, considerable progress has been made overall with CAD, but the isolation of the division within which the research was concerned from the mainstream has meant that this somewhat unco-ordinated approach has led to considerable problems of integration. Yet again, MH and MI appear as examples of less than effective implementation with ensuing poor performance.

Virtually all the cases handled the problems of *information load* and *resource scarcity* by moving slowly. A typical initial installation was four or less terminals, applied to the easiest problems. The learning and skills gained from that installation were then deployed in justifications for further equipment as system use reached capacity - if the system was fully used for productive work, then an application for further funds was made. The story at MC is typical of many. An evaluation in 1980 had identified the value of CAD/CAM, but the *resource scarcity* ensuing from the recession in the early eighties led to plans being shelved. However, another site which already had a CADDS 3 system was merged with the case site in 1982 - that system was acquired and second purchased. By 1986, the system had developed to eight terminals served by two central processors. A re-evaluation at that time led to a change to Medusa, and five Sun 2 workstations were installed in June 1986. These proved to be rather slow, and were replaced by Sun 3 workstations the following February. By September 1988, 21 workstations were operational, and a further 12 were installed in March 1989. Additionally, the system began to spread into manufacturing - two workstations were located in Production Engineering for development work, and three in Operations Planning for part programming. The CV system was gradually run down and by 1989 was only used for some automated draughting routines. The "Catch 22" of *resource scarcity* at MB where manufacturing is caught between needing the system to meet its high workload, but not having the slack resource to learn how to use the system precisely because of that workload, was discussed in the previous section

The effects of *size* were noticeable at ME and ML. Both took major policy decisions to implement large scale CAD/CAM systems after initial experiences on a smaller scale. At ME, the decision to make an initial investment of £5m (1980 prices) encouraged caution. The decision to choose IBM which was already established for business systems and CADAM, the standard amongst their competitors in the aerospace industry, went against the organisational learning on the trial system, which was offered by a small and relatively unknown company. This decision was supported by a report from an internationally reputed firm of specialist consultants. Similarly, when ML took a corporate decision to standardise on Computervision with an investment of £24m over 3 years (1984 prices), it was in the context of the identification of the production information flow for body engineering and press tooling as critical to the company's future competitive advantage. To ensure the technical success of this investment, an intensive relationship with the vendor was established which will be discussed further below.

Size and *speed* combined at MK to make the implemention there the most risky amongst the cases. The decision to replace a technically successful CV system which was being used for the bulk of drawing work with a £2.2m (1989 prices) investment in CATIA to allow further technical and organisational integration has meant the adoption of the only example amongst the cases of a *participative* approach. The implementation is in the context of a major overhaul of the business process. As part of this, a task force has been examining the production information flows within and between the engineering and manufacturing departments, and has recommended changes to these to take advantage of CATIA and new methods of design team working. The implementation project management can be considered *participative* because it is in the context of a much wider process of organisational development which requires considerable organisational learning as part of a move towards CIM.

The *inner context* in terms of whether the mission is *engineering*, *manufacturing*, or *production led* appeared to make little difference to the preferred form of project management organisation. However, the difficulties at MI and MH can be clearly placed within the existing inner context of highly segmentalist organisation with little tradition of communication and co-operation between the "barons". Similarly, the inner context at MK of a major organisational development programme clearly encouraged a participative approach to CAD/CAM implementation. On the evidence of these cases, it does appear that participative approaches only emerge where the *information load* is high, and in addition, *size* and *speed* are also significant.

11.3 VENDOR RELATIONS

Generally, relationships with vendors were reported to be good, but did not usually figure highly as part of informants concerns. Where they did, it was around relations with Computervision. At ML, the strategic concern to achieve a CAD/CAM link for the body engineering and press tooling production information flow meant that after 1984, a joint project team was established involving representatives from the vendors, Tool Engineering, Manufacturing Engineering and the corporate IT department to tackle the NC programming capability - in particular the taking of surface definitions from the product data base and using them to program 5-axis millers. After some five years, the system is technically successful with around 10% of press tooling being prepared in this way. The balance is cut by 3-axis millers or copy-milled from NC cut models - both these routes require hand finishing. MK similarly engaged in collaborative development work with Computervision for the development of the part programming capability. MI are jointly developing 3-D models of a key component with a similar aim in mind - earlier in-house attempts had foundered on the mathematics of the complex shapes involved.

The experience at MH has been less happy. The problems with the CADDS 3 software for pipework which "never worked" have already been discussed, and CADDS4X is still inadequate for MH's type of work. In an attempt to improve relations, a three tier hierarchy of meetings has been agreed with Prime. The "operations" level consists of bi-monthly meetings between Prime engineers and users. the "tactical" level consists of a meeting between representatives at the group level (including MI) and Prime engineers, while the "strategic" level is a twice annual meeting between directors and senior management on both sides. Even so, in the six months prior to fieldwork, relations had deteriorated over the latest software upgrade which was supposed, finally, to solve the pipework problem.

11.4 HUMAN RESOURCE MANAGEMENT

The human resource management issues were reviewed in section 6.3. However, they did not feature strongly in the concerns of most informants. None of the cases which are vehicle or vehicle component manufacturing companies reported industrial relations problems associated with the installation of their CAD/CAM systems. However, four of the other cases did. MH's engineering function is located on the same site as the branch factory of MI, and two other companies in the same corporation making products for the electrical distribution and transport industries. These other two companies installed Calma systems in the late seventies and the drawing office union - TASS - took the opportunity to negotiate the formalisation of the salary structure which had previously been based on individual payments. Although the MI drawing office was formally part of a completely separate company, the effects of coercive comparison across the site meant that when the CADDS system was installed, management were obliged to accept the same salary structure.

A similar process occurred at MG. Another yard in the corporation had earlier installed CADAM, and agreed a "going rate" for the acceptance of CAD of 5%, plus another 2% for competence on the system. In addition, a 20% premium was paid for moving to double day shift working. The management at MG were obliged to accept this agreement, but the real problem arose when the union proposed 1100 staff for training when there were only 24 terminals. The issue was resolved by doubling the number of terminals installed and negotiating the reduction of the number to be trained to 300 in the first year and 200 in the second. The tracers, who were effectively made redundant by the system, were trained up as drawing staff. These problems delayed the achievement of full technical success until 1986, nearly two years after the initial installation.

A similar delay occurred at MK. Although the system was delivered in 1980, what one informant described as a "stand off" with the unions took place for about a year, and technical success was not achieved until a new technology agreement had been negotiated with the unions. The settlement included a no redundancy clause; a review of health and safety issues; training for all staff; and a £400 lump sum to be paid on completion of training. Shift working was not an issue.

At ME, however, it was the main issue. During a major downsizing of the company in the mid eighties, some years after the system had first been installed, an attempt was made to move to a double day shift attracting a 25% premium. Although many of the staff were prepared to accept these new conditions, the matter was, in the opinion of one informant, badly handled. Management tried to force staff to work the new system, and threatened recalcitrants with dismissal. The ensuing rift with TASS led to a month long strike. Management were obliged to concede the issue, and afterwards, "heads rolled", including that of the Engineering Director.

Stark (1988 chap 10) has suggested that training for CAD/CAM implementation should take five forms - awareness training; basic user training; advanced user training; user section manager training; and CAD/CAM manager training. No company reported a formal programme of awareness training, although the task forces which carried out the initial evaluations can be considered as the main way in which the organisation makes itself aware of the potential of the technology. However, such expertise remained impacted with the task force and others involved in evaluation decision making, and rarely diffused out to the rest of the organisation.

Basic user training almost always took the form of a week-long course to cover the principles of 2D draughting. Initially, such courses were held by the vendor, but in most cases, the CAD/CAM management function slowly took responsibility for this. More advanced courses may take up to a month, and usually cover 3D modelling. Most informants emphasised the vital role of practice on live projects for developing competence with the system - formal training can only give a technical overview of how the system works. Such practice was supported in various ways by internal user groups as well as more informal advice from the system managers and more experienced users as required.

MB made extensive use of open learning techniques prior to the installation of the system, in addition to conventional basic user training. EITB videos were adapted to the company's requirements, and given to the engineers to take home, together with a workbook. DTI videos were also used. One informant considered that this gave a 12 month lead time advantage in implementation, and stated that "the secret of CAD introduction is training. Open learning is magic because you can do it all before you invest in equipment. Open learning is wonderfully cost effective". This enthusiasm may not be unconnected with the fact that the Manufacturing Director is also the Chair of a company that distributes open learning materials.

The issues of industrial relations and training have not loomed large as part of the CAD/CAM implementation process. None of the implementation task forces included personnel specialists. Where there have been industrial relations problems they have, like those in the car industry (Turner et alia 1967 chap 3), been associated with pay, conditions and job security, rather than the implemention of new technology itself. Training programmes appeared to be minimalist and reactive, and, like White and Ghobadian (1984), little evidence was found of payment systems being changed in response to the implementation of new technologies.

11.5 SUMMARY

The *installation and consolidation* process was managed in much the same way as the *evaluation* process, although the task force was sometimes strengthened. Most of the problems in achieving *technical success* derived from the failure to evaluate CAD and CAM jointly, and the lack of an *implementation champion* who could push the project through. *Technocratic* approaches to the management of the implementation project were overwhelmingly favoured, which limited the rate of organisational learning associated with implementation. As a result, progress in all companies was slow, a problem that was compounded by *resource scarcities*.

Few companies paid significant attention to human resource management questions - only MK with its *participative* approach could be said to have systematically thought through such issues. However, this lack of attention to human resource management issues in implementation may be a mistake. As Adler concluded from a review of the implementation of new technologies, "in the overwhelming majority of cases, it was the human resource issues that were the stumbling block in implementing new technologies" (1988 p 48).

12

ACHIEVING BUSINESS SUCCESS

12.0 INTRODUCTION

The implementation model developed in chapter 5 stressed the distinction between *technical success* and *business success* as outcomes from the CAD/CAM implementation project. While a number of companies could be clearly identified as having achieved technical success, the situation with business success is a lot less clear. The next two chapters will explore the question of the extent to which organisational changes complement the technical changes have been made, and attempt to explore the extent to which business success has been achieved. This chapter will discuss the final stage of the implementation process in some detail, and discuss one of the organisational changes most immediately associated with implementation - the system management section. It will then review the lessons for effective management of implementation projects that can be drawn from the experiences of these 15 cases. Chapter 13 will explore the more general issue of differentiation and integration in metalworking production first raised in chapter 4.

12.1 THE CONSOLIDATION PROCESS

The outcome of the installation phase is defined as *technical success*, and the varied extent to which the case study companies achieved technical success was discussed in the last section. The outcome from the consolidation phase is defined as *business success*. Providing a reliable measure of this criterion proved impossible, as most companies did not measure the performance of the system on any sort of regular basis. Two companies - MJ and ML - did conduct audits aided by the vendors, but the results from these were privy to the Board alone. This section will discuss the ways in which the rest of the companies have attempted to measure the performance of the system, and the extent to which identifiable business benefits have been achieved.

Typically, the CAD/CAM system was run as a cost centre under a manager whose main objective was to stay within budget while meeting the requirements of users. The most frequently used measure of system performance, found in nine cases, is system uptime. In another case this measure had been dropped because of the reliability of the later generation of systems. Five of the companies claimed to measure labour productivity, but only one, MN was able to present a comprehensive set of productivity savings over manual systems. A 3:1 gain in mechanical drawing; 4:1 in electrical drawing; and 12:1 in part programming for prismatic parts were reported. One-off contract drawings are still prepared by hand as it is slower to use the system.

These figures confirm the impressionistic evidence from the other cases that the main productivity gains came in producing system designs such as electrical drawings which are inherently two dimensional problems where the relationship, rather than the distance, between points is the critical factor, and in part programming where the ability to access the product data base in integrated CAD/CAM systems, and the much greater ease of proving programs brings benefits. In the case of mechanical drawing, which is the main activity of all the case companies, it is not at all clear that the costs of purchasing and running the system do not outweigh the savings from productivity gains, unless repetitive work is required. Certainly, an appraisal at MH carried out in 1983 came to this conclusion. Where 3D modelling is used, drawing office productivity can even fall compared to manual drawing, and what productivity benefits there may be accrue in using the model for finite element analysis or part programming.

Nine of the companies claimed to measure design to manufacture lead time, but the difficulties of clear assessment were acknowledged. Most were vague as to how they were doing this, and aside from taking individual projects and imputing a manual time to them, seemed to be getting little hard data. Again, MN were the only ones to confidently offer a figure of a halving of drawing production time. MM still uses a productivity measure, while realising that this is not the key issue, but has not yet found an alternative. The criterion emphasised at present is "success in executing my work". It is perhaps notable that the only two companies that claimed to use more than five measures out of a list of 10 in the research instrument (see Q.F4) were MA and MB - the recent implementors. The suspicion is that they had not yet acquired the confidence in the system to drop the rhetoric of a hard-nosed appraisal of their investment.

Another problem with making an hard measure in terms of cost savings is that the parameters are continually shifting. MK found that the productivity of part programmers using the system steadily dropped, measured by the number of programs produced by each engineer. This was because the new generation of CNC machining centres on the shop floor were much more powerful tools than earlier generations, and so each program was more complex. Similarly, the availability of more sophisticated engineering analysis software to the design team means that more analytic work is done which takes longer, but can improve product quality and performance.

A number of companies reported unforeseen benefits from their CAD/CAM implementation. Most were fairly marginal, such as the ability to do plant layouts for the manufacturing system engineers. However, the one remaining independent company - MB - reported the importance of the system in creating the perception of a dynamic engineering company amongst City analysts. The system is deliberately "shown off" to visiting analysts who apparently believe that unless a metalworking firm has a CAD/CAM system, something is wrong. In a similar spirit, the President of Unimation stated that "I don't think a guy will be able to go to his country club if he doesn't have a CAD/CAM system....He's got to be able to talk about his CAD/CAM system as he tees off on the third tee - or he will be embarrassed" (cited Noble 1986 p 330).

The overall picture emerging is that little attempt has been made to measure quantitatively whether the implementation of CAD/CAM systems has yielded business benefits - the most frequently used measure, system uptime, is more a measure of technical than business success. The other main measures - productivity and design to manufacture lead time were only half-heartedly used. This was not because they were considered unimportant, but simply because of the uncertainties and ambiguities of measurement. There has, however, been a shift over the last ten years amongst these companies, and productivity is now seen as a less important criterion of business success than measures such as customer response times and product integrity. CAD/CAM systems, on their own cannot deliver such benefits - they can only facilitate broader organisational changes aimed at such goals. Indeed, it is probably these changes in the approach to assessing the performance of CAD/CAM systems that has led to the shift in evaluation criteria noted in section 10.2.

The appraisal of the performance of CAD/CAM systems tends to be bound up in the performance of the departments that use it - the system forms part of the budget of those departments. Usually, these are cost centres, but as noted earlier, in three companies, engineering and manufacturing are established as separate profit centres, and engineering purchases manufacturing services in an internal market transaction. However, these management accounting arrangements can be a major handicap to the achievement of business success, particularly as the power dyad between engineering and manufacturing identified in section 10.3 comes into play.

The problem lies in the fact that for manufacturing to gain the full benefits of CAM, engineering need, in many cases, to do more work than they might otherwise do, and therefore to incur additional cost. This is most notable in the case of the 3D models that manufacturing require for programming the machining of complex prismatic parts. At MK, a 4:1 productivity gain over using APT was achieved in part programming once engineering moved to full 3D modelling; however, this benefit to manufacturing represented a cost to engineering. At other companies, engineering have been less willing to accommodate manufacturing.

At MI, despite work by a CAD/CAM Steering Group over a number of years from 1983 to reduce feature variety and to standardise items such as corner radii and tooling, one informant argued that "engineering design for efficiency without much consistency"[22]. At MG, the drawing office was

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[22] "Efficiency" is here defined as the energy performance of the product in service

again accused of inconsistency, and not fully modelling items such as corner radii, tending, rather, to draw the corner square and annotate it. This raised the question of who owns the drawing geometry - if the drawing office draw the radii their costs go up; if the part programmers draw them, they are interfering with the drawing. An experimental CAD/CAM link at MH in 1989 to the new multi-spindle drill was considered unlikely to go ahead on a routine basis because it involved the drawing office in additional work preparing the plate drawings so that the part programmers could use them directly. It is perhaps notable that all these companies score low on the technical integration scale, and, as will be seen in the next chapter, also have poor organisational integration.

Manufacturing, too, share a responsibility in acting unilaterally to minimise costs at the departmental level while increasing them at the business level. At MG manufacturing were accused of scheduling components that had been designed on CAD onto conventional machine tools. At MM, a major reduction in the level of investment in CNC machine tools for production meant that many of the expected downstream benefits were lost, and the policy of preparing all drawings on the CAD system was considered rather pointless by engineering. This issue came to a head at MK in 1985 when the drawings for a particular contract were partly prepared on the CAD system and partly manually. Manufacturing then subcontracted out the manufacture of most of the parts that had been modelled in 3D, while the manually drawn parts were manufactured in-house. However, the response of the Chief Engineer was positive - the only way out of the dilemma was for all drawings to be prepared on the system, and he authorised a major expansion.

While the issues regarding the apportionment of costs between engineering and manufacturing can be resolved by changing the criteria for cost centre performance and valuing co-operative behaviour which saves money at the business level, the problem of manufacturing planning is more intractable. A product development project is like a wave rolling through the company which washes through engineering long before it breaks on the shores of manufacturing. In many of the companies with long product development lead times or product life cycles much of the design work for existing production was carried out before the CAD/CAM systems were fully implemented. Thus at MG and MJ, the present product development programme is the first which can fully exploit the CAD/CAM link with an "all CAD" boat or car, and in both cases, the product is some years from being in production. At ME, the present production aircraft were designed before CAD was fully implemented, and the latest aircraft has not yet been productionised. Even in the companies with shorter product lead times, MK quoted 18 months as the typical period between the design and manufacture of a component, while at MH this is two years. Under such circumstances it is difficult for manufacturing to predict how they are going to make a particular component. The key issue is whether the reaction is that of MK - to prepare all drawings on CAD - or to see it as yet another reason why full technical integration is not worth pursuing.

12.2 MANAGING THE CAD/CAM SYSTEM

One of the earliest decisions that is usually made in the consolidation phase is the way in which the new system is to be managed. Earl (1989 chap 7) provides an extensive discussion of the management of IT systems in general, and the role of IT Directors. He identifies two main issues that need to be resolved - the level of centralisation of the system, and the balance of influence between system users and IT specialists in system development. The evidence from this case survey suggests a third issue - the relationship between the management of production IT systems such as CAD/CAM to the management of MIS elsewhere in the business. All the case companies except MD, which has one of the smallest systems amongst the cases, set up a system management section soon after installation. However, there is a considerable variation between the cases in how this section is organised. This range of organisation is summarised in table 12.1, together with the presence at the business level of an IT Director independent of the Finance Director.

At three of the cases - MJ, MF and MH - the CAD and CAM systems are managed separately by dedicated *CAD Managers* and *CAM Managers* who report within the engineering or manufacturing departments as appropriate. The explanation for this is simple - these are the three cases where engineering and manufacturing are located on completely separate sites. Other than this, the three have little in common. Until the re-organisation during fieldwork, MH came under the auspices of MI's systems directorate which is discussed below, yet has no data link between its two systems. MF's systems communicate through a HASP link which was installed in 1987, and no technical problems were reported during operation. However, it was clear from the informants that while MF is actively developing a co-ordinated CAD policy at the corporate level between its three main design offices, this activity does not include the branch manufacturing site studied for this case.

MJ has a much greater level of co-ordination. Life is somewhat easier in this case because both the Engineering Centre and the main manufacturing plants are in the same city, as opposed to different countries of the Union in the case of the other two. Product Engineering Technical Services and Manufacturing Technical Services provide CAD and CAM support respectively, and closely liaise with each other. There is a weekly meeting chaired by the Technical System Development Manager who reports within the finance department. It is this section which manages the hardware and the product data base, and the system is one of the more integrated amongst the cases. Thus, of itself, separate CAD and CAM management does not hamper development of close integration of the system, so long as effective organisational integration structures are in place. However, geographical remoteness does appear to hamper co-ordination - while distance can easily be overcome technically, organisational co-ordination is more difficult due to the time and costs incurred in travel.

The second, and most common, way of managing the system is to establish a *CAD/CAM*[23] *Manager* who manages both parts of the system. Usually reporting to the engineering director, the CAD/CAM Manager also supplies a technical service to manufacturing. MP, MB, MC, and MM all have this arrangement. Within its limited brief, this sort of arrangement often works well.

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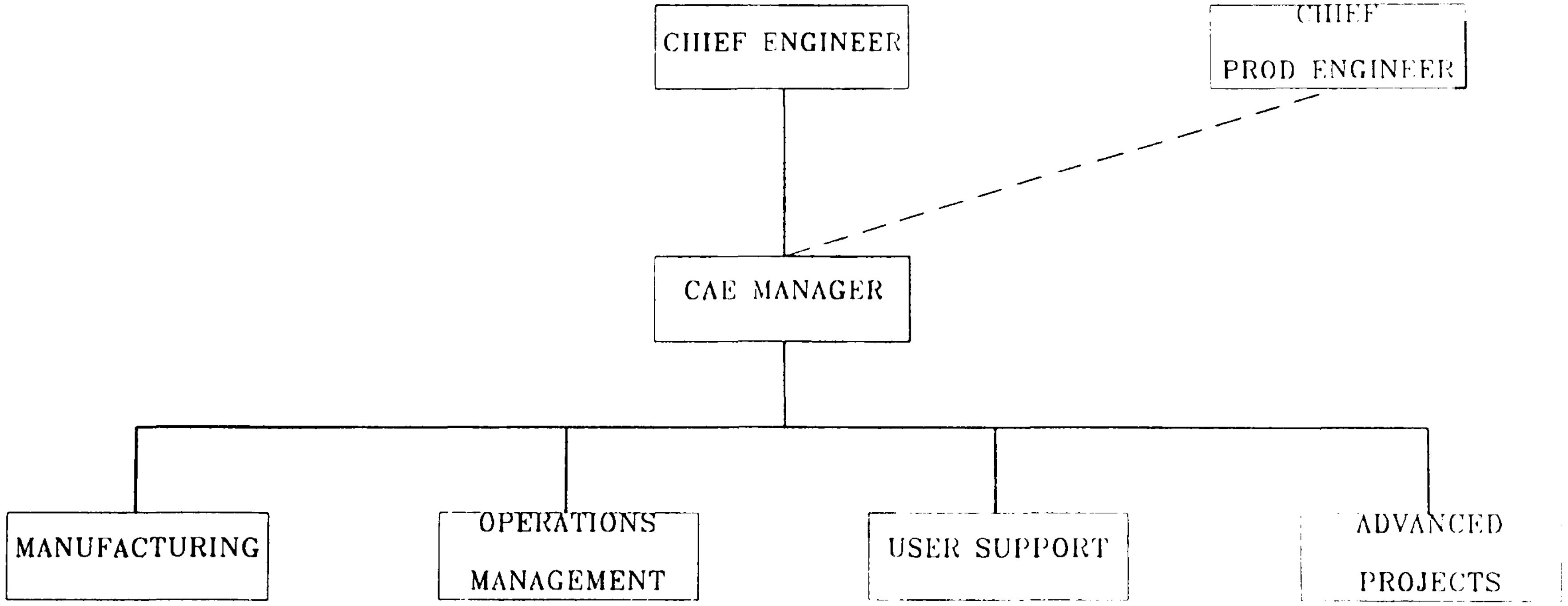
23) In most cases, this person is described as a CAE Manager. However, in line with the definition of CAE in section 2.3, the term CAD/CAM manager is preferred here



MK CIM MANAGEMENT

Figure 12.1

However, such managers are usually distinct from the managers for both the CAE system used for engineering analysis, and the CAPM systems used for manufacturing planning and control. For instance, at MC, the manager of the Medusa system reports to the Engineering Director, but the software systems for engineering analysis are mounted a GEC minicomputer under the auspices of the Product Development Director, while the manufacturing systems and the alpha-numeric part programming and process planning are on Data General and GEC minicomputers respectively under the auspices of the Computer Department, which reports to the Finance Director. Thus the four different computer systems used at each stage of the production information flow are managed by three separate sections, and boundary problems do surface. In particular, the implementation of GNC for part programming linked to the Medusa system, and sharing the same Sun workstations is leading to conflict between Engineering and the Computer Department over who is to be responsible.

The third type of arrangement found was that of what might be called the *CIM Manager*, where responsibility for the majority of the systems that are used along the production information flow are under a single manager. MK and MN both fall into this category. At the former, separate support functions for CAD and CAM reported to the Chief Engineer and Chief Production Engineer respectively until 1988. In the autumn of that year, the present CAE Manager was appointed with an overall system brief; while he reports to the Chief Engineer, he has a strong "dotted line" relationship to the Operations Manager. A team of 12 now reports to him covering manufacturing systems such as DNC, as well as CAD/CAM and CAE. This is illustrated in figure 12.1. The existing COPICS (IBM CAPM) system is managed by the finance department, but the CAE Manager is responsible for the interface between it and the CAD/CAM system. This is being developed through two IBM packages - Product Engineering Support, which is a relational database for engineering product information, and Distributed Communication System which carries the manufacturing data.

At MN, the CAE Engineering Development Manager has had a number of different jobs since he

TABLE 12.1
THE ORGANISATION OF SYSTEM MANGAGMENT

COMPANY CODE	SYSTEM MANAGER	IT DIRECTOR
MA	CAD	-
MB	CAD/CAM	-
MC	CAD/CAM	-
MD	-	-
ME	DP	-
MF	CAD	-
MG	SYSTDIR	*
MH	CAD	-
MI	SYSTDIR	-
MJ	CAD	-
MK	CIM	-
ML	SYSTDIR	*
MM	CAD/CAM	-
MN	CIM	-
MO	CAD	-

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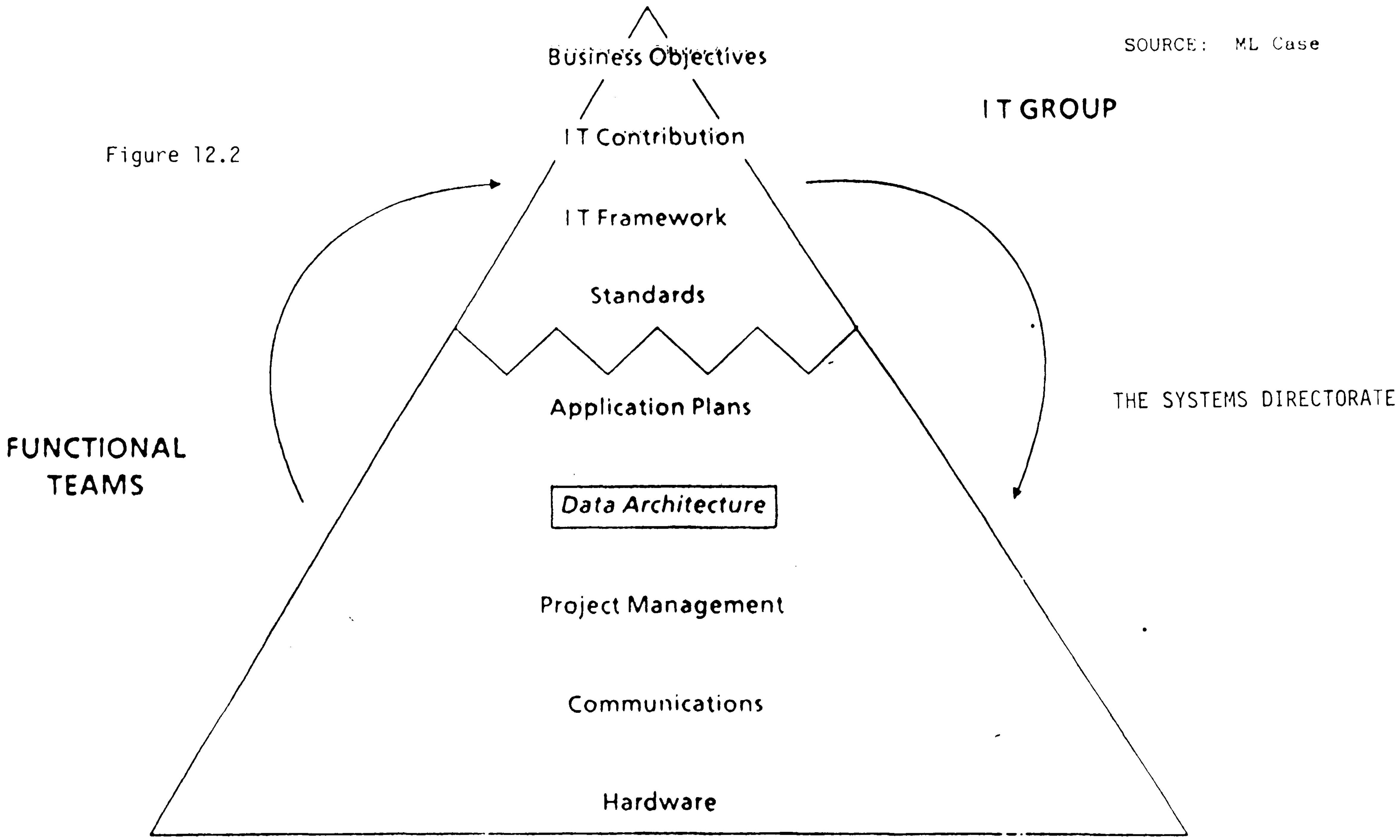
was appointed CAE Manager in 1977, when the system was first installed, including System Manager responsible for both business and production systems. He presently reports to the Technical Director and has a team of 6 focused on networking and installing workstations, as well as all computer hardware. There is now a data processing manager responsible for business applications reporting to the Managing Director, who chairs a monthly Business and Manufacturing Control System Development Group covering all IT in the company.

The management of the CAD/CAM systems in these companies, then, has tended to follow the

Figure 12.2



SOURCE: ML Case

evolution described by Stark (1988, chap 3), but they all adopt what Earl identifies as the "decentralised" approach to IT management. Initially, the manager has a relatively junior status - he may have been an early user, or have project managed the installation of the system. As the system, and hence the budget allocated to its running, grows then the status of the manager responsible grows too. The earlier manager either grows with the job, or is replaced, but he still does not act as a champion of the system. As the awareness of interfaces with other production systems grows, then systems expertise on the part of the manager becomes increasingly important, but without a loss of understanding of the production process - the type of "hybrid manager" identified by Campbell and Warner (1987) starts to emerge. This manager begins to develop a strategic role covering both the further development of production systems, and the interface with the company's business systems. As Simmonds and Senker (1988) have suggested, the new breed of CAD/CAM management requires the skills of engineering, computing and strategic management.

ME has adopted a completely different strategy from the other case companies by retaining responsibility for the management and development of the system within the *Data Processing* section, which reports to the Management Services Manager - an example of what Earl identifies as the "centralised" approach. This manager's responsibilities cover the entire range of computing, both within the case company and the other companies in the corporation. He has long represented a very powerful voice, championing the merits of IBM systems - sometimes against the wishes of the users in engineering and manufacturing. Seven specialist computing groups report to him - CAD, CAM, ELECTRICAD, and Engineering Computation (CAE) amongst them. An overall CAD/CAM Manager took early retirement in 1986, and has not been replaced. This centralisation has not encouraged the development of integrated systems for two reasons. Firstly, there is no champion for production systems as a whole, and secondly, there is a lack of commitment to CAD by engineering because they do not have responsibility for it - the Design Office Manager who is in charge of the system within engineering merely provides a space for the terminals.

Three of the cases have what might be called a *Systems Directorate* which takes responsibility for the overall development of production systems - akin to Earl's "federal" arrangement. At MI management of the CAD system, and the CAM systems at the main site and branch site are located within their respective departments. However, co-ordination is provided by a Computer Systems Development section which reports to the Production Director. This section also covered MH until the re-organisation. However, although it includes two applications programmers, the role of the section is limited to liaison and advice. While it must sign off all justifications for new systems, its role is one of support to initiatives elsewhere, and to interdepartmental committees concerned with issues such as a common data directory. A Company Development Working Party meets quarterly to develop system policy, but cannot impose its policies on the operating departments - the source of system initiatives is clearly located with the departmental managers. A result of this is that some managers flout the policy - for instance the VAX only policy was broken by the Project Management Department, and another part of the company bought CADAM instead of CADDS.

The Business Process Development Group at MG developed, eventually, out of the initial CAD/CAM project team. The team went on to examine the potential for other IT systems, and was soon merged with the Computer Systems Department, who managed the new system, under the CAD/CAM project team manager. This arrangement lasted for two years, but it became apparent that IT systems were not being diffused through the organisation. In the opinion of one informant, this was for two reasons. Firstly, the level of awareness of the potential of systems was low, and, secondly, there was a general suspicion of the role of the Computer Systems Department.

It was, therefore, decided to devolve responsibility for IT systems to the users, and CAD was the first candidate for this treatment. CAD and CAM for lofting was, therefore, placed under the responsibility of Engineering Programmes, while Manufacturing Operations retained their own CAM management and the data processing department was placed under the wing of the Information Technology Director. The original manager became the BPDG Manager reporting directly to the Managing Director. He runs it as a project team evaluating new systems, co-ordinating initiatives, and raising the level of perception of IT within the company. The Group operates by setting up interdepartmental project teams to look at particular issues of systems integration. Membership is usually by secondment on a full-time basis, and each team has a project manager who reports to a project sponsor. The sponsor is usually a director particularly interested in the area in which the project team is working. At the completion of the project, it is the responsibility of line management to implement the proposals.

An example of their work is the CIMS Group which investigated resource planning throughout the company. For instance, it made a full analysis of the data flow in the stores and mapped its requirements. It recommended the implementation of an MRP system which would interface with the CV system. The project started in late 1987, and the proposal went to the Board in February 1989. However, it was deemed too late to implement it for the present product lines, and the new product has not yet received build authorisation from the Ministry.

ML have developed a sophisticated relationship between system managers reporting to user department heads, and the overall co-ordination of systems within the company by the IT Director, who reports to the Strategic Planning Director. During the seventies and early eighties, a centralised corporate IT department evolved into an independent profit centre, and was launched as a separate company in 1987 through a management buy-out. At the same time, IT sections evolved within the operating departments on an informal basis. The reporting relationships were confused, and there was little co-ordination between departmental IT sections. The inability of such an arrangement to grasp the strategic implications of IT led to the implementation in 1989 of the organisation illustrated in figure 12.2. Now, a small IT strategy group under a Director of IT reports to the Strategic Planning Director, and is responsible for a framework for IT systems complementary to business objectives which is then implemented by the departmentally based IT sections.

At the present state of the art, the *CIM Manager* approach does appear to work well in the smaller company, perhaps supported by a high level IT committee. If that person has systems as well as production expertise, he or she can champion further developments, and act as an overall co-ordinator, particularly of interfaces with the company's business systems. However in the larger companies, this is inadequate. ML is the largest single company amongst the cases, and after ML, MG and ME have the largest single sites. MH and MI in combination with another site was also of a similar size before the re-organisation. Here, a *Systems Directorate* approach is more useful. Centralising system management, as ME and MG have found out, leads to implementation problems in the user functions. On the other hand, the *Systems Directorate* needs enough authority to keep wayward users in line, or the result is the proliferation of systems and lack of technical integration found at MH and MI. If the directorate there reported to the Managing Director, rather than the Production Director, its authority would probably be greater, for its present remit runs only informally over engineering. It is perhaps notable that, as table 12.1 shows, the more successful *Systems Directorates* operate in the context of an IT Director championing IT across the business.

However, in all these cases, the broader issue of strategic co-ordination of the production systems and business systems remains unaddressed, with the possible exceptions of MN and MK. In some cases, most notably at MB, there is a strong sense of CAD/CAM being an engineering system, and a keeping of data processing, usually under the authority of the Finance Director, at arms length. From the production point of view, the issues start to come to a head as the CAD/CAM systems begin to interface with CAPM systems to form CIM systems. Although used by manufacturing, CAPM systems as heavy data processing applications have usually been managed by computer sections, which, in turn, usually report within the finance department. Only MK is at this point now, but the technology is now becoming available, and organisational constraints as to who is responsible for what parts of the system are likely to emerge. Unless mechanisms for overall co-ordination are in place, progress towards full CIM systems is likely to be slow, and the integration of CIM with business systems to form Computer Integrated Businesses a dream.

12.3 EFFECTIVE IMPLEMENTATION MANAGEMENT

The lessons for the effective management of CAD/CAM implementation that can be drawn from the experience of these 15 cases can be most easily identified by comparing the experiences of those five companies which were identified in section 10.1 as having achieved technical success with the two that are furthest from that goal - MH and MI. In the latter case, there is no technical integration despite the fact that the CAD and CAM systems are fully compatible, while MH shows little prospect of moving towards any sort of electronic data transfer on a routine basis.

Inspection of table 10.2 shows that where MH and MI stand out most at the *evaluation* stage is the absence of an *implementation champion*. MI did most of the right things early on, but failed to follow through and ensure that someone was responsible for managing the overall implementation process. Moving on to *installation and commissioning*, table 11.1 shows that the absence of any form of specialist project organisation for implementation is again notable at both the poorly performing companies. Inevitably, both companies had *Model 0* implementation project organisations, while all the top performing companies had at least *technocratic* project organisations.

However, there are other companies which are not yet technically successful which had well organised implementation project organisations - notably MC and ME. What distinguishes the technically successful companies is the organisational context within which implementation has occurred. As the next chapter will demonstrate the five technically successful companies all have relatively high levels of organisational integration, and all have, as table 8.2 shows, *iterative* coupling commitments. Most of the other companies have relatively low levels of organisational integration, and no particular coupling commitment. MI stood out in the discussions in section 10.3 as an example of conflict between engineering and manufacturing, while MH faces the additional problem of the most serious geographical separation of engineering and manufacturing amongst all the cases. Both are resolutely *sequential* in their coupling commitments. A project team is an overlay on an existing organisation - no matter how well managed in itself, it cannot solve problems which are generated by the underlying organisational structure and processes.

12.4 SUMMARY

The last three chapters have analysed the management of implementation in the 15 case survey companies. It is clear that a well managed implementation project organisation is broadly based to include the three most interested departments, which are engineering, manufacturing and information technology; is driven by an implementation champion who is backed by top management; and facilitates single loop learning through technocratic project organisation. However, it is also apparent that these are necessary rather than sufficient conditions for achieving even technical success, never mind business success. Those companies which also paid significant attention to developing what Kanter (1985) calls "integrative" rather than "segmentalist" organisational structures and processes were the ones that achieved technical success and are starting to reap significant, if often unmeasurable business success. It is to the development of integrative organisation that the next chapter is addressed.

13

CO-ORDINATING THE ENGINEERING/MANUFACTURING INTERFACE

13.0 INTRODUCTION

The last five chapters have presented the main findings from the case studies, and indicated the ways in which they can be analysed using the conceptual framework for the implementation of Advanced Manufacturing Technologies outlined in chapters 3, 4 and 5. This chapter will focus on a particularly important aspect of organisation design in metalworking production - the interface between engineering and manufacturing. The integrating nature of CAD/CAM technology means that it is implemented across this interface, and some of the immediate issues it poses were discussed in section 4.3. However, the effectiveness of co-ordination across the engineering/manufacturing interface is also an issue for many other sources of competitive advantage - as Porter (1985 chap 2) points out, it is the linkages within the "value chain" which are critical. The improvement of product development performance through the implementation of total quality management, simultaneous engineering, and value engineering all require more effective co-ordination of this interface. The requisite level of integration in metalworking production is increasing, and CAD/CAM plays a crucial role as an "enabling technology" for greater integration across this interface.

The chapter will develop this theme of the co-ordination of the engineering/manufacturing interface at two levels. Firstly, it will look at the organisational processes by which the production information flow is co-ordinated between the draughting and planning stages identified in figure 3.1. Secondly, it will look at the organisational linkage structures by which these processes are facilitated. The factors by which transactions within the production information flow between the

FIGURE 13.1

ENGINEERING/MANUFACTURING COORDINATION PROCEDURES

COMMUNICATION PATTERN	**PHASE**		
	PRE-PROJECT	PROJECT	POST-PROJECT
SEQUENTIAL	Designers' tacit knowledge of manufacturing	Early manufacturing start with early design data	Manufacturing flexibility
RECIPROCAL	Design rules	Design reviews	Engineering change order
ITERATIVE	Functional strategy coordination	Joint design teams	Post-project appraisals

Source: adapted from Adler (1988)

draughting and planning stages vary were identified in the Production Model shown in figure 3.3 as *direction, intensity,* and *coupling*. Thompson's model of interdependence - or coupling - between departments was presented in section 4.4, followed by Adler's development of it into a full typology of organisational process. That section went onto discuss the typology of organisational linkage structures offered by Galbraith. The first two sections of the chapter will present developments of these two typologies, and then report the extent to the structures and processes identified were found in use amongst the 15 cases. The chapter will finish with a discussion of the relationship between technical and organisational integration in terms of the structuration of the engineering/manufacturing interface and conclude with a discussion of the conditions for business success.

13.1 THE PROCESS OF INTEGRATION

A revised version of the Adler typology is shown in figure 13.1; it simply replaces the terminology used by Adler to describe transaction governance by that developed in section 4.4. "Pooled interdependence" is not relevant to relationship between engineering and manufacturing - at the very least, the relationship must be a sequential one for a product to be designed and manufactured at all. The procedures are to be read as complementary, rather than as alternatives in the context of a given organisation, particularly horizontally on the temporal dimension. Informants were asked to identify the three most frequently used in their company (Q D8) - the replies from the most senior informant are presented in table 13.1.

Examples of all these procedures were found within the case study companies with the exception of *early manufacturing start with early design data* (EMS), although MJ had been experimenting with such an approach on a very limited number of components for the latest product initiative which involved letting pre-production components go through on relaxed tolerances. Only one company, ML, used *post project appraisals* (PPA), and then only for a product initiative by a division which has only recently been fully integrated into the main part of the company. The absence of *post project appraisals* was confirmed at the feed-back session to project participants who, when asked the question directly, replied that their companies did not evaluate project performance after completion, and the informant at ML explicitly noted their absence in the main part of the company. The reluctance to use them could well be related to the political repercussions of allowing what might be considered a failure to be recognised by senior management.

The traditional co-ordination procedure within the engineering industry is *designers' tacit knowledge of production* (TK). It usually operates in concert with some form of *manufacturing* *flexibility* (MF), even where this is not explicitly recognised as a co-ordination procedure. It is notable that two of the three companies which did explicitly recognise manufacturing flexibility - MH and MI - are the two cases which are probably the least integrated organisations amongst all the cases. Generally, those companies which relied upon this pairing of sequential procedures were the *engineering led* ones, and they tended to complement these basic procedures with *design reviews* or *engineering change orders*. The *task* of engineering in these companies is, in the words of one informant from MI, "to define the finished product". The exception here is MB which has

TABLE 13.1
CO-ORDINATION PROCESSES

COMPANY	TK	EMS	MF	DR1	DRv	EC	PPA	JDT	FSC
MA	*	-	-	-	-	-	-	-	-
MB	*	-	-	-	-	*	-	-	*
MC	*	-	-	-	*	*	-	-	-
MD	*	-	-	*	-	-	-	-	-
ME	-	-	-	-	*	*	-	*	-
MF	*	-	-	-	*	*	-	-	-
MG	*	-	*	-	*	-	-	-	-
MH	*	-	*	-	-	*	-	-	-
MI	*	-	*	-	-	*	-	-	-
MJ	*	-	-	-	*	-	-	*	-
MK	-	-	-	-	*	*	-	*	-
ML	-	-	-	-	-	-	*	*	*
MM	-	-	-	*	-	*	-	*	-
MN	-	-	-	-	-	*	-	*	*
MO	-	-	*	-	-	*	-	*	-

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institutionalised tacit knowledge in that all its design engineers have served trade apprenticeships in their factory. The procedure started to break down as new machining technologies began to be introduced during the eighties - particularly CNC machining centres - and training sessions were introduced for the engineers in new manufacturing techniques.

Although there was a lot of discussion about *design rules* (DRl), for the most part, their development has not gone past very detailed work on items such as corner radii. The two component manufacturing companies which identified it as important were referring to variant design procedures rather than new product development. The main exception to this is the implementation of a new tool management system at ME and MK. The tool library of "preferred tools", which is a heavily rationalised version of the previous range of tools, can be accessed by the CAD system, and design engineers are expected to design components that can be made with the tools in the library.

The role of *design reviews* (DRv) in the *engineering led* companies tends to be strongly influenced by the *outer context* of the industry as articulated through the customer's requirements. In particular, defence contractors such as MG and ME, are committed to extensive design reviews as part of their quality assurance procedures. These may well be attended by the customer's representatives, and form part of the mutual interaction with the customer inherent in the *concept to order* production strategy. Such reviews do not always involve manufacturing.

The *manufacturing led* companies are placing increasing emphasis upon *design reviews* as an engineering/manufacturing co-ordination procedure. MF, for instance, has implemented a hierarchy of reviews. Three years ago, according to one informant, drawings were "lobbed over the brick wall". First, a "methods review" was established at which the detailed design is presented to the manufacturing engineers. This is held just prior to the point where the design is frozen and will thereafter be subject to engineering change order procedures. Next, a "process review" was implemented at which the manufacturing engineers present to the design engineers how they plan to make the product, which is held after the design is frozen. Most recently, a "concept review" has been implemented at which the conceptual design is presented to senior manufacturing management, and issues such as materials, quality, and manufacturing engineering are discussed. The implementation of these review procedures has been facilitated by the separation of the manufacturing engineering function for new products from that for existing products under the *manufacturing planning* type of organisation which was discussed in section 9.3.

Virtually all companies use some form of *engineering change order* (ECO) procedure for altering the design to allow manufacturing to make it more easily, or to respond to late changes from the customer. They vary considerably in formality, and are apparently at their most bureaucratic in the aerospace related industries, where the *outer context* in the shape of the *regulatory system* demands particular procedures. In the aerospace components company, MK, the costs of going through the ECO procedure were a major driving force in pushing the company towards in-project co-ordination procedures, particularly joint design teams. Two of the three companies - MA and MD - which do not have such procedures both rely on the customer for most of the design work, while MG appears to rely the traditional manufacturing flexibility of the shipbuilding process instead of using ECO procedures.

Joint design teams (JDT) are most popular in the manufacturing and jointly led companies. MJ, MO, and ML have been increasingly deploying such teams for their new product development programmes. MK have the declared aim of moving to joint design teams, and had just started implementation at the time of fieldwork. At MM, the Business Development Organisations are joint teams from the engineering, manufacturing and commercial departments which focus exclusively on new product initiatives. MN has been working with *joint design teams* for more than 10 years, and has now got to the stage that the design and development of its latest product was project managed by a manufacturing engineer. However, recently, it has moved away from the formal inclusion of the production engineers in the design team because, increasingly, the production engineers are becoming highly specialised due to the increasing complexity of production technology, and so a single engineer can no longer cover all production processes. Reliance is placed increasingly on informal links in the context of a company culture which has valued a manufacturing input to design over a number of years.

Functional strategy co-ordination (FSC) is in place in three companies - ML, MN and MB. In the case of the latter two, this takes the form of manufacturing representation at Director level on the Product Planning Committee, or Product Development Group. Both companies are thereafter fairly relaxed about their co-ordination procedures, and rely heavily on informal co-ordination, rather than supporting functional strategy co-ordination with a battery of other procedures. One inference from this might be that once there is true engineering/manufacturing strategy co-ordination, then the rest follows as part of the company culture. At ML, the agency of *functional strategy co-ordination* is the Vehicle Directorate which was identified as a form of *programme management* in section 9.1. Here, teams representing the manufacturing, engineering and commercial departments decide on the overall conception of the new product, and project manage the *development route* information flow through to "job 1" and then on through the product life cycle. This Directorate is responsible for making applications to the Board for the release of funds at various stages of the programme, and for ensuring that the product initiative meets the requirements of the overall business strategy.

The use of iterative co-ordination processes tends to be more favoured by the *manufacturing led* companies - amongst the *engineering led* ones, ME used *joint design teams*, but only for the specialist application of mould tool design. MK is the only *engineering led* company to extensively deploy such processes, and for the reasons suggested in section 8.7, is approaching a *production led* mission. With the exception of MD, all the highly profitable companies identified in section 8.1 deploy at least one iterative co-ordination procedure, and, with the exception of MB with its deliberate development of *tacit knowledge*, tend to shun sequential co-ordination procedures.

13.2 THE STRUCTURE OF INTEGRATION

Galbraith's typology of organisational integration linkages was discussed in section 4.4. Examples of all the linkages that he identifies were found amongst the cases; however, other mechanisms which are sufficiently distinctive to warrant separate identification were also found. A proposal for a revised version of Galbraith's hierarchy is presented in figure 13.2. The ordering principle of the hierarchy is complexity - the higher up the hierarchy, the simpler and easier the linkage is to operate. The more complex the linkage, the greater the probable cost to the organisation in

TABLE 13.2
THE HIERARCHY OF INTEGRATION

COMPANY	DC	SD	LR	TF	PT	RC	CL	PM	MO
MA	-	-	-	-	-	-	-	-	-
MB	*	-	*	-	-	-	-	-	-
MC	-	-	-	*	-	-	-	-	-
MD	-	-	-	-	-	-	*	-	-
ME	-	-	-	*	*	-	*	*	-
MF	-	-	*	-	-	-	-	-	-
MG	*	*	-	-	*	-	-	*	-
MH	-	-	*	-	-	-	-	*	-
MI	-	-	-	*	-	-	-	-	-
MJ	*	*	*	*	*	-	*	-	-
MK	*	-	-	*	*	-	-	*	*
ML	-	*	-	-	*	-	*	*	-
MM	-	*	-	*	*	-	*	-	-
MN	*	*	-	-	*	-	-	-	*
MO	*	-	-	-	*	*	-	-	-

terms of increased overheads. For this reason, what Hrebiniak and Joyce call the "principle of minimum intervention" (1984 chap 1) applies. In this context, this means that if adequate co-ordination can be achieved through mechanisms higher up down the hierarchy, then they should be favoured. The extent to which these mechanisms are used by the cases is summarised in table 13.2.

Direct contact (DC) is the simplest, quickest and easiest form of engineering/manufacturing liaison, and such informal links are more or less common in all the organisations studied. Factors such as the existing company culture, and the "ecology" (Handy 1985 chap 5) of the organisation in terms of its physical layout appear to be the most important factors in facilitating this structure. Companies were only identified as using *direct contact* if they had made a positive move towards facilitating it such as placing manufacturing engineers and design engineers in physical proximity. The importance of physical proximity is demonstrated by the low levels of integration achieved by the two companies - MF and MH - with remote split sites. Four companies - MB, MJ, MK, and MG - have tried to increase the amount of informal contact by physically seating manufacturing engineers in the same areas as design engineers. Clearly, continuity of personnel within the organisation is also likely to be a factor here as longer served employees build up personal networks, and human resource management policies of moving personnel between functions during their careers with the company as at MB are also important. The development of IT system processes such as electronic mail and teleconferencing can also be a major support for this structure.

Secondment (SD) is a well established co-ordination structure, and can be used as part of a career development programme to embed the sort of culture which facilitates *direct contact*. Secondment can be used as a co-ordination structure on its own, while it also forms the basis of many other structures such as cells and project teams. It is used most systematically in the *manufacturing led* companies, particularly vehicles, where a representative from manufacturing engineering may be seconded for a year or two to the product development team in engineering. The intention is that

THE HIERARCHY OF INTEGRATION

DIRECT CONTACT

SECONDMENT

LIAISON ROLES

TASK FORCES

PROJECT TEAMS

JOB DESIGN ROLE CONVERGENCE

ORGANISATION DESIGN CELLS

PROGRAMME MANAGEMENT

MATRIX ORGANISATION

FIGURE 13.2

secondees then move back to manufacturing as the new product is being productionised. MG and MN have experimented with longer term secondments of production engineers to engineering, but found that secondees tend to loose touch with the latest developments in manufacturing processes on the shop floor.

Liaison roles (LR) of two types were found. The first type is those that come in pairs where the manufacturing person has an identified opposite number in engineering. For example, at MB, a Standards Technician in engineering, and a Material Standards Engineer in manufacturing liaise closely, particularly over such matters as the types of steel specified and the choice between castings and forgings. The second type is where a particular group within one function also reports to another function. Thus, at MB, the production engineers report primarily to the Manufacturing Engineering Manager, but they also report across to the Works Managers. In the two companies where engineering and manufacturing are on distant separate sites, an outpost, called Residential Engineering at MF, of engineering is located on the manufacturing site to deal with routine issues such as ECOs and concessions.

Task forces (TF) are a widely used technique for solving particular finite problems. They can be distinguished from committees in the sense that they are usually responsible for the implementation of policies rather than policy formation. Companies normally use them on a casual basis as required; for instance, in most cases, as shown in table 10.2, the evaluation of the CAD/CAM system was carried out by a joint engineering/manufacturing task force. Some companies are starting to develop more formal strategies to facilitate task forces. For instance, Quality Panels are increasingly used in ME operating under the guidance of a committee of senior managers. These are popular amongst middle managers because a presentation to the Board is made at he end of the Panel's work. Where necessary, such as in the latest review of the CAD/CAM system, these task forces cross the engineering/manufacturing interface.

Project teams (PT) can be distinguished from task forces by their full-time, and, usually, longer term nature. The most obvious example of this is the product development team. Most of the engineering functions in the organisations studied, except MH and MI, have moved towards product orientated design teams, often within a matrix structure for the organisation of engineering as discussed in section 9.2. Examples of project teams which crossed the engineering/manufacturing interface are less common, and certainly still considered something of an experiment. ME has utilised a Manufacturing Systems Engineering project team to review the process of modifications to existing products in service in response to customer demands. MG has set up a separate section to promote project team initiatives - the Business Process Development Group - which facilitates a variety of initiatives across the company and reports direct to the Managing Director.

Although more strictly related to dedifferentiation rather than integration as discussed in section 4.1, *role convergence* (RC) can be included here for convenience. Within engineering there appears to be a general move towards *role convergence* between engineers and drawing staff on design work. The old division of labour between the design office and the drawing office is breaking down, and only MH, MI, and MG retain drawing offices completely differentiated from the design section. However, at another level, differentiation is being reinforced by the proliferation of specialist conceptual, or advanced engineering, design groups working on particular development problems and deploying very sophisticated technical expertise. Within manufacturing, a number of companies are trying to converge the manufacturing engineering roles - tool designer, NC programmer, and process planner. MD has taken the opportunity of the departure of the Production Engineering Manager to merge planning and tool design with the aim of training the younger planners up as tool designers. MI has just reached an agreement with the trade union, MSF, for flexibility within the production engineering function. However, only at ME is role convergence across the engineering/manufacturing interface between detail drawing staff and production engineering staff even mooted, and even here it is just a possibility at present.

Effective implementation of all the above lateral linkage structures was found across the full range of cases studied. They have in common the fact that they only require changes in job design for their implementation. This is fairly obvious in the case of the first three and role convergence, but even in the case of project teams, a functional person is seconded to the project team, and expects to return to a clear functional home at the end of the project. Indeed, the essence of project management is co-ordination across established departmental structures. It is because they do not require structural change of the overall organisation that the structures already discussed tend to be easier to implement, to be fairly widespread, and to be developed pragmatically. Where problems were experienced, such as with secondment at MJ and role convergence at MM, it was in combination with their deployment in cells

In order to support these changes in job design, and to improve engineering/manufacturing co-ordination procedures even further, some of companies have implemented changes in organisation design as well. Thus, it is suggested that hierarchy of integration makes a qualitative change at this point. While the earlier linkage structures can be overlaid upon the existing organisation structure, the ones now under discussion require changes to that structure itself. For this reason, they are less commonly found, and more difficult to implement.

At ME a *cell* (CL) has been established, defined around the technology of surface modelling which was described in section 11.1. This method of working across disciplines was established when the component - a major innovation in materials technology - was introduced at the beginning of the eighties. In 1988, the method of working was formally recognised by the establishment of the WESTRID Group as a cell of four people consisting of NC programmers and design staff sitting together in the design office. While this cell organisation is not yet reflected in changes in reporting relationships, which remain departmental, it has become a major force for the re-evaluation of the whole CAD/CAM system because of the way it works at the interface between CAD and CAM. It is within this group that role convergence across the engineering/manufacturing interface has been mooted.

Other companies have used *cells* in a much more proactive way. The establishment at MJ of New Vehicle Concepts (NVC) in 1985 was described in section 9.2, and is discussed in greater detail by Winch and his colleagues (1991). More recently, MM has established the Business Development Organisations (BDO) described in the previous section as commercially orientated new product development cells[24]. At ML, the New Model Centre operates as a cell consisting of a small planning team reporting to the Operations Director which is responsible for ensuring that all the manufacturing resources are in place for new product initiatives, and the pilot build facility. As product initiatives move through the development life cycle, staff are seconded to it from the relevant operational sections.

The experience of these *cells* has been mixed. NVC at MJ has provoked significant animosity elsewhere in the organisation, and secondees returning to their home sections have been treated like "pariahs" (Winch et alia 1991). The BDOs at MM also have their critics. One informant distinguished clearly between "multi-disciplinary teams" or *cells* of the BDO type, and "multi-functional teams" or *project teams* for product development. The danger with the *cell*, he argued, is that it risks the development of "jacks of all trades" who are amateurs at what they do, while the *project team* brings together experts from different disciplines who come together for a particular project, but do not have to "live together" all the time. The problem at MJ and MM seems to be that the *cell* has been set up as an elite product development section, and stands outside the mainstream of the production information flow. Where the *cell* is part of the normal product development process and integrated into the production information flow, as at ME and ML, fewer problems arise.

The discussion in section 9.1 identified the emergence of *programme management* (PM) in many of the case companies, particularly the ***engineering led*** ones. These are, in essence, the product orientated "integrator functions" described by Galbraith (1970) in his study of Boeing which have responsibilities for co-ordinating both engineering and manufacturing. They usually have a number

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[24] This development is discussed in more detail by Winstanley and Francis (1990)

of project managers of *project teams* reporting to them and may, in turn, report to a *projects division*. Projects divisions are not considered here as integrating structures because they, in many senses, form part of the *outer context* of the organisations studied. They are always separate divisions of the corporation and act as the customer's agent.

The most sophisticated lateral linkage structure in Galbraith's hierarchy is the *matrix organisation (MO)*. However, no instances of a fully developed matrix across the engineering/manufacturing interface were found currently amongst our cases. MN had such an organisation in the early eighties, which was reported in Winch (1983). It moved to a much simpler structure in 1985 because each of the product divisions had become big enough to support their own manufacturing operations, and there was no longer any need to use matrix organisation to gain manufacturing economies of scale. MK is so close to implementing a matrix organisation as part of its organisational development programme that it has been classified as having one in table 13.2. The next stage after moving the manufacturing engineers into physical proximity with the design engineers is seen as including them within the overall matrix organisation of the engineering function, thereby creating a matrix which straddles the engineering/manufacturing interface.

The mechanisms lower down the hierarchy tend to be used to support mechanisms higher up down - in particular, while the job design innovations are viable on their own, they can be significantly reinforced by organisation design changes. For instance, *cells* provide a good opportunity for developing *role convergence. Matrix organisations* provide a fertile ground for deploying *project teams* extensively - particularly, it seems, within the engineering department. *Programme management* can provide authority and support for all sorts of other initiatives such as *task forces* and *project teams*. In practice, organisations deploy multiple lateral linkage structures to achieve a range of specific goals. For instance, at MJ, all of the integration mechanisms except *role convergence, programme management* and *matrix organisation* were found deployed with varying degrees of success (Winch et alia 1991).

Overall, the *manufacturing led* companies deploy an average of 3.6 linkage structures, if the idiosyncratic MA and MD are excluded, while the *engineering led* companies deploy an average of 2.8. The two *production led* companies only manage an average of 3.0, but this is because MB is largely undifferentiated, and so does not need sophisticated integration structures. Those companies that have an iterative element to their co-ordination processes use an average of 4.0 linkage structures, while those that only use reciprocal and sequential processes, again excluding MA and MD, use an average of 2.0 structures. This strongly suggests a process of structuration in the way in which structure supports process. The five highly profitable companies identified in section 8.1, excluding MD, deploy an average of 4.25 integrating structures, while the less profitable ones, excluding MA, deploy an average of 3.0. Overall, it can be argued that the deployment of integration structures tends to be favoured by *manufacturing led* companies and to have a correlation to profitable business performance.

13.3 THE STRUCTURATION OF ORGANISATIONAL INTEGRATION

The dynamic of co-ordination across the engineering/manufacturing interface is a special case of transaction governance within the production information flow. The last two sections have shown the importance of both structure and process in this dynamic. The evidence is that structural integration and processual integration are correlated - those companies which deploy a high number of structural linkages also tend towards iterative processes within their production information flows. The only company where this is not true is MB, but this company, as discussed in section 9.2 is relatively undifferentiated, and does not, therefore, have much of a role for integration structures. Structure and process can, therefore, be considered to be mutually supportive in achieving organisational integration within the production information flow.

The extent to which this correlation reveals a process of structuration can be shown with an historical perspective on the cases. This shows the ways in which structure is used to create process, and process generates structure. The former is clearest at MN, where a matrix organisation evolved over the decade prior to 1985. This provided a context in which *joint design teams* could flourish and *functional strategy co-ordination* could be established. It also provided a welcoming *inner context* for the implementation of the CAD/CAM system (Winch 1983). After 1985, the organisation structure reverted back to a simple functional one with the emphasis upon integrating structures at the job design rather than the organisation design level, whilst retaining the iterative elements of process. Even the deployment of *project teams* across the interface is now less common, but what has been emerging is a business culture where *direct contact* is the norm. This same sort of business culture based on *direct contact* is also actively encouraged at the other *production led* company, MB.

The organisation development initiative at MK provides an example of a company presently implementing a highly integrated organisation structure in the form of a *matrix organisation* in an explicit attempt to generate integrative processes. It remains to be seen whether its evolution over the next five years is a move away from the matrix organisation as integrative processes become part of the organisational culture. The dynamic here is, perhaps, best captured by the sense of loose/tight relations developed by Peters and Waterman (1983 chap 12), but it also shows that their insistence upon a simple form (chap 11) is misleading - a complex form, such as a matrix organisation, may well be a crucial step upon the road to effective loose/tight relations sustained through the business culture which simultaneously deploys highly integrating processes with simple, cheap, and effective integrating structures. At the same time, Kanter's insistence that "to produce innovation, more complexity is essential" (1985 p 148) is also misleading - the relative advantages of simplicity or complexity in organisation structure depend upon the history of the organisation in relation to its *outer context*.

Process can also be seen to be generating structure amongst these cases. The development of the cell around the process of surface definition of mould tools at ME is an example. Here, the overwhelming processual logic of those involved in surface definition working together in *joint design teams* has led to the almost subversive evolution of a *cell* defined around the technology of surface modelling. It took well over five years to be recognised by senior management and is only now, after almost a decade, starting to have an influence elsewhere in the organisation as the benefits of integrating structures start to be appreciated. A similar concern for process around surface definition encouraged the movement of lofting staff into *direct contact* with the drawing office at MG. These two cases indicate the ways in which the evolution of integrating processes generates integrating structures, and, at least in the case of ME, shows how structure is starting to influence process as the lessons of the WESTRID Group start to diffuse out through the rest of the business.

13.4 ORGANISATIONAL AND TECHNICAL INTEGRATION

The earlier sections in this chapter have developed and presented typologies for the structure and process of integration within metalworking companies. While the development of a requisite level of structure is crucial for the effective development of the processes of integration, once the processes are part of the company culture, then simpler linkage structures may be all that are required. So, there is a sense of integrating processes being substitutes for integrating structures, but that a sophisticated integrating structure on its own is not an adequate definition of organisational integration. This can be most clearly seen in the way in which *programme management* can be imposed over an otherwise unintegrated structure. In the end, structure is a means to process, for it is through the production information flow and associated materials flow that the business creates value. Structure is a way of ordering process; integrating structures are a means to the end of integrated processes.

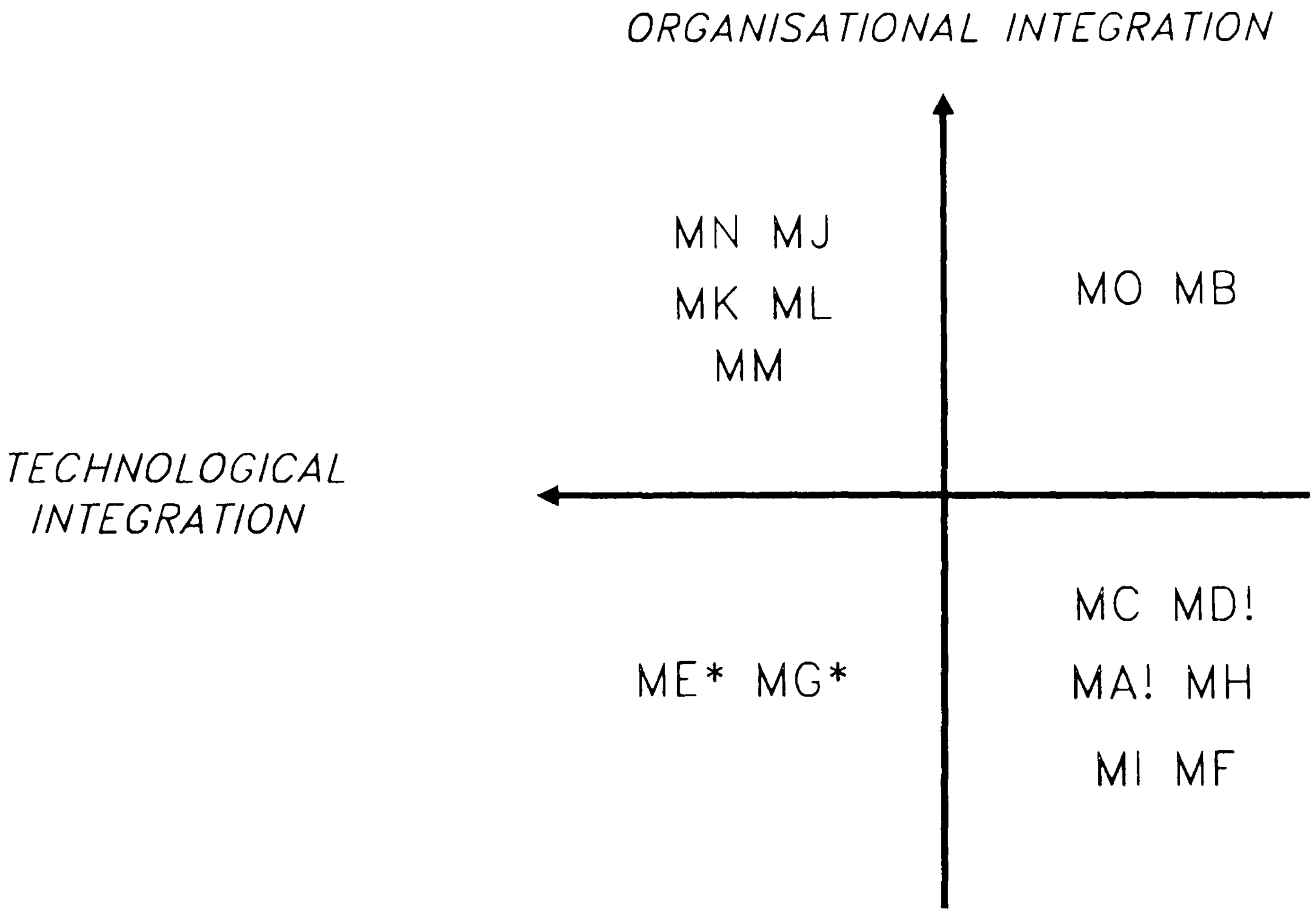
On this basis, inspection of table 13.1 reveals that eight of the cases can be considered to be organisationally integrated in that they have elements of iterative production information flows. However, ME only achieves this for the highly specialist surface modelling application, and remains relatively unintegrated for most of the production information flow. It can, therefore, be eliminated from his group of organisationally integrated companies. The results of this classification are displayed on the organisational integration dimension of figure 13.3.

The criteria for the assessment of technical integration were described in section 10.1. The results are displayed on the technical integration dimension of figure 13.3. The top left hand corner can be considered the high performance zone of high organisational and technical integration. Achievement of this status is correlated with business success - three of the five highly profitable companies as defined in section 8.1 are in this sector, while ML and MJ have achieved remarkable business turnarounds over the last decade. The other two highly profitable companies are MB, with high organisational integration, and MD. Those companies in the bottom right hand corner with low organisational and technical integration, with the exception of MD with its low level of requisite integration due to the nature of the production process, might be considered to be the poor performers and to have achieved neither technical nor business success.

The two cases that have achieved integration for surface modelling applications alone are interesting. The exploration of the possibilities of surface modelling technology appears to have facilitated technological integration, due to the major savings available from maintaining complex shapes on a single data base for both drawing office staff and manufacturing engineers to use. Perhaps because of its specialist nature, it does not seem to have prompted more widespread organisational changes. The *cell* development at ME is very localised, and the main co-ordination structure between the drawing office and the lofters at MG is *direct contact* through physical proximity. Aside from these special cases, no company has presently achieved high technical integration without high organisational integration.

On the other hand, two companies have high organisational integration without high technical integration. MB's presence there is probably explained by being one of the late implementors amongst these case, and its inability to implement the part programming element of the system is due to *resource shortages* as discussed in section 12.3. MO is further from technical integration, but is actively working on an interface between its CAD/CAM system, and the CNC wire erosion

THE LEVEL OF INTEGRATION



* = surface modelling applications only
! = little requisite integration

FIGURE 13.3 Technological and Organisational Integration across the Engineering/Manufacturing Interface machines in the toolroom and the new DNC machining cell in the factory. For these companies, high organisational integration is a way of achieving high technical integration. Both have *inner contexts* which favour organisational integration - MB is relatively undifferentiated, while MO is the only company identified in section 9.1 as having the type of product division business organisation design advocated by proponents of organisational integration along the *production information flow* (Winch 1983).

Perhaps the most interesting question that can be explored using figure 13.3 is the preferred route from the low performance to the high performance sector. MN moved through the high organisational integration sector during the seventies as it developed a *matrix organisation* in a response to market pressures which provided a welcoming *inner context* for the development of technical integration. On the other hand, the more popular route appears to be through high technical integration - MJ and ML took this route working around the process of surface modelling, and it was also followed by MK with the earlier CADDS4X system and by MM. While this route may well provide opportunities for organisational learning about the potential of CAD/CAM there are reasons to suppose that the route through organisational integration is preferable. Firstly, the case of MB does suggest that high performance is possible with high organisational integration alone. Secondly the other benefits of organisational integration associated with total quality management, value engineering, and simultaneous engineering suggest that this route has more general benefits along the way, while technical integration can only yield CAD/CAM related benefits, significant though these might be, related to productivity savings and product integrity.

13.5 SUMMARY

Figure 13.3 is an attempt to summarise the experience of the 15 case survey companies with the implementation of CAD/CAM systems over the last decade. The experience has been very mixed, as the last six chapters have shown. However, a number of general lessons can be drawn for both organisation theory and the sources of high performance business in the metalworking industries, and those others with similar production information flows such as electronics and construction. These will be explored in the next chapter, but here it might be useful to relate the experience of these companies back to the discussion in section 5.2 on implementation project organisation. In particular, the distinction was drawn between those companies which implement and then adapt the organisation, those companies which have developed already the desired organisation, and those which attempt synchronous implementation.

Of these cases, only MN and MB, the two jointly led companies, had integrated organisation processes and integrated or undifferentiated organisation structures prior to the first implementation. In these cases, *technocratic* implementation project organisation has been adequate, due to the relatively low *information load.* All the others are suffering from a greater or lesser degree of *organisational lag* - the problem being much greater in the *engineering led* companies than the *manufacturing led* ones. Amongst these cases, only MK is attempting synchronous implementation, and this is only on the basis of the technical success achieved with an earlier system - the inherent riskiness of the implementation project and the way in which the company has adopted a participative project organisation has already been discussed. It does seem as if the synchronous implementation advocated by some is only likely to be viable in special cases, and that what is need is the minimisation of organisational lag through double loop organisational learning. Where companies do not already have an integrated organisation, this can be facilitated through the adoption of a participative implementation project organisation.

14

IMPLEMENTING AN INTEGRATING TECHNOLOGY

14.0 INTRODUCTION

The implementation of CAD/CAM systems in the metalworking sector is a complex and difficult process. Like the implementation of other integrating technologies, it requires the mobilisation of all the functions involved in the production process, the commitment of senior executives, effective project management, and a sophisticated capacity for organisational learning. Few of the 15 firms included in this *case survey* can be considered to have effectively handled this task, but hindsight is a perfect science, and these companies were struggling with considerable uncertainties as they attempted to implement a completely new type of advanced manufacturing technology with few examples of best practice to follow. The aim of this chapter will be to draw some lessons from their experience of the *process* of implementation so that others can learn to do things more effectively. Before that is done, however, it is important to summarise the evidence on the *content* and *context* of implemention so those concerned with other industries and other AMT's can be guided in drawing their own lessons.

14.1 CONTENT: INTEGRATING TECHNOLOGIES

The concept of an integrating technology developed in section 2.2 describes a new type of AMT which only began to diffuse widely during the nineteen eighties. An integrating technology is distinguished from other AMTs such as CNC machine tools, flexible manufacturing systems, and applications such as electronic mail by both its systemic and its complex characters, as summarised in figure 2.2. The main examples presently being implemented in metalworking are CAD/CAM and CAPM, but these, in turn, form two of the main building blocks for Computer Integrated

Manufacture - CIM. The integrating nature of these technologies across the three spheres of production means that they pose many of the same issues as other developments in the management of production such as total quality management and simultaneous engineering.[25] In the automobile industry, this emergent re-configuration of production organisation has been called "lean production" (Womack et alia 1990).

The evidence from this case survey is that the reality and the rhetoric are far apart. As discussed in section 10.1, and summarised in table 10.1, only five of the firms studied could, in 1990, be considered to have an integrated CAD/CAM link for prismatic parts operating on a routine basis. The majority of the case only had links for very specialist applications, or were making data transfers through IGES links, with the attendant limitations on functionality. Many of the problems were apparently technical in origin in that there were incompatibilities between the CAD and CAM systems, but in one case there was no data transfer between fully compatible CAD and CAM systems. Here, the problems were clearly organisational in origin, but where the systems were incompatible, the basic problems were also organisational. Frequently, the explanation lay with the fragmented organisation of the process of evaluation and adoption of the new technology which, in turn, was the result of the organisational context in which implementation was taking place - in other words, the way in which the production process was being managed prior to implementation.

14.2 CONTEXT: MANAGING PRODUCTION

The established approach to the management of the production process is to focus on the manufacturing process alone. The materials flow, and the elements of the production information flow most immediately associated with it such as production planning, have bounded the horizons of most analysts, and the engineering design process has been almost entirely ignored. Previous

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25) Bessant (1991) provides a valuable overview of these developments as part of his analysis of what he calls the "fifth wave" of development in production technology

work has, until very recently, consistently failed to appraise the issues associated with the production information flow and its interaction with the materials flow which were identified in section 3.4. The approach developed theoretically in chapter 3, and empirically in chapters 8 and 9, attempts to break with this tradition, and to develop a way of looking at organisations engaged in the production of goods which covers the whole production process from conception to completion.

The production model developed in section 3.5 and summarised in figure 3.3 is an heuristic which specifies the interrelated set of contingencies which are considered here to be essential for the comprehensive analysis of production organisations. Chapter 8 explored the upper line of the model empirically and developed a taxonomy of the three generic production missions which develop in response to particular *outer contexts* - in particular, the product market environment. These were defined as the *engineering led*, the *manufacturing led* and the *production led* missions. The first two were identified as the established missions in metalworking production, while the third was cast as an emergent form[26].

The main features of each type of mission were summarised in figure 8.8, and a more detailed comparison is provided in table 14.1. The model starts with the relationship to the customer as articulated in the production strategy. Four basic types of order pattern were identified, defined around where the market transaction with the customer enters the production information flow. The *concept to order* strategy is used in the procurement of defence goods; it is also found in other industries involved in the creation of large capital assets such as construction. The distinctive feature here is that the product is specifically designed to an individual customer's requirements, and so the customer enter the production information flow right at the start. Often the "design order" is separate from the "build order". This strategy generates a distinctive production information flow which was called the *procurement route*, where there is a clear distinction

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26) The *production led* mission has been called elsewhere the "response led" mission (Voss and Winch, forthcoming) due to the ambiguities around the word "production". However, it was decided to retain "production" here as a way of articulating a view of the whole process of engineering and manufacturing combined

TABLE 14.1

n=13	ENGINEERING LED	MANUFACTURING LED	PRODUCTION LED
CASES	MC, ME, MG, MH, MI, MK	MF, MJ, ML, MM, MO	MB, MN
Production Strategy	concept to order/design to order	make to order/make to forecast	make to order/make to forecast
Production Information Flow	procurement route/tender route	development route	development route
Materials Flow	low volume (one-off/small batch)	high volume (large batch/flow line)	low volume (small batch)
Order Winning Criteria	"turn-key" capability product delivery programme price	product quality new product development rate after sales service	product variety new product development rate
Market Entry Criteria	product technology	price	product technology

between the "concept design and feasibility", and the "project definition" stages as shown in figure 8.4. This, in turn leads to a *low volume* materials flow because the customer-specific requirements of the product restrict order volumes.

The second production strategy identified was *design to order* relationship to the customer, where the customer enters the production information flow after the concept design has been completed. Here, the distinctive feature of the production information flow is the tender loop, shown in figure 8.3, where the company tenders to the customer on a basic design, and then proceeds to further design development and detailing after being awarded the contract - usually on a "turn-key" basis. For this reason it was called the *tender route*. Again, the customer-specific nature of production means that a *low volume* materials flow is chosen. These two missions were shown to possess important sources of convergence as the product market for concept to order products shifts towards the design to order pattern. The two were, therefore, grouped together in the *engineering led* mission. It was given this title because of the clear hierarchy within the business - traditionally, manufacturing has been seen very much as a service to engineering, and the prime source of competitive advantage was believed to be "engineering excellence".

Another group of companies related to the customer on a *make to order* basis where the order pattern is a contract against the customer's forward schedule. Here the market transaction with the customer enters the production information flow at the production planning stage. These were all vehicle component suppliers to high volume production companies. In these cases, the production information flow was defined as being of the *development route* form where the company itself undertook the development of products, or generic product types, which could then be customised to the requirements of particular customers through a process of "variant design", as illustrated in figure 8.7. These companies, as they were supplying *high volume* manufacturers also produced in high volumes - defined as more than 100 off in one batch - on either a large batch or flow line basis.

The two vehicle companies produced on a *make to forecast* basis where the contract with the customer enters the production information flow at its end, and production planning is on forecasting basis, instead of against actual orders. Again, these companies both had a *development route* production information flow, where the distinctive feature is that product development takes place against forecasts of market demand, rather than to the requirements of specific customers. It is illustrated in figure 8.5. These are the classic "mass production" industries, which deploy *high volume* flow-line materials flows. This distinctive configuration of make to order or make to forecast order patterns with development route production information flows and high volume materials flows was called the *manufacturing led* mission because in these companies the main sources of competitive advantage have traditionally been seen as manufacturing based, with engineering, and indeed marketing, being expected to meet the requirements of manufacturing.

Four of the companies in the case survey could not be fitted into either of these two configurations. MA and MD both had *tender route* production information flows leading to *high volume* materials flows. This was because neither had significant design capabilities. Invitations to tender from potential customers included concept drawings, and so the production information flow was restricted to some detailed design and tooling drawings. The contract with the customer, therefore, was entering the production information flow during the draughting stage. However, as discussed in section 8.7, both these companies were trying to move away from this situation to incorporate more of the value chain within their own operations and, as illustrated in figure 8.9, were moving towards the *engineering led* and *manufacturing led* missions respectively.

The other two companies which did not fit into the two main generic missions were MB and MN - both have development route production information flows coupled with low volume materials flows. A third, MK, was also seen to be moving in this direction. These companies are three of the five highly profitable cases in the survey, and compete strongly in world markets. They have also arrived at this distinctive production mission through determined organisational development over recent years. This suggests strongly that they are cases of an emergent configuration which was called the *production led* mission, because of the equal emphasis that they give to the concerns of both engineering and manufacturing as part of the whole production process.

14.3 CONTEXT: ORGANISATION DESIGN FOR PRODUCTION

The production mission represents a strategic choice on the part of the business in response to the threats and opportunities presented in the outer context. It is through the production strategy that the business enacts this external environment and that choice bounds the subsequent selection of technologies and make/buy options which form basis for the production information and materials flows. As discussed in the previous section, on the evidence of these cases, this set of choices generates three distinctive configurations, or production missions. In section 3.4 it was suggested that it is the production information and materials flows and the character of the transactions within them which result from the choice of production mission that are the main contingencies influencing organisation and job design in terms of both structure and process.

The conceptual framework for analysing these transactions was summarised in the lower line of figure 3.3. An analysis of a particularly important transaction within the production information flow - the engineering/manufacturing interface was developed in chapter 4, and is also the focus for an extended treatment for an example of the manufacturing led mission, cars, by Clark and Fujimoto (1991). One of the most important transactions within the materials flow, the relationship between buyer and supplier, or what has been called the "supply chain", has been the focus of much analysis of late - Bessant (1991) provides an overview, while Womack and his colleagues (1990) again explore the issue within the car industry.

From the evidence presented in chapter 9, a clear pattern emerged of the ways in which companies were organising themselves to enable them to complete their production missions which is summarised in table 14.2. While there was remarkable commonality at the business level in organisation design, due to the almost universal choice of functional organisation and the

TABLE 14.2

n=13	ENGINEERING LED	MANUFACTURING LED	PRODUCTION LED
CASES	MC, ME, MG, MH, MI, MK	MF, MJ, ML, MM, MO	MB, MN
Business Organisation	Functional	Functional	Functional/Matrix
Engineering Organisation	Matrix/Functional	Matrix/Product	Matrix/Unified
Manufacturing Organisation	Unit	Manufacturing Planning	Functional
Favoured Organisation Design Linkages	Programme Management Projects Division	Programme Management Cell	Project Teams Task Forces
Organisational Integration	Low	High	High
Coupling	Sequential/Reciprocal	Reciprocal/Iterative	Iterative

instability of both product and matrix organisation structures, at the level of the engineering and - manufacturing departments, great divergence was found which turned on the type of coupling desired within the production information flow - what was defined in section 8.6 as the *coupling commitment.*

As can be seen from table 9.2, *matrix organisation* is becoming the established way of organising engineering for all types of mission - the divergences become clear when the alternative option is examined. For engineering led companies, the favoured alternative is *functional* organisation, while for the manufacturing led ones, it is *product* organisation. This would suggest that the two types of firm are approaching the establishment of matrix organisation in engineering from opposite directions. The production led companies favour highly integrated engineering organisation - either a *matrix* organisation, or where the organisation is small enough, a *unified* organisation.

So far as the organisation of manufacturing is concerned, table 9.2 again shows that the manufacturing led companies have opted entirely for the *manufacturing planning* type of organisation, with its clear distinction between "manufacturing engineering" and "conformance engineering" as illustrated in figure 9.5. At the engineering led companies, the *unit* type of organisation illustrated in figure 9.6 is rapidly becoming the favoured option, although some still have a *functional* structure. Meanwhile, at the production led companies, a *functional* structure is favoured - notably, the engineering led company which is moving towards the production led mission explicitly rejected the *unit* option. This retention of the functional form would appear to be due to the twin problems of retaining a centralised expertise to contribute to engineering's project teams, while at the same time managing general purpose technologies on the shop floor as opposed to the specialised ones typically managed by manufacturing planning type organisations.

The choice of *matrix* organisation in engineering would appear to be largely explained by the coupling commitment. Examination of tables 8.2 and 9.2 shows that four of the five firms with matrix organisations in engineering espoused *iterative* coupling commitments, while in the fifth case no opinion was obtained. The other two firms which espoused *iterative* coupling commitments both have product organisations in engineering. The three companies, all engineering led, which espoused *sequential* coupling commitments all had functional organisation for engineering, and had, or were moving towards, unit organisation in manufacturing. It was also amongst the engineering led companies that, as discussed in section 9.1, the development of internal market transaction governance between engineering and manufacturing was found in which engineering "buys" manufacturing capability from the factory. A strong picture emerged of manufacturing and production led companies expressing considerable concern for the engineering/manufacturing interface, while engineering led companies did not consider it to be one of their priorities.

Those companies with a functional organisation of engineering showed relatively little concern for the project management of design development at the departmental level. However, those same engineering led companies tended to be much stronger in the development of *programme management* - only at ML was programme management found in the manufacturing led companies. The development of *projects divisions* to provide turn-key services to the customer was restricted to the engineering led companies, as might be expected from the nature of their market transaction with the client. The complexity of many capital and defence goods has meant that no metalworking company is capable of having access to all the necessary product technologies, particularly electronics systems and power sources. Yet the risks are too great to simply subcontract for these technologies as a manufacturing led company would because of severe problems of asset specificity - the client often wishes to specify the system that will be used, and in any case, there are few alternative suppliers in the market. In response to these problems, projects divisions have emerged as a type of trilateral governance structure (Williamson 1985 chap 3) to take some of the risk off the client, while not passing it directly to the producer.

This emphasis upon the entire production process, including engineering design, rather than the more conventional emphasis solely on the manufacturing process suggests that some widely used organisational models require amendments. Mintzberg's model of the "five basic parts" of the organisation (1979 chap 2) hardly mentions engineering design, but it would appear to be allocated to the "support staff". The thrust of the argument above suggests that it should, rather, be considered as part of the "operating core". Similarly, Porter's model of the "value chain" (1985 chap 2) allocates engineering design to one of the "support activities" - "technology development" - while it could more usefully be considered to be part of the "primary activities". The problem appears to be that both Mintzberg and Porter have, implicitly, based their analyses on the model of the traditional manufacturing led company, and ignored the existence of the engineering led companies. Even amongst the manufacturing led companies, the recent work at Harvard and MIT on the car industry (Clark and Fujimoto 1991; Womack et alia 1990) suggests that the traditional support relationship of engineering to manufacturing can no longer provide competitive advantage in the face of "lean production" techniques, and that engineering has to be increasingly seen as a primary part of the operating core.

14.4 PROCESS: IMPLEMENTING CAD/CAM

An *implementation approach* to the process of technological change in organisations was developed in chapter 1 and articulated in detail in chapter 5. It was argued that the process of implementation is a dynamic and recursive one in which organisations configure and reconfigure the new technology to meet the needs of their information and materials flows. An important finding is that many organisations have gone through more than one cycle of implementation, and use previous cycles as organisational learning about the problems and possibilities of CAD/CAM technology. This model of the implementation process was summarised in figure 5.2, while a more detailed heuristic for the selection of an appropriate implementation project organisation was presented in figure 5.3.

A review of the existing literature on the implementation of AMT in chapter 6 showed how few studies have covered the entire implementation process from evaluation, through installation and commissioning, and on to consolidation within the existing organisational context. Chapters 10, 11, and 12 covered in detail the experience of the 15 companies in this case survey with implementation. All had, in order to be included in the case survey, to have adopted CAD. While most companies could claim to have achieved technical success for their CAD implementations fairly easily, this was much less true for the CAD/CAM links - only one third could be said to have technically successful links, and another third had implemented technically incompatible CAD and CAM systems.

Business success was more difficult to measure, as only two companies audited their CAD/CAM systems, and the results of these audits were privy to the Board only. Only one company was able to provide a detailed breakdown of benefits from the implementation in terms of productivity improvements and reduced product development lead times, and a general picture emerged of little effort being directed at appraising the returns from the substantial investment in CAD/CAM that these companies had made. As explored in section 12.1, the problem appears to be bound up with the ways in which cost centres are controlled within metalworking organisations. Inherent in its nature as an integrating technology, CAD/CAM is normally implemented across more than one cost centre, while the business benefits from CAD/CAM - be they concept to completion lead time reduction, productivity, product integrity or whatever - are distributed unevenly across cost centres. Most notably, the 10-fold productivity gains possible for part programming in manufacturing through accessing directly the product data base directly can only be achieved at a cost to engineering in setting up the 3D model on the data base correctly.

The extent to which the adoption of CAD/CAM leads to technical success and business success is, on the evidence of these cases, a function of the effectiveness of the project management the implementation process. Those firms, such as MH and MI which failed to develop any form of project organisation for implementation fared noticeably worse than the other companies. Inspection of tables 10.2 and 11.1 reveals the overall requirements for effective implementation project management. These are the inclusion of all three interested parties in the implementation task force, (ie engineering, manufacturing and the IT function); a strong implementation champion who may either be the implementation project manager, or be directly responsible for that manager's activities; and support from senior management. However, as the discussion in section 12.3 shows, these are necessary rather than sufficient conditions for effective implementation management - an implementation project team can only be as effective as the context in which it operates.

That context is very different in the engineering led companies on the one hand, and the manufacturing and production led ones on the other. On the measures developed in chapter 13, none of the engineering led companies could be considered to have a high level of organisational integration; nor could they be considered to have high technical integration on the criteria discussed above for technical success. Only in the very limited application of surface modelling did two of the engineering led companies achieve a measure of technical success. Yet, as figure 13.3 shows, all those companies which had high technological integration also had high levels of organisational integration. This strongly suggests a link between the achievement of technical success and the establishment of high levels of organisational integration, and emphasises the importance of the consolidation stage within the overall implementation process.

The crucial variable appears to be the organisation's view of the engineering/manufacturing interface. A comparison of table 8.2 and figure 13.3 shows that five of the six companies identified as espousing an iterative coupling at that interface measured high on both measures of technological and organisational integration, while the sixth had high organisational integration. On the other hand, the three companies that espoused a sequential coupling commitment all had low levels of both organisational and technological integration. The effective implementation of CAD/CAM is very much function of whether the organisation sees its competitive advantage lying in the effective management of the engineering/manufacturing interface, or whether its is believed to lie elsewhere in engineering or manufacturing.

14.5 CONSOLIDATION AND THE PROCESS OF ORGANISATIONAL CHANGE

The discussion in chapter 1 stressed the ways in which technological change is simply a special case of organisational change, while the framework established in chapter 5 emphasised the importance of the consolidation process by which the organisation's structures and processes adapt to the changes in the information and materials flows consequent upon the implementation of advanced manufacturing technologies. The discussion in section 5.2 discussed three possible relationship between the processes of organisational and technological change during mutual adaptation to new technologies - the enabling organisational context for the new technology already exists; the technology is implemented and there is "organisational lag" while the organisation adapts, or both technology and organisation mutually adapt in a process of what some have called "synchronous innovation".

Only one of these cases - MK - could be considered to be going through a process of synchronous innovation using the *participative* form of implementation project management organisation which manifests a concern for both organisational and technological change. However, this was a re-implementation, and MK was only able to embark upon this somewhat risky approach on the basis of nearly 10 years of organisational learning derived from its earlier implementation. The other successful implementors had used a *technocratic* form of project management organisation which only manifests a concern for the technological change process alone. As discussed in section 5.3, the uncertainties inherent in implementing integrating technologies pose considerable *information loads*, and most firms have chosen to proceed more cautiously, implementing the technology first.

There are, for most companies, two routes from low technological and organisational integration - choosing to increase organisational integration first, or choosing to increase technological integration first. Of the companies scoring high on both dimensions, only MN took the former route - the remainder developed their CAD/CAM systems before developing stronger organisational linkages across the engineering/manufacturing interface of the kinds discussed in chapter 13. In developing awareness of the benefits of integration, surface modelling applications have been particularly important, for the reasons discussed in section 13.5. Both MG and ME are presently starting their progress towards high integration by this route.

In achieving organisational integration, companies deliberately used the organisational linkages identified in the hierarchy of integration summarised in figure 13.2 to achieve the iterative organisational processes summarised in figure 13.1. Once such linkages have been firmly established, evidence from the two production led companies suggests that iterative production information flows across the engineering/manufacturing interface become self-sustaining through the organisational culture, and the more complex and expensive linkages can be abandoned. However, the benefits that accrue from technological integration provide a learning vehicle to generate awareness about the potential of organisational integration, as is well illustrated by the role played by the WESTRID cell at ME in the present re-evaluation. This dynamic interaction between structure and process in these organisations provides evidence for a structuration approach to the dynamics of organisational change, in which the process of organisational learning is central.

14.6 SUMMARY

This evidence from the 15 firms in this case survey of the implementation of CAD/CAM systems in the UK metalworking sector leads to a number of conclusions. The first is the importance of the examining the whole production process from the conception of the product to its completion for the customer, rather than focusing simply on the manufacturing process. Second, it is apparent that there are at least three generic production missions, and it is important to specify which the firm has chosen in order to understand the overall context of CAD/CAM implementation. Thirdly, while effective implementation project management can improve the chances of achieving technical and business success, it is not a sufficient condition, and the crucial variable is the overall organisational context in which implementation takes place. Finally, business success can only be achieved if organisational change also takes place, and organisational learning is critical to this change. As well as providing a guide for others wishing to implement CAD/CAM systems and other integrating technologies, this research raises some broader questions which will be pursued in the final chapter.

15

IMPLICATIONS AND NEW DIRECTIONS

15.0 INTRODUCTION

The last fourteen chapters have developed a distinctive conceptual approach to the analysis of manufacturing organisations, and then deployed it in the analysis of a case survey of 15 UK metalworking companies which have implemented CAD/CAM systems over the last decade. The study focused on CAD/CAM as an example of an integrating AMT for two reasons. Firstly, because it is, together with CAPM, one of the main buildings blocks of CIM, and, secondly, because of its role as an enabling technology for two of the other main developments in the organisation of production over the last decade - simultaneous engineering and total quality management.

In the developing some of the implications of this thesis, the argument will explore of some of the implications of this research for the development of organisation theory. A *tectonic approach* to the analysis of complex organisations which has relevance far beyond the issue of the implementation of AMT will be advocated which emphasises the structuration of organisations through the dynamic of structure and process within specific industrial contexts. Finally the theme raised in the introduction of the paradox of flexibility and productivity will be revisited and some possibilities for the future suggested.

15.1 AN APPROACH TO ORGANISATION THEORY

The experience of the companies reported in this research suggests that any adequate theory of organisation must consist of three elements. Firstly, it should be able to characterise the organisation at any given point in time. This means an understanding of both the different parts of the organisation, and how they fit together to form the whole. Secondly, it should understand the relationship of the organisation to its environment in a detailed way. Thirdly, it should be able to analyse how that organisation changes over time in terms of the relationships between the parts, and the form of the whole, and the relationship to the environment. In other words, it should be able to simultaneously handle both morphogenesis and morphostasis. This applies whether the organisation chosen for analysis at the level of the work group, the section, the department, the business, or the corporation. The framework presented in section 1.2 gives one way of deciding which is the most appropriate organisational level for the topic under consideration.

The approach to organisation theory taken in the analysis deployed over the last fourteen chapters is heavily influenced by the empirically based critique of classical management theory which developed during the sixties - largely in the UK. The influence of Burns and Stalker, Lawrence and Lorsch, and Woodward can be seen throughout the thesis. The debate over the relevance of this contingency approach has been long and hard. One of the most important critiques came from within - that of Child who argued that the contingency approach ignored the role of strategic choice in the design of organisations. In essence, his critique poses the issue of process, against the emphasis upon structure inherent in the earlier work.

Another approach which was also developing in the UK over the same period is that of the Tavistock Institute which became known as socio-technical systems theory - notably that of Trist, and, of most immediate relevance to this research, Klein (1964). Here the emphasis is more upon process, particularly on the process of production, cast as the technical system, and the processes of individual interaction, cast as the social system. There is also a concern for how organisations change which is lacking from the earlier versions of the contingency approach. However, the work does tend to suffer from a lack of awareness of the structural context of the socio-technical systems under investigation.

The strengths and weaknesses of these traditions are debated in some depth in Van de Ven and Joyce (1981), but the main problem seems to be a failure to build creatively upon the original perspectives. In the case of contingency theory, this would appear to be the result of the development of a "pairwise approach to fit" (Van de Ven and Drazin 1985 p 344) based on correlation analyses which tend "to focus on simple relationships among few variables in search of direct causation" (Miller and Friesen 1984 p 11). Social-technical systems theory has made almost the directly opposite error of concentrating on single case studies as a result of an emphasis upon consultancy rather than academic research (Brown 1967). Two main groups of analysts have attempted to move beyond both simplistic quantitative research, and single case studies - the Montreal group, and those associated with Andrew Van de Ven.

The Montreal school (Mintzberg 1979 & 1983; Miller and Friesen 1984) has advocated a "configuration approach" to organisational analysis:

> "The objective of this approach of synthesis is to discover richly described, revealing configurations that are sufficiently common to capture an important organisational entity or occurrence....Ultimately, the aim is to generate typologies or taxonomies" (Miller and Friesen 1984 p 12).

It differs from the conventional contingency approach because the latter presumes that the relationships between variables remain constant between types, while in a configuration analysis, they vary.

While there is much that is attractive in the configuration approach, and Mintzberg's five basic types of organisation remain a powerful tool, the discussion in chapter 9 illustrates its weaknesses. All 15 of the cases surveyed would have been classified in Mintzberg's terms as "machine bureaucracies", yet the data presented show considerable contingent variation between the cases, and three configurations - the manufacturing led mission; the engineering led mission, and the production led mission - were identified. There is no reason in principle why each of the five basic configurations cannot be subjected to further analysis at levels below that of the business unit, and this is precisely what is proposed here.

The "organisational assessment" approach of Van de Ven and his associates (e.g. Van de Ven and Ferry 1980) has chosen a much more detailed empirical methodology. Through the implementation of four different research instruments, and the collection of contextual information, a complete quantitative picture of the organisations under study can be constructed. The quality of the research instruments is beyond doubt, and they provide an indispensable mine of ideas for instrument development. However, the approach is enormously resource intensive both in terms of the researchers' time and the goodwill of the organisations under study - a problem of which Van de Ven is, himself, aware (1981). A case survey based on organisational assessment methods is beyond the resources of most traditionally funded academic research projects, and it is unlikely that any one organisation would be prepared to fund more than an assessment of itself which means that the crucial comparative element would be lost. At best, different units of the same organisation can be studied, which is what Van de Ven and Ferry did, but this means that it is unlikely that there will be sufficient variation between the units to allow the identification of configurations.

In an important sense, the approach deployed here is positioned between the generality of configuration and the specificity of organisational assessment by providing a robust and parsimonious methodology for collecting and analysing data on both structure and process. This may be called the *tectonic approach*[27]. It approaches organisations in a manner similar to organisational assessment, but uses a much simplified research instrument, with the aim of identifying configurations at the departmental and business level. This means that it is possible to reach the number of cases required for pattern analysis leading to the development of taxonomies of configurations; one possible development of the *tectonic approach* would be to perform enough case studies to allow the appraisal of the configurations found using simple statistical tests.

All the firms in the case survey were clearly one broadly specified industry - metalworking -

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27) "a series of arts which form and perfect vessels, implements, dwellings, and places of assembly. We call this class of artistic activities tectonics" Oxford English Dictionary, 2nd edition.

defined in terms of the commonalities between the information and materials flows across the sample. This industrial definition allowed enough variety within the sample to enable the identification of distinctive configurations, but retained enough similarity to enable the configurations to be meaningfully related to each other. This facilitated the comparative analysis of the ways in which the parts related to the whole in each configuration and deepened understanding of the dynamics of change. Clear industrial definition greatly eases the assessment of the relevance of the lessons for this particular sample of businesses for those in other industries. For instance, the findings of this research might be expected to be more directly relevant to industries with relatively similar information and materials flows such as electronics, less relevant to those with more differentiated ones such as construction and chemicals, and of little relevance beyond the most general principles to the service industries which do not process materials at all such as finance. One way of exploring some of these contingent variations in terms of production information flows was indicated in figure 3.2. Thus, it is through the clear specification of the industrial context and its enactment in the strategy process that the tectonic approach analyses the relationship of the organisation to its environment.

The *tectonic approach* can, therefore, handle effectively the analysis of organisational form, and the relationship of that form to its environment; can it also handle the genesis and transformation of form? The approach pays equal attention to structure and to process - the latter is particularly manifested in the information and materials flows, and the choices regarding the production strategy. In an extensive review of the requirements for a theory of change in organisations, Van de Ven and Poole (1988) suggest that the structuration approach as developed by Giddens (eg 1984) provides the most likely way forward. Others, such as Ranson and his colleagues (1980), have also advocated Giddens' work, while Barley (1986) demonstrates the value of a structuration approach for the analysis of technological change in organisations at the job design level. The analysis of the evidence from the case survey has shown the ways in which structure both constrains and is constrained by the information and materials flows, and by strategic choices regarding both the production strategy and the decision to implement CAD/CAM. The *tectonic* *approach* can, therefore, claim to handle simultaneously both morphostasis and morphogenesis.

At the conceptual level, the approach is of broader relevance than the metalworking industries. While the findings are specific to certain sectors of manufacturing, the way of analysing organisations can be applied elsewhere. If the operational flows within the organisation - which in manufacturing are the production information flow and the materials flow are redefined, then the tectonic approach can be applied in other industries, particularly in the service sector. For instance, the operating (production) flow can be through of consisting of funds in financial services; clients in personal services; or customers and merchandise in retailing. These will again be supported by distinctive flows of financial and human resources, and marketing information flows.

15.2 RESOLVING THE PARADOX OF FLEXIBILITY AND PRODUCTIVITY

The paradox of flexibility and productivity in the management of production organisations was posed in the introduction. The paradox is generated because the strategies that have been so successful in generating the remarkable growth in productivity over the last four decades have compromised the ability of organisations to respond flexibly to the new demands being transmitted by the market during the last decades of the century. The new challenge posed for production management is how to create flexible organisations without jeopardising their ability to continue to generate advances in productivity.

There are, essentially, two responses that an organisation can make to paradox - the first is *endurance* through trying to live with it, and cope by incremental adjustment; the second is *transcendence* through developing new organisational forms which, to take the analogy of dialectics, create a synthesis with the old. The first option is likely to lead to managerial overload as decision makers cope with apparently contradictory information; then to the generation of slack by decoupling those elements of the organisation which are at the poles of the paradox; and finally to a loss of competitiveness as overheads rise and decision times lengthen due to the implementation of more and more vertical co-ordination procedures. The second option may seem more difficult and expensive in the short run, but is more likely to pay dividends in the medium term. In the long term, the new organisational form will provide the base for the next paradoxical transformation.

The transformation of metalworking organisation since 1945 is broadly summarised in figure 15.1. The transformation has two moments - form and context. Context summarises the ways in which production is consumed, and how the wishes of consumers are transmitted to producers through the market. Form, on the other hand, describes the types of organisations which are designed to respond to those wishes. The two are linked through the strategy process and market structure.

Perhaps the most important feature of the post war context for the present discussion is that competition was essentially national in orientation and revolved around growth in national market share through cost competition - productivity was the key to competitive advantage. Regulated by Keynesian demand management policies, it led to the distinctively bureaucratic organisational form of the large corporation meeting demands for mass consumption through mass production which is called here the *unitary form*. It is unitary in two senses - firstly, the corporation is an unambiguously bounded entity with a clear delineation between the internal and the external. Secondly, it is divided into clear functional units - the "chimneys" of Ford (Pascale 1990 chap 5), or the columns of Apollo's temple (Handy 1985 chap 7).

Few metalworking organisations fully met this mass production model - vast areas of production in capital and defence goods remained resolutely batch orientated - but the mass production industries became the model for others to emulate, and functional units the basic elements of organisation. The unitary form became an hegemony, just as "normal science" does under a paradigm (Kuhn 1970 chap 9), which stifled the articulation of alternative models. It is perhaps significant that many of the elements of the new form which will be articulated below, particularly

THE DEVELOPMENT OF ORGANISATIONAL FORM

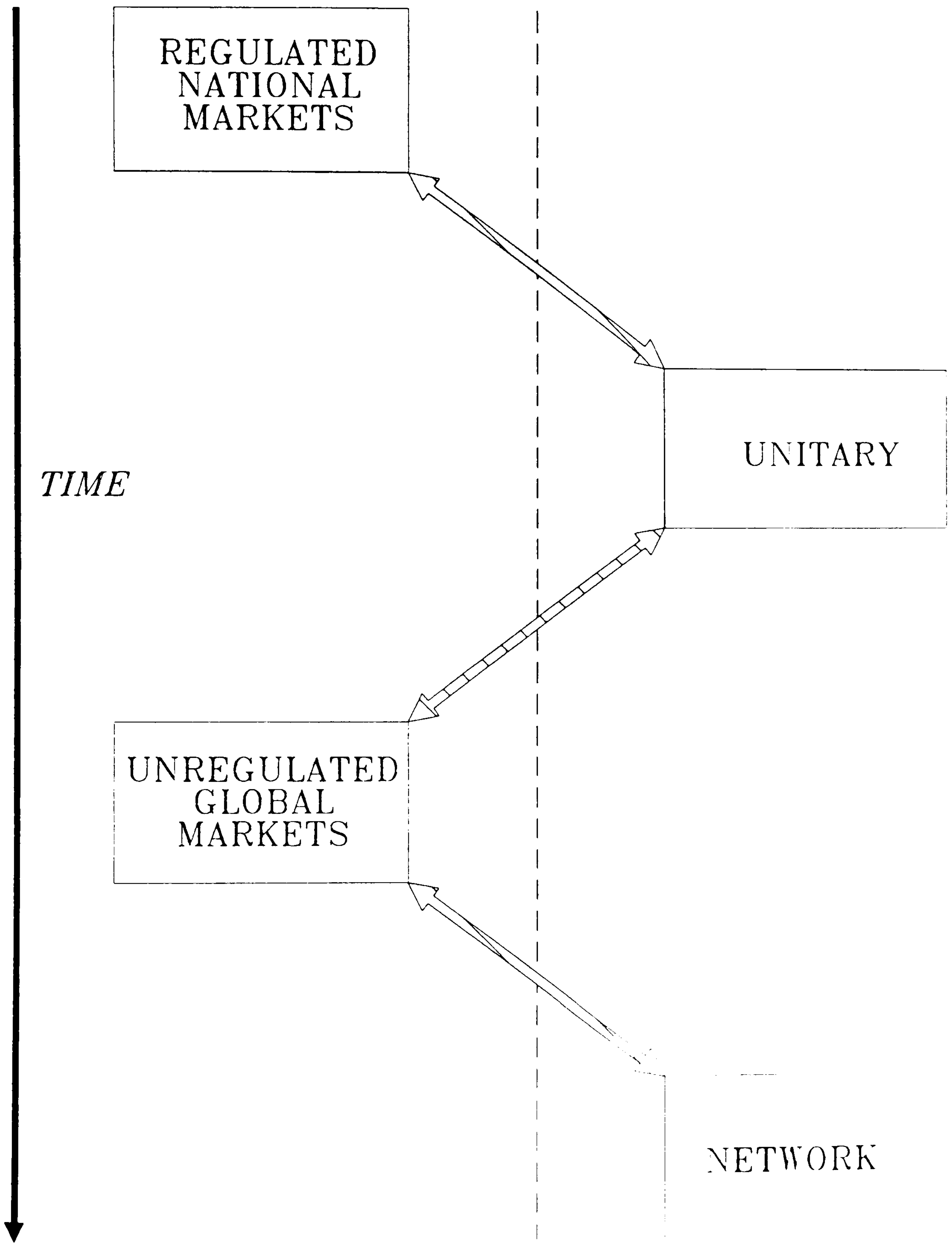

Figure 15.1

the organisational structures and new techniques of project management, first began to emerge the sector furthest from a mass consumption market - the defence industries.

As world markets changed after the end of the long boom, they began, falteringly at first, to transmit new demands. The main changes were a breakdown of the national regulatory mechanisms for demand, and the shifting of the competitive arena to the global level. These factors increased both competition and uncertainty as markets became both more dynamic and increasingly complex. Productivity growth was now a necessary rather than sufficient condition for competitive advantage, and flexibility of response to customer demands became the new source of competitive advantage - the paradox of flexibility and productivity was thereby posed. The dilemma is that the solutions developed to solve the problem of productivity in the unitary form compromised the flexibility of manufacturing organisations.

One proposal for the resolution of this paradox is Piore and Sabel's (1984) advocacy of a return to the pre-unitary, or *craft form*, of "flexible specialisation". This is the option chosen by the construction industry (ibid chap 5), an example which exposes well its limitations. Here, the premium placed upon flexibility has stunted productivity growth and stifled innovation - the strategy has only been viable because construction markets remain almost entirely national in character (Ball 1988; Winch 1989). The other examples of the *craft form* cited by Piore and Sabel are mainly of companies choosing focus strategies in niche markets such as designer clothes and high technology goods early in the product life cycle. In neither case is productivity central to competitive advantage, and, by definition, only a small proportion of production can be for niche markets - the bulk of turnover must come from the main markets. Niche markets are also open to attack from mainstream producers as the battle for the luxury car market segment illustrates. The problem is that under the craft form, firms have normally achieved flexibility through slack resource - a return to this form would amount to endurance rather than transcendence. While the craft form may be a sufficient response to uncertainty, it is not adequate to meet the productivity growth demands of global competition. For these reasons Womack and his colleagues criticise the work organisation developments at Volvo as a doomed attempt at "neocraftsmanship", rather than a viable basis for global competitiveness (1990 p 101).

Some analysts stress the differentiation of the production process within the network to gain flexibility. Thus Miles and Snow (1986), and Eccles and Crane (1987) propound the notion of the "dynamic network", in the search for flexibility. However, Miles and Snow again cite construction as an example, while Eccles and Crane focus on investment banking, an industry whose institutional weaknesses have been severely tested in the recent recession. The problem with "dynamic networks" is that the sources of integration are poorly developed, and rely on the activities of "brokers" whose power and motives are unclear.

Others have chosen to stress the integration that comes from stable relationships within networks. Johnston and Lawrence (1988) outline the benefits of the "value-adding partnership" (VAP)[28], while Charan (1991) shows the way in which clearly defined networks of middle managers can help a company to gain flexibility without compromising efficiency. Perhaps the most important work along this theme is that of Rockart and Short (1991) who stress the role of IT in making possible the "networked organisation" as a response to the new forms of global competition. Arguably, such a form of organisation is differentiated enough to achieve flexibility of response while developing the high levels of integration required to sustain productivity growth.

Thus a new organisational form is required and its shape is beginning to emerge around the notion of networks - it may be called the *network form*. It is networked in three senses. Technologically, it relies heavily on IT for the transmission of the bulk of information around the organisation. Organisationally, lateral communication is the norm through both formal and informal interpersonal networks. Contextually, the boundaries of the firm are less clear - suppliers enter into value adding partnerships while non-core activities are sub-contracted out, and the "flexible firm"

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[28] Although perversely, they also cite construction as an example of a VAP, when the reality of a typical construction contract is a bitter struggle over the distribution of "margin" within the "value chain".

(NEDO 1986) may become the model for human resource management.

None of the 15 organisations in this case survey have fully made the transformation to this new form. However, the evidence presented here does allow some important features to be sketched out, and some of the dynamics of transition to be indicated so far as production in metalworking firms is concerned, particularly at the engineering/manufacturing interface. Three main strategies for change at this interface were identified. The first is the implementation of integrating technologies and techniques in pursuit of a technical integration; the second is the development of iterative processes within the production information flow; and the third is the development of organisational linkages to generate and sustain the iterative organisational processes. These will be discussed in turn.

The implementation of *integrating technologies and techniques* has a major force for organisational change in the case survey companies during the last decade. Integrating technologies were identified in chapter 2 as the group of advanced manufacturing technologies such as Computer Aided Design and Manufacturing systems, and Computer Aided Production Management systems whose implementation must cross functional boundaries for success to be achieved. It is this inter-spherical, or *systemic*, characteristic, combined with their *complexity* which distinguishes integrating technologies from other AMTs. These characteristics were summarised in figure 2.2, which also gave examples of other types of AMT. Integrating techniques are those such as total quality management, value engineering, and simultaneous engineering which are similarly inherently inter-spherical in their implementation. The research chose to focus upon CAD/CAM because of its inherently integrating character across the engineering/manufacturing interface, and because, as one informant put it, it is an "enabling technology" which allows TQM and simultaneous engineering to be implemented successfully.

The implementation of CAD/CAM systems is a process that can be divided into the three stages discussed in chapter 5 and summarised in figure 5.2 - evaluation and the decision to adopt;

THE CHANGING ORGANISATIONAL FORM

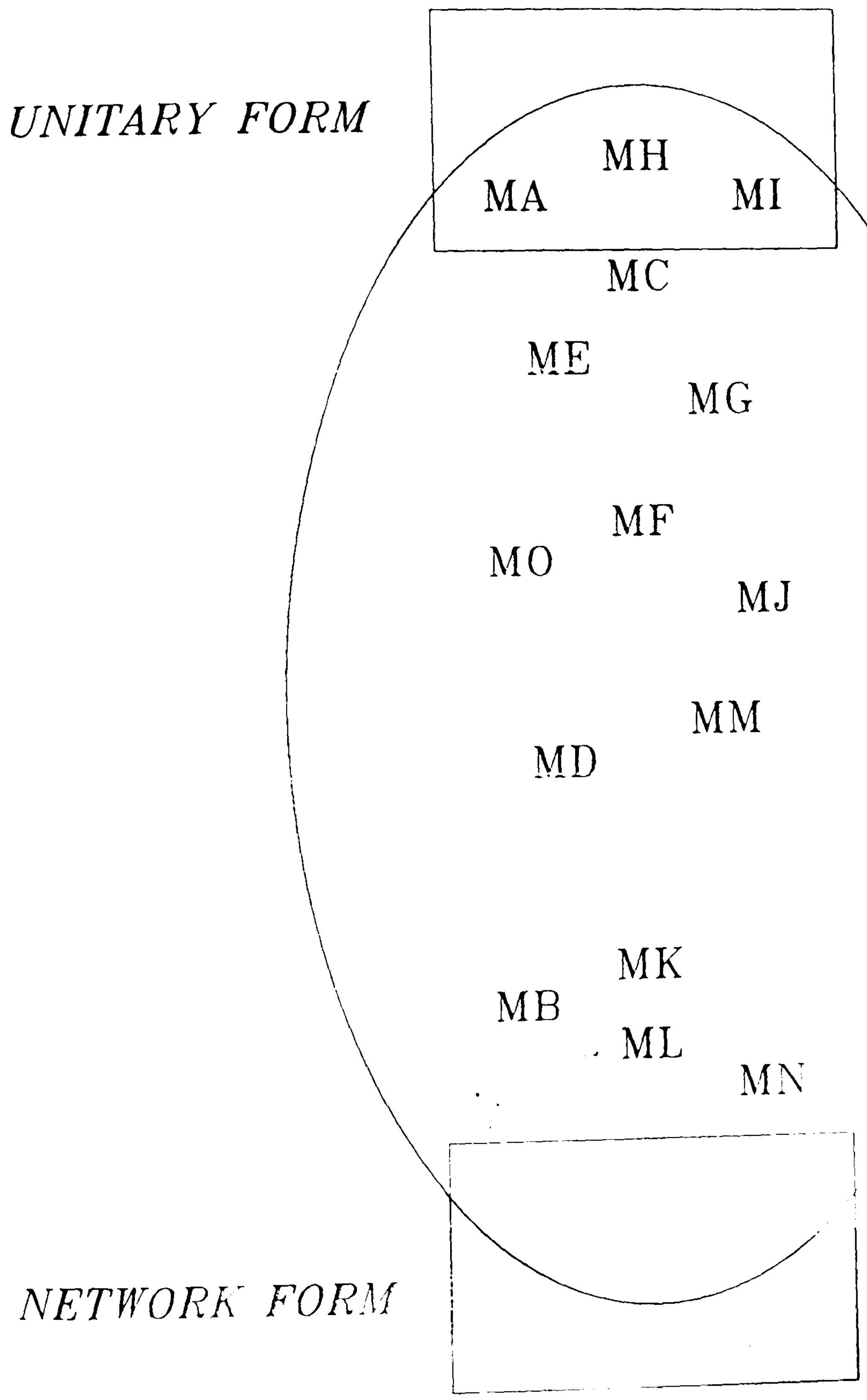

Figure 15.2

installation and the achievement of technical success; and consolidation and the achievement of business success. Technical success was defined as the point where the implemented system is performing to specification, while business success is the point where the system can be said be yielding the returns envisaged during the evaluation stage. The evidence is that these stages are both cyclical in that many companies have implemented CAD/CAM and then re-implemented their CAD/CAM systems, and recursive in that the organisational learning from the process of consolidation provides the basis for the next stage of evaluation.

In terms of the evolution towards the *network* form, the implementation of CAD/CAM has two roles. Firstly, the achievement of an integrated system in which all the actors within the production information flow are able to access the same product data base is an obvious example of the IT aspects of the network form. However, no company had yet achieved this goal, although it was an articulated ambition in many. The extent to which technical success had been achieved in the case companies was summarised in table 10.1. As can be seen, many companies had yet to reach even this goal, partly due to the installation of technically incompatible CAD and CAM systems. However, these technical problems were due in turn to the poor project management of the implementation process.

The second role of the implementation of CAD/CAM is in changing the organisational context. The integrating nature of CAD/CAM technology means that attempts to implement or re-implement it tend to stimulate inter-sphere dialogue and debate. At MG, the Business Process Development Group, which acts as the main change agent within the organisation developed out of the original CAD/CAM implementation team which was the first ever cross-functional team in the organisation. At ME, a cross-functional cell, which developed around the CAD/CAM interface for surface modelling, is now providing a role model for other inter-functional task forces and teams. The development of a matrix structure at MK to integrate the production engineers within the product development teams is intimately linked to the re-implementation of a completely new CAD/CAM system which has the functionality to support interactive team working. However, this lone example of "synchronous implementation" (Ettlie 1988) using a participative implementation project team organisation is only possible on the foundations of 10 years of organisational learning associated with the previous system.

In virtually all the case survey companies, the CAD/CAM system had either played a role in revealing to managers the inadequacies of the existing levels of organisational integration, or provided a catalyst towards moving a more integrated organisation. At MN and MO, the implementation of value engineering and simultaneous engineering respectively also had the same effect. In these cases, the existing levels of organisational integration provided a welcoming context for CAD/CAM implementation. However, it is also clear from these cases that integrating technologies cannot provide a technical fix for the resolution of the paradox of productivity and flexibility, because they must be supported by levels of organisational integration appropriate to the organisation's production information and materials flows.

The product development process can be thought of as a flow of information which stimulates a flow of materials within the manufacturing process, in the manner described in chapter 3. The point at which this "production information flow" (Winch 1983) crosses from the engineering to the manufacturing function is a major interface within the product development process. The major question regarding the quality of this transaction is whether information flows sequentially, reciprocally, or iteratively across the interface. Figure 13.1 presented a typology developed from the work of Adler (1988) which articulated the variety of ways in which this transaction can be co-ordinated, while table 13.1 presented the three most common means of co-ordination amongst the cases.

In all the cases surveyed except one, the engineering and manufacturing functions were highly differentiated, and represented by different executives at board level. The one exception was differentiated at the level immediately below director. The examination of the very different task contingencies faced by the two functions in chapter 4 showed why this is likely to continue to be the case. Except in the very smallest firm with limited engineering design capability, co-ordination between engineering and manufacturing cannot be achieved through de-differentiation, or the merger, of the two functions, but the through integration of the differentiated functions using organisational linkages.

For these reasons, the cases have all developed horizontal organisational linkages over the last few years in order to increase the information processing capacity (Galbraith 1977) of the engineering/manufacturing interface and thereby facilitate the development of iterative production information flows. A typology of such links, developed from the work of Galbraith, was presented in figure 13.2, while their incidence across the cases was presented in table 13.2. The ordering principle of the hierarchy is complexity, with the most complex at the bottom of the list. They are grouped into those which only require changes in job design for implementation and those which require more thoroughgoing organisation design changes. The more complex the linkage, the greater the probable cost to the organisation in terms of increased overheads. For this reason, the principle minimum intervention applies (Hrebiniak and Joyce 1984) - if adequate co-ordination can be achieved with simpler linkages, then they will tend to be preferred.

The dynamic of co-ordination across the engineering/manufacturing interface is a special case of transaction governance within the production information flow. The chapter 13 showed the importance of both structure and process in this dynamic. The evidence is that structural integration and process integration are correlated - those companies which deployed a high number of structural linkages also tend towards iterative processes within their production information flows. The only company where this is not true is MB, but this company is relatively undifferentiated, and does not, therefore, have much of a need for integration structures. Structure and process can, therefore, be considered to be mutually supportive in achieving organisational integration within the production information flow. The extent to which this correlation reveals a process of structuration (Giddens 1984) in which structure is used to create process, and process generates structure was also discussed. Here lies the main engine of change in these organisations.

15.3 THE PROCESS OF TRANSCENDENCE

The networked metalworking organisation is, then, very different from that normally existing in the industry, and only a few of the case survey organisations are very far along the road towards the *networked form*. Many still rely largely on the sequential processes indicated in figure 13.1, and few have moved beyond reciprocal processes. However, all are implementing some form of linkage mechanism to gain greater organisational integration between the engineering and manufacturing functions, and some have explicit ambitions to achieve a fully iterative production information flow. An indication of the range of position amongst these cases is given in figure 15.2. It is intended merely to illustrate the relationship of each case to the ideal types established earlier, rather than to suggest a teleological evolution. The dynamic paradox of flexibility and productivity will be resolved within each industry in different ways depending on the specific context. Thus "lean production" (Womack et alia 1990) may well be the appropriate resolution for the car industry, but it is to reiterate the errors of the debate on "fordism" to suggest that it is a universal panacea[29]. This will tend to lead to the suppression of the lessons that can be learnt from industries as diverse as biotechnology (Dodgson 1991) and North Sea oil (Stinchombe and Heimer 1985) on the potential shape of the *network form*.

The strategy process is central to the dynamic of change. Strategic shifts by both customers and competitor firms generate changes in market structure, which are signalled to the business as performance gaps. Most of the time these are part of the normal give and take of competition, and can be relatively easily accommodated through incremental shifts in the production mission. However, over time, more fundamental shifts take place and tensions start to develop in the existing organisational form. Attempts to alter the mission with reconfigured information and materials flows are constrained by the existing structure which cannot accommodate the required changes. Eventually, the tensions accumulate to such an extent that only a shift in form is possible.

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29) While Womack and his colleagues may well argue that they are occasionally carried away in their enthusiasm for lean production, and that their claims are not universal, their French publishers, in a subtle mistranslation of the title to "Le *Systéme* qui *Va* Changer le Monde" (my emphasis), clearly have no reservations regarding the hegemonic potential of lean production

As the tensions are generated through the market, they tend to be common to firms within an industry and to propel industry wide changes - those firms failing to change tending to disappear. Where the shifts in market structure are profound and widespread, they engender changes in the organisational paradigm as has been witnessed over the last few years, although the effects are inevitably uneven between industries.

The main problem of achieving a shift of organisational form is awareness. Organisational form is a relatively intangible phenomenon, so it is rarely possible for changes in form to diffuse directly from one organisation to another. What can diffuse are innovations in technologies and techniques. Awareness of a performance gap can mobilise relatively easily around the use by competitors of new technologies such as CAD/CAM, and new management techniques such as TQM. Through the implementation process, awareness of tensions between the effective use of the new technologies and techniques and the existing organisational structure and processes grows. Organisational lag is inevitable in this process; it is the quality of organisational learning which will minimise it. Thus the implementation of new technologies and techniques is central to shifts in organisation form, the extent of the shifts varying with the character of the innovation on the dimensions of system and complexity discussed earlier. The integrating nature of CAD/CAM means that it tends to be relatively influential in developing such awareness.[30]

Change comes through the dynamic resolution of tensions between structure and process in the organisation. Strategic decisions - be they proactive or reactive - require changes in the flows of information and materials for their implementation. One of the most important ways of changing flows is to change the technology, and so the implementation of AMT is one of the main sources of change in the organisation. These changes in process become constrained by the organisation's structure, and so it too changes to facilitate the new flows. At the same time, changes in structure are used to deliberately alter information flows to release the potential of technological changes.

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30) This has also been the case intellectually. Jay Forrester, the director of Project Whirlwind at MIT which was central to the development of the first NC systems (Noble 1986 chap 6), is the acknowledged mentor of Peter Senge (1992 chap 1), one of leading advocates of "organisational learning"

Change is usually incremental within a given paradigm of organisational form, but when tensions become paradoxes, a shift to a new paradigm occurs.

GLOSSARY

Unless otherwise indicated, all the definitions in this glossary are taken or adapted from the glossary in Ingersoll Engineers (1985).

advanced manufacturing technology *(AMT)* General term to cover the application of various developing techniques such as CAD, FMS, robotics and ATE to industrial manufacturing.

algorithm In CAD/CAM software, a set of well-defined rules or procedures based on mathematic and geometric formulas for solving a problem or accomplishing a given result in a finite number of steps.

***alphanumeric* (or alphameric)** A term which encompasses letter, digits, and special characters which are machine-processable.

***APT* (Automatically Programmed Tools)** One of the principle software languages used in computer-aided manufacturing to program numerically controlled machine tools.

batch manufacture The production of parts in discrete runs of batches, interspersed with other production operations or runs of other parts.

beta site A user's CAD/CAM site of facility selected by mutual agreement between the user and the vendor for testing out a new system, application package, hardware or software enhancement before its sale to other customers of the vendor.

***bill of materials* (BOM)** Manufacturing data referring to parts and materials that list: what they are used for, how frequently and how they are structured.

BOM See bill of materials.

***CAD* (computer-aided design)** Describes the more demanding and elaborate preparation of complex schematics and blueprints. In these applications, the engineer constructs a highly detailed drawing on-line using a variety of interaction devices and programming techniques. Facilities are required for replicating basic figures; achieving exact size and placement of components; making lines of specified length, width, or angle to previously defined lines; satisfying varying geometric and topological constraints amongst components of the drawing; etc. A primary difference between interactive plotting and design draughting lies in the amount of effort the engineer contributes, with interactive design draughting requiring far more responsibility for the eventual result. In interactive plotting, the computation is of central importance and the drawing is typically secondary. A second difference is that design drawings tend to have structure, i.e., to be hierarchies of networks or mechanical or electrical components. These components must be transformed and edited. If, in addition to non-trivial layout, the application program involves significant computation of the picture and its components, this is the third and most complex category, that of interactive design. In addition to a pictorial datum base, or data structure, that defines where all the picture components fit on the picture and also specifies their geometric characteristics, an application datum base is needed to describe the electrical, mechanical, and other properties of the components in a form suitable for access and manipulation by the analysis program. This datum base must naturally also be editable and accessible by the interactive user.

***CAD/CAM* (computer-aided design/computer-aided manufacturing)** The integrated use of CAE, CAD, and CAM systems drawing upon the same product data base.

***CAE* (computer-aided engineering)** Analysis of a design for basic error-checking or to optimise manufacturability, performance, and economy (for example, by comparing various possible materials or designs). Information drawn from the product database is used to analyse the functional characteristics of a part, product, or system under design and to simulate its performance under various conditions. CAE permits the execution of complex circuit loading analyses and simulation during the circuit definition stage. CAE can be used to determine section properties, moments of inertia, shear and bending moments, weight, volume, surface area, and centre of gravity. CAE can precisely determine loads, vibration, noise, and service life early in the design cycle so that components can be optimised to meet those criteria. Perhaps the most powerfully CAE technique is finite element modelling. See also kinematics.

CAM (computer-aided manufacturing) The use of computer and digital technology to generate manufacturing-oriented data. Data drawn from a CAD/CAM database can assist in or control a proportion of all of a manufacturing process, including numerically controlled machines, computer-assisted parts programming, computer-assisted process planning, robotics, and programmable logic controllers. CAM can involve production programming, manufacturing engineering, industrial engineering, facilities engineering, and reliability engineering (quality control). CAM techniques can be used to produce process plans for fabricating a complete assembly; to program robots; and to coordinate plant operation.

CIM (computer-integrated manufacturing) The concept of a totally automated factory in which all production processes are integrated and controlled by an IT system. CIM enables production planners and schedules, shop-floor foremen, and accountants to use the same database as product designers and engineers.

COMPACT II A source language used in computer-aided manufacturing to program NC machine tools. COMPACT II is a registered trademark of Manufacturing Data Systems Inc.

computer-aided process-planning (CAPP) An application program that is interactive with CAD/CAM and assists in the development of a process/production plan for manufacturing.

computer-aided testing (CAT) An application program that tests by modelling parts and product design and specifications through interaction with CAD/CAM.

computer numerical control (CNC) A technique in which a machine-tool control uses a minicomputer to store NC instructions generated earlier by CAD/CAM for controlling the machine.

configuration A particular combination of a computer, software and hardware modules, and peripherals at a single installation and interconnected in such a way as to support certain application(s).

database A comprehensive collection of interrelated information stored on some kind of mass data storage device, usually a disk. Generally consists of information organised into a number of fixed-format record types with logical links between associated records. Typically includes operating system instructions, standard parts libraries, completed designs and documentation, source code, graphic and application programs, as well as current user tasks in progress.

detail drawing The drawing of a single part design containing all the dimensions, annotations, etc., necessary to give a definition complete enough for manufacturing and inspection.

direct numerical control (DNC) A system in which sets of NC machines are connected to a mainframe computer to establish a direct interface between the DNC computer memory and the machine tools. The machine tools are directly controlled by the computer without the use of tape.

finite element analysis (FEA) A method used in CAE for determining the structural integrity of a mechanical part of physical construction under design by mathematical simulation of the parts and its loading conditions. See finite element modelling (FEM).

***finite element modelling* (FEM)** The creation on the system of a mathematical model representing a mechanical part or physical construction under design. The model, used for input to a finite element analysis (FEA) program, is built by first subdividing the design model into smaller and simpler elements such as rectangles, triangles, bricks, or wedges which are inter-connected. The finite element model is comprised of all its subdivisions or elements, and its attributes (such as material and thickness), as well as its boundary conditions and loads (including mechanical loadings, temperature effects, and materials fatigue). See finite element analysis (FEA).

flatbed plotter A CAD/CAM peripheral device that draws an image on paper, glass, or film mounted on a flat table. The plotting head provides all the motion.

***flexible manufacturing system* (FMS)** An arrangement of machines (usually NC machining centres with tool changers) interconnected by a transport system. The transporter carries work to the machines on pallets or other interface units so that accurate work-machine registration is rapid and automatic. A central computer controls machines and transport. It may have a variety of parts being processed at any one time.

group technology A coding and classification system used in CAD for combining similar, often-used parts into families. Group technology facilitates the location of an existing part with specified characteristics, and helps to standardise the fabrication of similar parts. Grouping of similar parts in a family allows them to be retrieved, processed, and finally fabricated in an efficient, economical batch mode. See family of parts.

hard automation Use of specialised machines and machine lines to manufacture and assemble products or components. Normally each machine or line is dedicated to one function, such as milling. Hard automation is usually of a continuous manufacturing type and is used for high volume production in distinction to batch production.

hardware The mechanical, electrical and electronic devices which compose a programmable controller/computer and the application components.

***initial graphics exchange specification* (IGES)** An interim CAD/CAM database specification until the American National Standards Institute develops its own specification. IGES attempts to standardise communication of drawing and geometric product information between computer systems.

island of automation (Bright 1958) Stand-alone automated machine, (eg robots, CAD/CAM systems, NC machines) without the integration required for a cohesive system .

job shop A manufacturing facility which specialises in one-of-a-kind or limited production (small batch processing) of parts and subassemblies or products.

kinematics A computer-aided-engineering (CAE) proceeds for plotting or animating the motion of parts in a machine or a structure under design on the system. CAE simulation programs allow the motion of mechanisms to be studied for interference acceleration, and force determinations while still in the design stage.

machining centre A machine capable of performing a variety of metal removal operations on a part, usually under numerical control.

***materials requirements planning or manufacturing resources planning* (MRP/MRP II)** A variety of computer applications for ordering materials and managing inventories that are increasingly interactive with on-line manufacturing data and financial data. See bills of materials.

mechatronics "Mechatronics is the synergetic combination of precision mechanical engineering, electronic control, and systems thinking in the design of products and processes." (Bradley et alia 1991 p xvii).

modelling, solid A type of 3D modelling in which the solid characteristics of an object under design are built into the database so that complex internal structures and external shapes can be realistically represented.

***MRP* (Materials Requirements Planning)** A time-phased, level by level, netting and batching materials planning system.

***MRP II* (Manufacturing Resource Planning)** A development of MRP which takes into account the planned availability of capacity.

***numerical control* (NC)** A technique of operating machine tools or similar equipment in which motion is developed in response to numerically coded commands. These commands may be generated by a CAD/CAM system on punched tapes or other communications media. Also, the processes involved in generating the data or tapes necessary to guide a machine tool in the manufacture of a part.

simulation A CAD/CAM computer program that simulates the effect of structural, thermal, or kinematic conditions on a part under design. Simulation programs can also be used to exercise the electrical properties of a circuit. Typically, the system model is exercised and refined through a series of simulation steps until a detailed, optimum configuration is reached. The model is displayed on a CRT and continually updated to simulate dynamic motion or distortion under load or stress conditions. A great variety of materials, design configurations, and alternatives can be tried out without committing any physical resources.

surface modelling Automatic generation of NC tool paths to cut 3D shapes. Both the tool paths and the shapes may be constructed using the mechanical design capabilities of a CAD/CAM system.

turnkey system Any system for which the supplier/vendor assumes total responsibility for building, installing, and testing, and the training of user personnel. Usually implies a commitment by the vendor to make the system work, and to provide preventive and remedial maintenance.

wire-frame graphics A CAD technique for displaying a three-dimensional object on the CRT screen as a series of lines outlining its surface. See finite element analysis and finite element modelling.

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Institute for Management Research and Development

IMPLEMENTATION OF CAD/CAM PROJECT

The attached is a structured interview schedule for the collection of data for the Implementation of CAD/CAM Project. The Project is funded by both the Science and Engineering Research Council (SERC) and the Joint Committee of SERC and the Economic and Social Research Council.

The project is aimed at establishing the best practice for CAD/CAM implementation, and at developing a methodology for managers who are implementing in the future.

We want to collect information in the following areas:-

- the way in which your unit/plant is organised in terms of departments, communications, production processes and so on

- the product market and more general economic environment in which your unit/plant exists

- the way in which you went about implementing your CAD/CAM system

- the benefits of that implementation you have gained so far, and the problems you have met

All information will be treated confidentially, and no interviewee or company will be identified in the report of the results of the survey. It is not anticipated that any of the information that we collect will be commercially sensitive.

Feedback if the results to the participants will take place through the Warwick Manufacturing Roundtable, and through individual company sessions should you wish.

Very many thanks for your help

Graham Winch
David Twigg

IMPLEMENTATION OF CAD/CAM PROJECT

INTERVIEW SCHEDULE

COMPANY NAME..

ADDRESS...

....

....

INFORMANT'S NAME....................................

POSITION..

COMPANY CODE.........

INFORMANT CODE.......

THE INFORMATION COLLECTED IN THESE INTERVIEWS WILL BE TREATED WITH STRICT CONFIDENTIALITY

THE INFORMATION GIVEN ABOVE WILL BE USED SOLELY FOR ADMINISTRATIVE PURPOSES

A) THE ENVIRONMENT

In this section we want to establish the context in which your plant/unit operates.

1) Could you please describe the recent history of this site in terms of ownership, facilities and employment.

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2) How many employees are there presently on this site?

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3) Can you please tell us the total turnover of the manufacturing operations on this site.

....

4) In assessing the overall performance of this plant over the last two years, would you say that the *gross revenue* earned has been:

- well in excess of costs
- sufficient to make a small profit
- enough to break even
- insufficient to cover costs
- so low as to produce large losses

5) What are the *major* product lines (maximum 3) produced at this unit?

1...
2...
3...

6) For *each* of these major lines, is the market

1	2	3	
–	–	–	local
–	–	–	national
–	–	–	E.E.C.
–	–	–	global?

7) For *each* of these products is your market diversified in terms of the number customers, or largely dominated by a few (<4) customers?

1	2	3	
–	–	–	diversifed
–	–	–	few customers

8) For *each* of these products, would you describe the changes in the level of demand over the last two years, aside from seasonal variations as

1	2	3	
–	–	–	rising
–	–	–	largely static
–	–	–	falling.

9) Over the last two years has the level of competition in the product market for *each* of these products

1	2	3	
–	–	–	increased
–	–	–	stayed largely the same
–	–	–	decreased?

10) Please describe how your plant/unit fits into the structure of the larger corporation.

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If a single establishment firm go to Q 15

11) By what criteria is your unit's performance measured b
head office?

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12) How does your unit fit into head office's product market strategy?

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....
....

13) How is head office's strategy communicated to your unit?

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....
....

14) What input does your unit make to the formulation of head office's strategy?

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....

15) What are the main sources of capital for new initiatives in your unit?

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....

16) Do any statutory requirements such as product liability, pollution, or quality controls impinge upon your engineering and manufacturing processes?

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....

B) MANUFACTURING STRATEGY

In this section we are trying to find out how the production plan of your plant/unit is related to the product market your plant/unit faces.

1) For *each* of the major products identified above, is each product:

1	2	3	
–	–	–	made to forecast and then sold from stock or the forward schedule?
–	–	–	assembled to customer order?
–	–	–	manufactured to customer order from a standard catalogue?
–	–	–	designed (at least in part) to customer specification and then manufactured?

2) What is the annual *unit* volume of *each* of these products?

1....................

2....................

3....................

3) How does the company plan to win orders in the market place? (order winning criteria)

From the following list, pick no more than three in each column, and rank them for each of the products identified above:

Criteria	Prod.1.	Prod.2.	Prod.3.
Price	....	....	....
Delivery			
Speed	....	....	....
Reliability	....	....	....
Quality			
reliability	....	....	....
finish	....	....	....
Rate of new product introduction	....	....	....
Product Design			
Technology level	....	....	....
Performance	....	....	....
Visual design	....	....	....
Other(specify)	....	....	....

4) Do you expect any long-term changes in the order winning criteria in the near future?

....
....
....

5) Does the overall volume of demand for the products of your unit usually vary significantly (>25%)

- over the previous month?
- over the previous year?
- not at all.

6) Would you describe the usual mix of your final products as:

- stable, with little change and easy to cope with
- variable, with reasonable variability with which manufacturing and engineering have the flexibility to cope
- unstable, with major variability in mix which causes major uncertainties and difficulties for engineering and manufacturing.

7) In terms of the major factors in mix variation, into which category do most of your parts fall:

- runners, with fairly continuous, repetitive demand
- repeaters, with regular orders (at least one order or batch per month)
- strangers, with orders on a one-off or very irregular basis (less than one order or batch per month).

8) Can you give a rough percentage of the proportion in each category?

runners ....

repeaters...............

strangers...............

9) How far in advance can you plan production with high certainty (>75%)?

- week
- month
- quarter
- year.

10) Which of the following descriptions most closely fits the role of your manufacturing unit in the overall business strategy of you company:

- the aim is to minimise the potential of manufacturing to lose money for the company;
- the aim is to achieve parity in terms of performance with competitors;
- the aim is to integrate manufacturing within the overall business strategy;
- the aim is to achieve competitive advantage through the development of the manufacturing function?

11) What is the total annual facility development budget for your unit for

next year................

this year................

last year................?

12) Do you have a written statement of the manufacturing goals of your unit?

- yes **(request copy)**
- no

13) Do you have a written statement of the engineering goals of your unit?

- yes **(request copy)**
- no.

14) How would you summarise the strategic goals of your unit?

....

....

....

....

....

15) Do you ever experience conflict between the goals o manufacturing, and the goals of engineering.

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....
....

C) TECHNOLOGY AND MISSION

In this section we want to establish the production processes employed in your unit and the way they are used to meet market demand.

1) For *each* product line, please describe the *main* production process(es) within your unit (outline process chart).

2) For *each* one, would you describe it as:

1	2	3	
–	–	–	one-off
–	–	–	small-batch (less than 100 off)
–	–	–	large-batch
–	–	–	flow line production?

3) Please briefly describe the evolution of these manufacturing processes.

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....

4) What is the main criterion by which day-to-day operational decisions are made with regard to the management of the manufacturing process?

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....

5) Please scale (1,2,3) the following manufacturing performance criteria in order of importance (three maximum):

Scale

- meeting delivery dates;
- maximising labour utilisation;
- maximising machine utilisation;
- minimising work in progress;
- maintaining quality;
- maintaining flexibility;
- maximising output;
- meeting budgets.

6) Please indicate for each of the following statements how well they describe your company's approach to new technology. (1-3 scale, 1 poor description, 2 satisfactory, 3 = good)

Scale

- We have a long tradition and reputation in our industry of attempting to be first to try out new methods and equipment.
- We are actively engaged in a campaign to recruit the best qualified technical personnel available in engineering or production.
- We are strongly committed to technological forecasting.
- We stress our new production or design technology in our marketing strategy.

D YOUR UNIT'S ORGANISATION

In this section we want you to tell us about the way your unit is organised in terms of the functions of the various departments and the relationships between them.

1) Please describe the structure of the manufacturing/engineering functions' organisation **(prepare organisation chart)**

2) Please describe any changes in this structure over the last three years.

....

....

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....

....

3) Please describe the flow of a typical job through these departments **(prepare production information flow chart and materials flow chart).**

3a) Has this pattern changed in the last three years?

....

....

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....

4) How would you describe the information flow between your department, and the one immediately upstream and immediately downstream from you **(show chart 1)**

4a) Has this pattern changed in the last three years?

....

....

....

....

....

4b) How would you describe the information flow between the engineering and manufacturing functions? **(Show chart 2)**

4c) has this pattern changed in the last three years.

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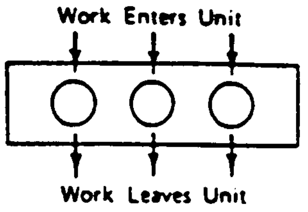
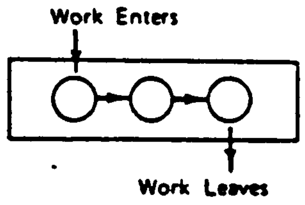
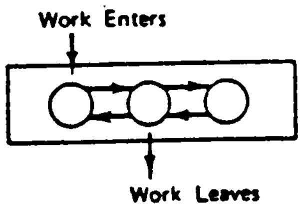
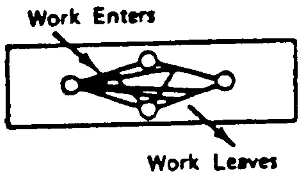
Chart 2

		Engineering/Manufacturing
A) Independent Information Flow		----------
B) Sequential Information Flow		-----------
C) Reciprocal Information Flow		-----------
D) Iterative Information Flow		------------

5) How frequently does your department exchange information with the department immediately upstream and downstream from it.

upstream	downstream	
–	–	daily
–	–	weekly
–	–	monthly
–	–	less than monthly.

5a) Has this pattern changed in the last three years?

....
....
....
....
....
....

6) How is liaison undertaken between your department and the department immediately upstream and downstream.

upstream	downstream	
–	–	informally
–	–	liaison person
–	–	working groups
–	–	matrix organisation

6a) Has this pattern changed in the last three years?

....
....
....
....
....

6b) How is liaison undertaken between the engineering and manufacturing functions?

- informally
- liaison person
- working groups
- matrix organisation

6c) Has this pattern changed in the last three years?

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....

7) Have you taken any steps to develop design for manufacture?

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....
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....
....

8) Which of the methods is closest to the way in which the manufacturing and engineering functions are co-ordinated in your unit (three maximum) **(Show figure 3)**

9) How is the performance of your department evaluated by senior management?

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Chart 3

ENGINEERING/MANUFACTURING COORDINATION PROCEDURES

	PHASE:		
	PRE-PROJECT	**PROJECT**	**POST-PROJECT**
COMMUNICATION PATTERN:			
ONE-WAY	Designers' tacit knowledge of mfg 3	Early mfg start with early design data 2	Manufacturing flexibility 1
STILTED TWO-WAY	Design rules 6	Design reviews 5	Engineering changes 4
TWO-WAY	Functional strategy coordination 9	Joint design teams 8	Post-project appraisals 7

Source:

P.S. Adler: The Managerial Challenges of Integrating CAD/CAM

Chart 4

Elements of Manufacturing Systems Integration

	Inventory Status	Master Production Scheduling/MRP	Shop Floor Control	Design Engineering (including CAD)	Manufacturing Engineering (including CAM)	Process Controls	Quality Reporting	Accounting	Order Entry	Purchasing	Distribution
Sales Planning (including Forecasting)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Inventory Status		☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Master Production Scheduling/MRP			☐	☐	☐	☐	☐	☐	☐	☐	☐
Shop Floor Control				☐	☐	☐	☐	☐	☐	☐	☐
Design Engineering (including CAD)					☐	☐	☐	☐	☐	☐	☐
Manufacturing Engineering (including CAM)						☐	☐	☐	☐	☐	☐
Process Controls							☐	☐	☐	☐	☐
Quality Reporting								☐	☐	☐	☐
Accounting									☐	☐	☐
Order Entry										☐	☐
Purchasing											☐

Please indicate which pairs of computerized subsystems (or tabases) you plan to better integrate over the next two years by checking appropriate box(es).

rce: Manufacturing Futures Survey, Boston University, 1985

E) IMPLEMENTATION

In this section we move on to discuss the implementation of your CAD/CAM system.

1) Please describe your CAD/CAM system, its history and the plans for its future development.

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....

2) What proportion of the total facilities budget given earlier do these developments take ?

- 25%
- 50%
- 75%
- 100%

3) Systems integration. Please indicate which pairs of computerised systems you plan to further integrate over the next two years by filling in the attached integration matrix **(Show figure 4)**

4) Which of the following statements best characterise your current CAD/CAM implementation strategy

- an experiment prior to full scale adoption
- an independent investment in CAD followed by linking to CAM
- A planned phased approach to CAD/CAM
- a fully integrated implementation - CIM.

5) What prompted you to evaluate implementing CAD/CAM.

....
....
....
....
....

6) Have any of your customers influenced your choice of CAD/CAM system?

- yes

- no

If no, go to Q 10.

7) Can you name them?

....

8) What has been the influence of these customers?

	CAD	CAD/CAM
Customer requires that you have technology, and specifies the system		
Customer requires that you have technology		
Customer suggests that you have technology		

10) On what criteria was the system justified?

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....
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....
.

11) To whom was the justification made?

....
....
....

12) Over what time period did you implement/do you plan to implement the system?

....

13) Which of the following statements best characterises your systems evaluation strategy?

- an independent systems consultant was retained

- a single CAD supplier was approached

- multiple CAD suppliers were approached

- a combination of consultants and suppliers were approached

14) Which of the following best describes your procurement strategy?

- use of external supplier for total turnkey operation

- joint design and installation - supplier dominant

- joint design and installation - your company dominant

- total control of design and installation by your company

15) How was the system designed?

- standard system - off the shelf

- system tailored to company environment

16) What criteria were used to select the supplier(s)?

....
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....
....

17) Please rank the quality of your unit's relationship with the system vendor during implementation for *each* of the following questions on a 1-3 scale (1=poor, 2= satisfactory 3=good).

<u>Scale</u>

- the quality of the relationship was very good

- supplier and user goals were compatible

- problem solving styles were easy to integrate.

18) Can a particular individual be credited with pushing the implementation through?

- yes

- no

19) If yes, please give his/her position in the organisation.

....

20) What role have senior management (i.e. director level) played in the decision to innovate and the subsequent implementation?

....

....

....

....

....

21) Was any specific grouping set up to evaluate and/or implement the system?

evaluate	implement	
–	–	informal group
–	–	part-time task force
–	–	full-time project team
–	–	specialist project manager appointed?

22) If so. can you please describe the brief it was given?

....

....

....

....

....

23) Which departments were involved in the

evaluation

....

....

implementation planning of the system?

....

....

24) Has the company had any previous experience of the implementation of:

- computerised business systems (e.g. purchasing payroll)
- CAD
- CAM
- CAD/CAM
- value engineering techniques
- group technology
- Just-in-Time production
- M.R.P./ M.R.P.2

25) If so, please describe them briefly

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....
....

26) Have there been any disputes between departments over the implementation of the system?

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....
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....

27) How did you obtain the expertise required for the evaluation and implementation of the system?

evaluation	implementation	
–	–	use existing staff
–	–	hire a consultant for an initial report
–	–	retain a consultant over the key stages of evaluation and implementation
–	–	hire full-time specialist staff.

28) Is there an implementation project manager?

- yes
- no

29) Is there a manager in charge of CAD/CAM operations?

- yes
- no

30) Please rate criteria for the selection of the managers specified in 29/30 on the following on a 1-4 scale (1 low 4 high)

	CAD/CAM MGR	PROJECT MGR
Design experience		
Software/systems expertise		
Prior experience of CAD or CAD/CAM		
Cross-functional management skills		

31) Were each of these managers recruited

internally: CAD/CAM man.........................
project man.........................

externally: CAD/CAM man.........................
project man.........................

32) What are the major sources of learning that you expect during the CAD/CAM implementation.

....
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....
....

33) If the system is operating, do you have a policy of getting improvements?

....
....
....
....
....

34) Please describe your training associated with the new technology for each of the following employee groups:

Personnel	Amount			
	<week	<month	1-9months	>9months
Design Engineer				
Draughstmen				
Production engineers				
Planning staff				
Manufacturing managers				
Engineering managers				
Senior managers				
Supervisors				
Others (please specify)				

35) What project management and planning tools have you used?

....

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....

F) PERFORMANCE

In this section we want to ask you about the outcomes from the implementation of CAD/CAM in your unit.

1) Does the system meet the criteria laid down in the evaluation in terms of

- cost

- deadline

- performance.

2) If not, why not?

....
....
....
....
....

3) How do you, or plan to measure the performance of the

implementation project

....
....

the implemented technology

....
....

4) Are any of the following used in the evaluation of the system performance?
(1=not used 2 = some use 3 =important measure)

Scale

-Time to install

-Cost to install
(%over budget)

-Uptime

-cycle time met

-ROI

-Design to
manufacture lead time

-labour productivity

-customer satisfaction

-operating cost
(versus budget)

-Cycle time

-Plant Utilisation

5) Who sets performance measures?

....
....

6) How is measurement done?

....
....

7) Who is measured?

....
....

8) What changes in these have there been in measures since

installation

....
....

commissioning?

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....

.....

9) How have your expectations of these projects changed since the start?

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10) What have been the key events:

The show stoppers
The key technical events
Other problems
Problems solved

since the start of the project

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in the last 6 months

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11) Have there been any changes in the organisation of your unit as a direct result of the implementation of CAD/CAM?

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12) If so, have you experienced any opposition from other parts of your company, outside your unit, to the changes you have made following implementation?

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13) Have you been obliged to make any changes as a result of such pressure?

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14) Have you gained any unforeseen benefits?

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15) If you were to start again, how would you manage this implementation differently?

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17) Looking back, do you think that you made the right choice in system specification?

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18) Are there any issues which you think ought to be addressed associated with CAD/CAM implementation which we have not covered in this interview?

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VERY MANY THANKS INDEED FOR YOUR TIME