A GENERIC MODEL FOR THE DESIGN AND ANALYSIS OF PRODUCTION SYSTEMS

PAUL LESLIE FORRESTER

Doctor of Philosophy

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Thesis Summary

This dissertation studies the process of operations systems design within the context of the manufacturing organization. Using the DRAMA (Design Routine for Adopting Modular Assembly) model as developed by a team from the IDOM Research Unit at Aston University as a starting point, the research employed empirically based fieldwork and a survey to investigate the process of production systems design and implementation within four UK manufacturing industries: electronics assembly, electrical engineering, mechanical engineering and carpet manufacturing. The intention was to validate the basic DRAMA model as a framework for research enquiry within the electronics industry, where the initial IDOM work was conducted, and then to test its generic applicability, further developing the model where appropriate, within the other industries selected.

The thesis contains a review of production systems design theory and practice prior to presenting thirteen industrial case studies of production systems design from the four industry sectors. The results and analysis of the postal survey into production systems design are then presented. The strategic decisions of manufacturing and their relationship to production systems design, and the detailed process of production systems design and operation are then discussed. These analyses are used to develop the generic model of production systems design entitled DRAMA II (Decision Rules for Analysing Manufacturing Activities). The model contains three main constituent parts: the basic DRAMA model, the extended DRAMA II model showing the imperatives and relationships within the design process, and a benchmark generic approach for the design and analysis of each component in the design process. DRAMA II is primarily intended for use by researchers as an analytical framework of enquiry, but is also seen as having application for manufacturing practitioners.

Two hypotheses defined at the start of the research were tested. The first related to whether a generic model of production systems design could cover the range of operational and organizational contexts explored in the research. It is contended that DRAMA II now provides such a model. The second hypothesis related to whether market and environmental factors are the primary influences upon systems design. The second hypothesis is rejected as merely a partial explanation of the determinants involved in production system design, with other considerations such as technology, organization structure, conflict, culture and inertia also having important influences.

Key words or phrases:
Production Systems Design, Manufacturing Strategy, Decision Process Modelling, Design Process, Organizational Decision Making

Dedication

To my Parents, my wife Gill and my children Stacie and Natalie, without whose enduring support, encouragement and sacrifice this work would not have been possible.

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This thesis would not have been possible without the support and access provided by a large number of individuals, organizations and bodies. First and foremost I wish to acknowledge the help and encouragement provided by my supervisor, David Bennett. From the start of my academic career David has always shown great enthusiasm for the research upon which we have jointly embarked and has always taken time out from his extremely busy schedule to provide advice and guidance. It was David who provided the opportunity for me to pursue my academic career by recruiting me as a Research Officer at Aston. He has invested considerable time mentoring my progress: I hope that, in some small way at least, I have reciprocated his assistance and will continue to do so into the future.

It is also important to acknowledge the financial support provided for my research over a total of six years by the Science and Engineering Research Council's *Application of Computers to Manufacturing Engineering (ACME) Directorate* who have funded two projects into production systems design that I have been involved with. I must also acknowldge the Economic and Social Research Council (ESRC) who have also funded work of a more social and organizational nature, as well as part-funding my salary for a period as an ESRC Management Teaching Fellow.

It is impossible to acknowledge all the people and organizations that have been involved in the research, but it is important to specially recognize the time, access and interest provided by personnel at International Computers Limited where the initial research was conducted. Special mention must go to Peter Wright who, during the ICL research, was the Manufacturing Engineering Manager at The Ashton-under-Lyne plant. Peter was always on hand within the company for frank advice and discussion and provided me with levels of access which most researchers probably only dream of. Thanks to all the people in all the other companies as well for their valuable time and immense hospitality: you know who you are!

Finally I would like to acknowledge two more people with whom I have, at various stages of the doctoral project, worked very closely. Sushil Rajput was my research colleague for the initial work on the IDOM project at ICL and conducted a substantial part of the investigative work as well as helping to develop the DRAMA model and methodology. Secondly John Hassard at Keele University joined the ICL project at an early stage as a co-opted investigator and helped guide the organizational and social aspects of the research. I have now been working with John as a colleague at Keele for a number of years where he has continued to provide advice as well as offering himself as a sounding board for any new ideas or initiatives. To both Raj and John, a big "thank-you".

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Chapter One
PROJECT OVERVIEW

1.1 Introduction

The practice of designing production systems has a long history which can be traced to well before the Industrial Revolution: consider the construction of the pyramids in Ancient Egypt and the line assembly techniques adopted in the Middle Age Venetians in the building of ships (see Wild, 1973). The means by which resources are drawn together and facilities and people are organized in an appropriate manner must always be addressed when considering the manufacture or assembly of any product, whether this involves factory production, is a cottage industry or "on-site" manufacture such as building construction.

There have been some direct influences upon organization for production. Chronologically the most significant contributions have been those of Adam Smith and the division of labour (Smith, 1776), Frederick Taylor and the principles of scientific management (Taylor, 1911), Henry Ford and volume assembly (Ford, 1923), the Human Relations School including Elton Mayo and the Hawthorn studies (Roethlisberger and Dickson, 1939) and the Socio-Technologists, most notably from the Tavistock Institute (Trist et al, 1963). Developing the work of a Russian economist, Kondatriev, and that of Freeman et al (1983), Bessant (1991) has argued the existence of a "long wave" model of technological and organizational development which recognizes clusters of innovations associated with economic prosperity and a corresponding deficiency in such innovations in periods of decline and depression.

More recently manufacturing organizations have faced accelerated rates of technological innovation in products and processes, combined with the increased saturation of markets, heightened demands from customers for product variety and differentiation and intense competition (Boer,1990). Such factors explain contemporary views which advocate market-driven and responsive design and operation of production systems (Bennett et al, 1992; Bennet and Forrester, 1993). The role of production systems as a determinant of business performance is, as a result, under close scrutiny. This matches with Bessant's (1991) view which, having identified the existence of four long waves of economic development to date, argues that the "fifth wave" now beckons providing the stimulus and challenges for the next generation of technological innovation.

The widespread perception is that no longer can most companies rely solely on low cost and efficient manufacture to maintain competitive edge, but that quality, service, time and other factors enable strategic advantage to be achieved at the systems level (Skinner, 1978, 1985; Hayes and Wheelwright 1984). The key seems to be that production systems should, above all, be "effective" over and above being "efficient". This brings into focus the comments of Peter Drucker (1954) who, as long ago as the 1950s, argued that companies should concentrate on "doing the right things" rather than merely "doing things right". The net result of the above developments is that today the effective functioning of operations systems, coinciding with appropriate corporate and marketing strategies, are critical in the overall success or otherwise of a manufacturing organization (Hill, 1991).

The development of Production and Operations Management has been closely tied with the major industrial events and emergence of a number of schools of thought over the last 200 to 300 years. In the 1800s the prime focus was the general management of the factory (see Gaither, 1992), but as scientific management practices became more widespread in the early twentieth century the discipline changed from general Factory Management, with control and decision making within the domain of the business entrepreneurs, to Production Management where specialists in engineering and work study provided expertise in their relevant fields. The wider operational perspective brought in by OR to encompass transportation, logistics and supply plus the growing need to incorporate and learn from service operations has broadened the discipline further. Now, subject to the influence of computer developments and the emergence of "Japanese-influenced" approaches, theory and practice continues to develop subject to a number of different, and often conflicting, influences. The historical dimension of production systems design is useful here by way of introducing the subject area. Understanding the influences upon the development of the discipline discloses the reasons for alternative approaches to process design, the differing objectives of those organizations introducing new systems and thus promotes an understanding of modern day practice and from where and when its philosophies emerged[1].

The influences upon the design of modern production systems are numerous. The historical dimension, from Adam Smith through FW Taylor and to contemporary views of system operation, has left a rich legacy. More recently, market and environmental factors have been recognized as exerting a strong influence upon facility decisions. Organizational issues have also shaped the design process which frequently involves trade-offs and compromises due to the forces of organizational inertia, power and politics upon the decision making process (Mintzberg et al, 1976).

The many diverse and conflicting strands influencing the design of production systems has led to a wide variety of approaches. The author argues that there is an absence of any single model for systems design which takes into account the full range of market, strategic, organizational, technical and behavioural forces upon the production systems design process. The current deficiency outlined above and the increasingly short life cycle of production systems leads one to believe that the development of a coherent and encompassing theory for the design of effective production systems is overdue.

This thesis addresses the issue of systems design. Design activities are analysed in a range of manufacturing situations within the framework of a process model for the design, development, implementation and evaluation of production systems. The central concern throughout is whether a generic model of this type can adequately describe and represent design activities within a diverse range of manufacturing conditions and organizations. This, it is suggested, depends upon the level of detail the model seeks to portray. It could be argued that any business has its own individualistic issues which are distinctive from any other organization. Likewise, production systems often have a high degree of specificity at the level of operations: they tend to be "domain dependent" (AMICE Esprit, 1990). However, to treat each case as entirely unique and to deny the existence of any

[1] See Bennett et al (1988); Ayres (1991) and Gaither (1992) for a fuller description of the evolution of manufacturing and its associated management practices.

generalisable features among different operating units would be to preclude the possibility of any theory in the field of production systems design.

Clearly, there exist common principles across the range of operational and industrial contexts and substantial literature exists both from management and engineering perspectives (see Chapter Four). Models do exist for the analysis of manufacturing design and other more general process models can be adapted for the same purpose. These, however, tend either to be restricted to conceptual levels of design, thus providing little by way of practical use for systems designers or research analysts, or else are overly prescriptive and limited in their scope and utility. Having considered the literature the question still remains as to whether a single comprehensive model can ever ever adequately encompass all aspects and contexts of systems design. This dissertation will explore the possibility of developing a generic model for the analysis of production systems design, applicable over a range of different industrial and organizational contexts, and capable of being used in a pragmatic way beyond conceptualisation.

1.2 Aims and Objectives

This thesis has one overriding aim: to evaluate and translate a model for the design of electronic assembly facilities ("DRAMA") into a model with generic properties across a wider range of manufacturing situations. The author was centrally involved in the development of the DRAMA model as a member of a research team based within the Innovation, Design and Operations Management Research Unit at Aston Business School. The work was primarily based upon a three year longitudinal study of production systems design within International Computers Limited's (ICL's) mainframe computer assembly plant where ethnomethodology formed the core of the research investigations.

DRAMA, standing for "Design Routine for Adopting Modular Assembly", was conceived as a descriptive conceptual model for the design of electronic assembly and test systems and then developed into a more prescriptive process design methodology for the electronics industry. DRAMA was shaped and refined largely as a result of the ICL analysis, although a total of ten smaller comparative studies in other electronics companies were used to shape and refine the model. Throughout the development of DRAMA the research team regarded the model has having more generic properties for explaining the process of systems design and, furthermore, that it could be used as an analytical tool for research investigation or in-company evaluation (Bennett and Forrester, 1991). This thesis explores these potentials.

The primary objectives of the doctoral research detailed within this thesis are, therefore, two-fold:

1. To further validate DRAMA as a model for production systems design within the UK electronics industry; and

2. To consider the applicability of DRAMA as a generic model for production systems design across a predefined range of industrial and organizational contexts.

A central theme running through all chapters in this thesis is the blending of established theory and practice with contemporary issues and ideas in the design of production systems. It is argued that the DRAMA model, in a modified form, structures this convergence of theories and practices and thus offers a vehicle for advancing knowledge and understanding in the analysis of systems design activities.

1.3 Scope and Utility

The research has been conducted within four identified industrial sectors. These are "electronics assembly", "electrical-engineering", "mechanical engineering" and "carpet manufacturing". Although the current scope of the modified DRAMA model is arguably restricted to the analysis of operations, there still exists considerable possibility for further testing and validation of the model as a generic portrayal of production systems design across a range of other manufacturing contexts. It is even considered that DRAMA could be extended to the design of service operations. The thesis indicates the prospects for further application and research throughout.

The original DRAMA methodology, as set out in the "DRAMA Manual" (Bennett, 1990) was intended primarily for use by practising managers and engineers in the electronics assembly industries. It comprises a set of guiding principles which should assist in the design and implementation of flexible assembly systems for electronic products. The manual had a sound theoretical and academic foundation, containing a detailed analytical case study of ICL and sections dealing with theory and contemporary best practice. Being sponsored by the Science and Engineering Research Council's ACME Directorate, a high degree of industrial relevance, pragmatism and generality to other organizations with similar production systems issues was also called for. The main purpose was to develop an empirical methodology containing guidelines for the development of more effective assembly systems for the UK electronics industry.

The IDOM research team believed that the basic model underpinning the DRAMA manual offered a framework for the analysis of manufacturing operations beyond the scope suggested by the ICL case. This has led to the development of "DRAMA II", "Decision Rules for Analysing Manufacturing Activities". The emphasis in the expansion of DRAMA has been to move away from a detailed, prescriptive and process choice orientated methodology applicable to a limited range of operations to evolving the model into a state by which it can be used for the analysis of manufacturing design in general.

This thesis is therefore aimed mainly towards the research community and is contained largely at a conceptual level. DRAMA II is presented as a framework for investigating process design and change within manufacturing organizations. As such it does not claim to present a detailed set of specific design options as can be found within the DRAMA manual. Having said this, the model does provide the basis for developing industry specific design methodologies should these be required, and Chapter Nine of this thesis illustrates how this might be done. Thus DRAMA II could be used as the structure for developing DRAMA-type manuals for different manufacturing sectors.

DRAMA II offers the opportunity for predicting outcomes. The model is centred around a notion of organizational decision making and is chiefly concerned with the manner by which strategic and marketing decisions are translated into specific manufacturing process choices and their eventual operation. The thesis explores the way in which different choices at the strategic level of a business effect the design process for new production systems and suggest the likely outcomes of alternative strategies on the effectiveness of manufacturing.

This thesis, therefore, addresses the need to provide a model for researchers in the field of production systems design. On the evidence of the literature review such a model does not currently exist. The main utility of the model is seen as providing a structure for the analysis of manufacturing decisions on the formulation of strategy and its translation into choice of processes. There is, however, a predictive element as to the manner in which different design options lead to alternative outcomes. Constraints of time and the desire to perform in depth case analyses has meant that the research has been restricted to four industrial sectors. Beyond this there is considerable scope for the use of DRAMA II to be validated, refined and applied across a wider range of organizational and operational contexts, manufacturing and service industries.

1.4 Research Design

The research methodology adopted for the doctoral project is presented in detail in Chapter Three. However, the overall research design will be summarised here to provide an overview of the project.

The starting point for the research was the original DRAMA methodology, as presented within the DRAMA manual[2]. The doctoral project has built upon this work, but advanced the research into production systems design two stages further. Firstly the findings in the original study were primarily based upon the research conducted within ICL, and the company's Ashton-under-Lyne mainframe assembly factory in particular. The ICL case is presented in some detail within the manual and provides the foundation for the design methodology. The research approach adopted in the original study had its merits: the quasi-

[2] The DRAMA manual is the edited work by Bennett developed by the IDOM research team at Aston Business School (Bennett, 1990).

ethnographic and participative observation generated a richness of data which could not be expected using other research methods such as periodic interviews and surveys[3]. The approach adopted, however, has its limitations, particularly with regard to the extent to which it could be claimed as a means for developing a generic methodology and model for systems design, being largely based on the one case. This criticism of generalising from the single case is addressed to a degree. Within the manual there exists a track through the document entitled "Assessment" where, in addition to reference to existing theory, details are given of ten comparative case studies. These case companies had comparable manufacturing operations to ICL, namely electronics assembly or associated technology, and faced similar environmental factors where increased demands for variety, flexibility and response were being placed upon production. This analysis enabled the IDOM researchers to develop an interpretation of "best practice" within the industry, thus giving bench-marks against which ICL's production system design activities could be assessed.

The doctoral project has examined production systems design in the electronics industry in greater detail than in the original IDOM study, using the DRAMA model as a framework for analysis. This part of the research relates to the first objective presented: "to further validate DRAMA as a model for production system design within the electronics industry".

The material used in this analysis is similar in nature to that used in the ACME project. It is predominantly primary data sourced directly from within the organizations involved. The data for the doctoral project has come from two main sources:

i From the ACME project

The amount of data collected from the comparative company studies during the ACME study was substantial and offered the potential for more detailed analysis, beyond that performed in the interpretation of industry best practice. The author was, in fact, primarily responsible for the collection of these data during the ACME project and the material

[3] A full narrative on the advantages and caveats of the research approach adopted in this work is contained in Bennett et al (1992).

comprises initial site visit reports[4], tape recorded interviews and interview notes[5], company documentation and other researchers' notes. Not all the comparative organizations used to develop DRAMA are presented. Rather four cases have been chosen for detailed analysis[6].

ii From a questionnaire survey

Using the DRAMA model as a basic framework, a questionnaire on production systems design was developed[7]. Respondents from the electronics industry included the four companies presented as cases above, but also a further five companies.

In addition to electronics manufacturers, production systems design within three other manufacturing sectors was studied using comparable methods. This part of the analysis addresses the second objective: "to consider the applicability of DRAMA as a generic model for production systems design across a predetermined range of industrial and organizational contexts". The three sectors chosen were the electrical engineering, mechanical engineering and carpet manufacturing industries. The rationale behind the choice of these sectors was simple. Firstly they represent a reasonable cross-section of U.K. manufacturing industry. Secondly there were opportunities for access into companies in these sectors. Data were collected in almost identical fashion to that compiled from electronics companies. It involved:

i The Development of Detailed Case Studies

Three organizations from each of these sectors were visited and studied in detail. In addition to the initial site visit report, semi-structured interviews formed the predominant research method.

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[4] Initial site visit reports where based around the questions asked on a pro forma sheet reproduced in Appendix A. An example report developed from an initial visit is given in Appendix B, with identity of the company removed.

[5] See example interview agenda in Appendix C.

[6] See case study material in Chapter 5 and the subsequent analyses in Chapters 6 to 8.

[7] The questionnaire is reproduced in Appendix D.

ii Questionnaire Survey

The same questionnaire employed in the electronics industry was circulated to companies in the other three sectors. A total of 25 responses were received, including those from all the case companies, in addition to the 9 responses received from electronics companies. This data now provides a wide catchment of responses to questions on production system design.

The analysis performed has been a combination of qualitative and quantitative examination of the data. The detailed case studies are presented using the DRAMA model as a framework. Therefore they are presented in Chapter 5 in a narrative which explores the design in relation to the ten components of DRAMA: Market and Environment, Manufacturing Strategy, Organization, Justification, Project Management, Physical System Design, Control and Integration, Work Design, Implementation and Evaluation. The survey questionnaire is also structured within this framework and so Chapter 6 provides detailed quantitative information on the nature of production systems design in the respondent companies. The main analysis is presented in Chapters Seven and Eight. However to have presented this analysis within the classification of the ten DRAMA components would have run the risk of merely restating much of what is contained in the DRAMA manual and the book which stems from much of this research (Bennett and Forrester, 1993). Rather these chapters are presented in such a way that highlights a recurring theme throughout the analysis: how do the decision making mechanisms within an organization, from the strategic to operational levels, interrelate and result in the choice of specific system design options?

1.5 Cases in Sector Studies of Production System Design

A total of thirteen case studies of production systems design are presented and referred to within this thesis: four from the electronics industry (in addition to the initial ICL study), and three each from the electrical engineering, mechanical engineering and carpet manufacturing industries. Each study is intended to provide rich material concerning the systems design process and the nature of organizational decision making.

The Electronics Assembly Industry

Being the foundation of the original ACME project resulting in the development of DRAMA, ICL is referred to throughout this thesis. The case is presented in detail in the DRAMA manual and also in the Bennett and Forrester (1993) book, so to repeat the case study here in detail would be unnecessarily repetitious[8]. Four other cases of production systems design in electronics companies are presented in Chapter 5. Anonymity of these companies has been maintained throughout the dissertation and so each has been given a pseudonym. Brief details of each company are as follows:

Company A	A large multi-national manufacturer of computer-related products making banking equipment and large computer components within the factory studied.
Company B	Another large multi-national company producing document handling equipment within the plant researched.
Company C	A multi-national company manufacturing advanced test equipment in their U.K. factory.
Company D	A relatively small U.K. based company, recently taken over by a European multi-national, producing sound mixing equipment for broadcasting and audio recording studios.

The Electrical Engineering Industry

The three companies providing the cases within this sector are as follows:

Company E	A U.K. manufacturer of automotive electrical wiring products.

[8] A brief summary of the case, however, is provided in Chapter 2 as background to the research.

Company F Part of a worldwide parent organization producing office equipment, the company produces office duplication machines at the site studied.

Company G The U.K. subsidiary of a multi-national company producing household electrical appliances.

The Mechanical Engineering Industry

The cases investigated in depth in this sector include:

Company H A medium sized British firm which fabricates body panels and large subassemblies for U.K. and European motor vehicle manufacturers.

Company I A large international company manufacturing a wide range of specialised heavy duty vehicles at their U.K. plant.

Company J A small company supplying fabricating and supplying tubular steel products and pipe assemblies to U.K. motor vehicle and gas appliance producers.

The Carpet Manufacturing Industry

This is a largely traditional manufacturing industry where British producers remain as world leaders in the high quality and customised niches of the market. The cases are:

Company K A privately owned U.K. manufacturer of woven carpets which has a high degree of vertical integration in its operations.

Company L A small producer of very high quality Axminster and Wilton carpets.

Company M Part of a large diversified multi-national company which, in addition to woven carpets, also manufacture lower priced tufted products.

Each of the thirteen companies above have been investigated to provide a detailed case of production systems design and the process of strategy formulation and decision making. The cases are presented in narrative form, but structured within the DRAMA framework. They are intended to give insights into the process of designing and implementing production systems and the way in which decisions on strategies and system choices are made. Finally they provide a test for the rigidity of the DRAMA model as a framework for the analysis of production systems design activity, and highlight the need to adapt the basic model to make it more comprehensive a tool in a generic sense.

1.6 Survey of Production Systems Design

A questionnaire on production systems design has been developed and used within the research project[9]. This has been used in conjunction with a survey of organizations within the four chosen industrial sectors to complement the detailed case studies introduced above. The logic underlying the choice and configuration of questions is described more fully in Chapter 3, but it is useful here to indicate the purpose of the survey:

i The survey enabled the author to "follow-up" those companies which form the detailed case studies. The survey not only had the effect of validating the case material, but also served to update and clarify the researcher's understanding of production system design within these companies.

ii The survey was used to increase the catchment of companies and the sample size of the overall study. The case studies provide a richness and depth of information, but are of limited validity when one attempts to generalise findings. The questionnaire survey has therefore been used to interpret generic practice in systems design and validate the DRAMA model across a wider range of industrial and organizational contexts.

[9] See Appendix D.

1.7 Structure of Thesis

The structure of the main body of the thesis is now described in detail. A major concern of the author was to distinguish the personal doctoral study from the work conducted as part of the original ACME project. The structure of the thesis is intended to clarify this and demonstrate the contribution to the understanding of production system design in a generic sense made by this research over and above the ACME project. Following a description of the work conducted as part of the ACME project in Chapter Two, Chapters Three to Ten present the doctoral work in further developing and validating the DRAMA model.

Chapter Two provides commentary on the background to the doctoral research project and, in so doing, necessarily describes the ICL case which forms the basis of the work underpinning the development of DRAMA. The research leading to its development is then explained. The DRAMA model is then described in detail and the concepts of design *components* and organizational *domains* of decision making, as contained in the model, are introduced. The detailed design methodology for the design of high variety assembly systems for electronics, as presented in the DRAMA manual, is then articulated and the limits to its application declared. Given its specific nature, the author then suggests the potential for DRAMA to be used as a generic model for production systems design beyond the scope implied by the ICL case. At this point the doctoral research is distinguished from the original work and it will be shown how this project seeks to extend DRAMA for use by researchers as a framework of analysis for systems design, and manufacturing decision making generally. The chapter concludes with stating two hypotheses that form the basis of the research. The hypothesis are:

Hypothesis 1

> **Production systems design can be represented by a generic process model across a defined range of operational and organizational contexts.**

Hypothesis 2

> **Production systems design is most strongly determined by market and environmental factors as reflected within corporate and manufacturing strategies.**

The methodology adopted to test the hypotheses is described in Chapter Three. The overall research design is explained and then the specific methods used are presented. These include a literature review, site visits, interviews, a questionnaire survey and analysis of the data provided by these. The methodology is compared with that employed in the initial ACME project and is defended and justified against other forms of research design commonly used for industrial research.

A review of the literature relating to production systems design and organizational decision making is presented in Chapter Four. An important and recurring theme in this review is the concept of flexibility and it is noted how the concept of flexibility is interpreted differently from a number of paradigms. Such a discussion also seems appropriate when one considers the often stated desire for production systems to be increasingly responsive, adaptable and responsive to the dynamic market and customer demands that characterise contemporary markets, and the consequent need to adopt a contingency approach to decision making. The literature review is presented in a format that is compatible with the DRAMA model and the links between the categorisation of the literature and the components and domains of the design model will be established and identified throughout the chapter.

Chapter Five presents the case studies, categorised by manufacturing sector, and considers the degree to which the DRAMA model can be used as a valid and useful means of analysis. In addition to the detailed cases, the results of the survey for organizations within each sector are presented, thus providing a picture and evaluation of the nature of production systems design for each industry. This chapter is geared towards testing the hypotheses and so the discussion and examination of the material is two-fold; firstly to consider the degree to which the component and domain concepts inherent within DRAMA provide a logical framework for the analysis of systems design and, secondly, to examine the linkages between the environment, strategy and design and operation for each company and for the sector generally.

Chapter Six presents the results of a complementary postal survey on production systems design. The survey was conducted after the empirical case study research presented in Chapter Five was conducted. It serves two purposes; firstly, to increase the number of organizations from which data was conducted for the project; and, secondly, to act as a follow up to those case study organizations described in Chapter Five. The main purpose of the survey was to validate and increase the confidence of the conclusions derived from the case study research and to provide some quantitative data to support the qualitative results generated thus far. The questionnaire used and the covering letter and other guidance sent to respondents is given in Appendix D. The chapter begins by giving information on the number and range of survey responses, before providing the results in a summarised format. The responses from those organizations investigated as case studies in Chapter Five are then isolated and the results compared to the qualitative impressions given in the cases. Finally the results from the survey are consolidated into statistics so that similarities and differences can be identified both within and between those industrial sectors chosen.

The findings of the research are summarised in the final three chapters. Chapters Seven and Eight focus on the nature of production systems design generally and the current state of the art. These two chapters are primarily concerned with the decision making process and exploring the extent to which systems design is determined by market, technological or strategic factors. This discussion centres upon the second hypothesis, exploring decision making within the production systems design process and the manner in which influencing factors are translated into systems designs and operation at the operational level. These analyses however are couched within the framework provided by DRAMA and, as such, are also intended to test the validity and appropriateness of using the model as a means of critique, thereby addressing the first hypothesis.

Chapter Nine expands upon the findings regarding the appropriateness of DRAMA as a generic model for the analysis of production systems design activities within manufacturing organizations. The development of the model is discussed and DRAMA is modified from the limits of electronics assembly into a more appropriate structure for the analysis of production systems design in general. The evolving model, "DRAMA II", with its change in emphasis and presentation, better satisfies the demands for a generic process model than the original model (Bennett and Forrester, 1993).

The main issue that needs to be stressed is that a generic model of production systems design will necessarily be contained at a conceptual level and the fine details of design and the feasible options vary from industry to industry, and even company to company within a single sector. However it is argued that DRAMA II now offers the means for developing detailed design methodologies to suit specific circumstances and situations. So a DRAMA-type methodology, such as the one developed and contained within the DRAMA manual for high variety electronics assembly (Bennett, 1990), can be developed for a wide range of operations using the DRAMA II model as a framework.

1.8 Research Findings

The research findings are presented in detail within Chapters Seven to Ten. The main findings are summarised here in relation to the hypotheses presented above.

In relation to Hypothesis 1:
Production systems design can be represented by a generic process model (DRAMA II) across the range of operational and organizational contexts examined in this research. However it is recognized that limitations exist in the model's application for specific purposes. DRAMA II now provides a framework which assists in the analysis of operations systems design and has predictive qualities in terms of recognizing the implications of alternative choices on the eventual effectiveness and flexibility of systems operation. The model is most effective at the conceptual level of analysis and cannot purport to provide guidance in all aspects and levels of production system activity in all circumstances. Systems will always be developed in unique and specific ways to satisfy different requirements and specifications: no one system design project is identical in every detail

to another. To argue, however, that there are no common principles and similarities, and that lessons cannot be drawn from one situation for use within a different context, is to deny the existence of any theory of production management and design. Clearly this is not the case, and DRAMA II represents a model capable of providing a framework for identifying similarities and differences within each of its components and domains of decision making.

In relation to Hypothesis 2:

This hypotheses states that "production systems design is most strongly determined by market and environmental factors as reflected within corporate and manufacturing strategies." This turns upon the argument that market and technological determinism are prevalent during the design of production systems. It is concluded that market considerations, as interpreted by organizations in their marketing and manufacturing strategies, do play their part in shaping the design of production systems. Likewise, the currently available technology also determines systems configuration and the observed tendency towards a technological fix amongst many practising engineers was plain to see in a number of the cases studied[10]. Indeed, if one were to prescribe an approach to the design of effective production systems within a market economy one would logically argue the need for an overriding market driven approach coupled with the adoption of the latest and most appropriate manufacturing technologies.

Production system design in practice, however, does not necessarily follow the logical idealised approach suggested above. One only needs to consult the organization theory literature to conclude that market, environmental and strategic factors are not, in themselves, the sole influences upon decision making and design processes. Moreover, this thesis argues that the "open systems orthodoxy" (Silverman, 1970; Reed, 1985) of the literature distracts from the effect of internal influences upon design from within the organization. In just the same way as organization size and power-control relations, in addition to market, strategy and technology, are seen as important determinants of organization structure, likewise they influence and shape eventual systems designs.

[10] The influence of technology, however, was not identified as a major determinant in the responses to the production system design survey.

Organization structure, conflict, culture and inertia (largely governed by a company's history) all have their influence upon the system design process: they explain why the design process and eventual configuration of facilities differ between organizations, even where companies are offering comparable products to the same markets. The second hypothesis is therefore rejected as merely a partial explanation of the determinants involved in production system design.

1.9 A Generic Model for Production Systems Design

DRAMA II represents the modification of the original DRAMA model which was confined to electronics assembly systems design. The basic model, illustrated in Figure 1.1, comprises ten components and three hierarchical domains of decision making. This basic model still holds across the defined range of organizations and operations studied. Beneath this level the doctoral project has reoriented the content of the model to make it more applicable to operations other than electronics assembly.

Figure 1.1: The DRAMA Model

Aston University

Illustration removed for copyright restrictions

The strategic and tactical components of design have been further developed in the light of the validation process within the electronic sector and the testing of the model within other manufacturing situations. The most significant changes have occurred within the operational components and the way in which these are presented in the model. This is not surprising: the design of the operations system within any industry will tend to be more unique and relate to a number of industry specific design options. Physical system design, the nature of production control and computer integration, and the features of work design will vary considerably between, for example, electronics assembly, electrical engineering, mechanical engineering and the manufacture of carpets. The basic DRAMA model and its related methodology[11] was developed for the electronics assembly industry, and the computer assembly industry in particular. Therefore the presentation of the operational domain components reflect the industry specific nature of the production systems.

DRAMA II therefore represents a generalisation of the DRAMA model to make it valid as an analytical tool across a wide range of manufacturing contexts. The term "analytical tool" is important to stress and will be explained here as it reflects a change in emphasis in the use of the model. The DRAMA manual (Bennett, 1990) was geared very much for use by practitioners, especially within the overtly prescriptive methodology sections. DRAMA II is geared more for use by researchers investigating the production system design process. It is therefore largely retained at the conceptual level of analysis and enables the user to tailor the generic model to their own particular organizational or operational requirements. It is therefore intended that industry-specific methodologies (similar to those contained in the DRAMA manual for electronics assembly) can be developed using the structure of the DRAMA II model. The author is currently involved in systems design research in the electrical engineering industry where DRAMA II is being used as one of the bases for the development of a methodology for the design and introduction of Computer Integrated Manufacturing (CIM) for small and medium sized companies. This is further demonstrating the generic properties of the model.

[11] As contained in Bennett (1990).

Each component of the generic model is dealt with in some detail in Chapter Nine. Additionally the basic DRAMA model (Figure 1.1) has now been supplemented by a more detailed schematic representation of the whole design process as shown in Figure 1.2. This represents an adaptation and amalgamation of the separate "generalised methodology" flowcharts presented within the DRAMA manual. The DRAMA II model provides more detail than the basic DRAMA conceptual model, and does so in a relatively concise way. However it depicts a mere summary of DRAMA II and users of the model are urged to read the detail of the description contained in Chapter Nine to appreciate a comprehensive understanding of the scope and utility of the model.

Figure 1.2: The DRAMA II Design Process Model

1.10 Summary

This chapter has provided an overview of the doctoral research investigation into the applicability of expanding the established DRAMA model for electronics assembly system design to take into account and represent a wider range of industrial cases. The scope and utility of the resultant DRAMA II model has been discussed. Despite the belief that DRAMA II provides a generic framework for analysing production system design, the author acknowledges that its use has only been demonstrated across four industrial sectors. More work would be required to demonstrate and prove its wider applicability.

The details of the research project were summarised by a discussion of the case-in-sector and survey research design, an introduction to the cases and survey, and a chapter by chapter explanation of the structure of the dissertation. The findings of the project were that a single model for the description and analysis of production system design was applicable and appropriate over the range of operational and organizational contexts investigated. Furthermore the market, strategic and technical determinist views of production system design was disputed. These variables were not accepted as the sole explanations influencing production system design. Rather a number of additional influencing variables were recognized such as organizational size, structure, culture and inertia. These are incorporated within DRAMA II which was then summarised in the final part of the chapter.

Chapter Two
RESEARCH BACKGROUND

2.1 Introduction

As indicated in Chapter 1, the doctoral research has depended on work carried out by the Innovation, Design and Operations Management (IDOM) Research Unit based at Aston Business School. The original study was based upon a longitudinal programme of observation and analysis within ICL's Ashton-under-Lyne mainframe assembly plant where new process designs were being implemented. The project resulted in the development of the DRAMA model and an associated process design methodology for use within the electronics assembly industry. This chapter will, by way of providing the background to the doctoral project, review this initial project and the contents of the DRAMA model and methodology.

The latter part of the chapter will concentrate on the further development of the basic DRAMA model. The use of DRAMA as a generic framework for analysis of production systems design will be proposed and the objectives of the doctoral project presented. Finally two research hypotheses will be proposed, the testing of which forms the basis of the rest of the thesis.

In addition to describing the previous IDOM research, therefore, the distinction between the original DRAMA study and the doctoral research will be highlighted. As such this chapter acts as the link between previous work and the contribution provided by this thesis.

2.2 The ICL Case

The ICL case is an illustration of corporate turnaround in the 1980's. 1980 saw the Company of the verge of insolvency and it was still trying to apply what is now commonly seen as "technological push" of new products on to its customers. The result of this approach was that warehouses were full of completed assemblies and computing equipment not ordered by customers. ICL had a range of products of superior technical design, but not of the type demanded by the market at that time. Following the UK government baling-out ICL with a £200 million loan, the Company set about reorientating its strategies and operations to meet the challenges of the eighties[1]. The end result? An improved financial performance which led to the takeover of ICL by STC in 1985 and the eventual buy-out by Fujitsu in 1990. Moreover the company now displays a leaner and fitter profile. This has, however, been set against an inevitable backcloth of plant closures and organizational rationalisations, to the point that by 1989 ICL operated only two major manufacturing facilities, Kidsgrove in Staffordshire and Ashton-under-Lyne on the eastern outskirts of Manchester.

The company focus within manufacturing was to be "market-driven". It did this by concentrating on what are termed "downstream" operations (Bennett et al, 1992) where components, subassemblies and other parts are brought together into a configuration of final products to suit individual customer demands. The IDOM research team studied in detail how the Ashton plant tackled the need for market-driven operations and how this was translated into production systems. The Ashton factory was also the major downstream manufacturing facility within the company, producing mainframe and mini-computer products on a strictly "made-to-order" policy. Ashton engaged in assembly operations using materials and parts supplied by ICL's upstream manufacturing plants at Kidsgrove and Letchworth[2], in addition to external suppliers, one of the most important of which was Fujitsu in Japan, now the parent company, with whom ICL had a close technical collaboration in product design.

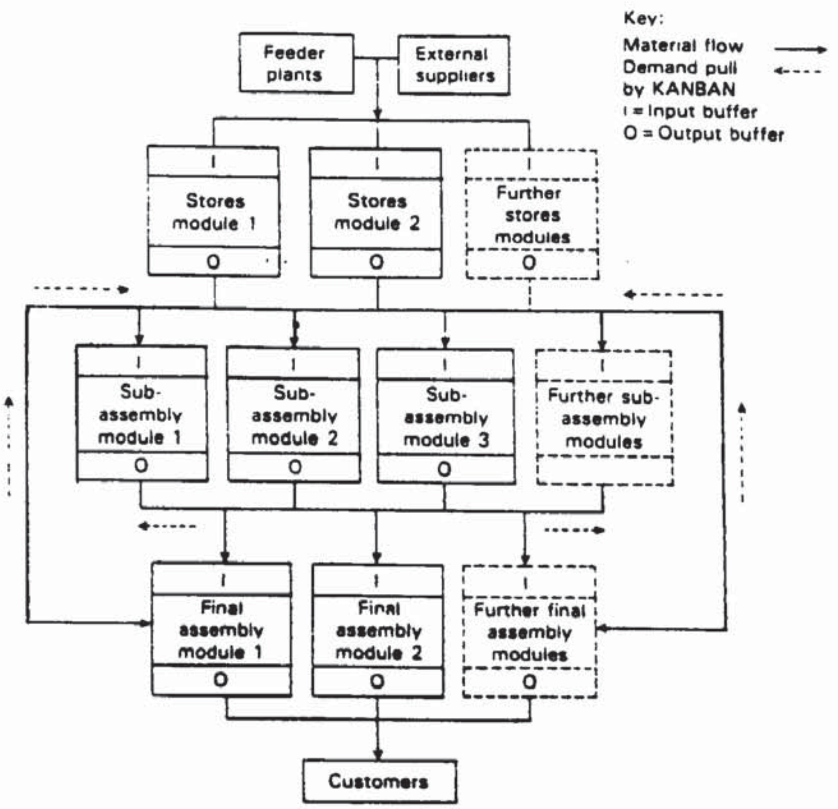
Ashton needed to respond to the demands imposed by the corporate objective to become increasingly market-driven. Since the early eighties the Company's mission statement has contained the phrase "selling solutions" which can be compared with the previous approach

[1] For descriptions of the actions ICL took at the corporate level to effect this turnaround refer to Lorenz (1986) and Caulkin (1987).

[2] ICL Letchworth was closed in 1989.

which could be described as "pushing hardware boxes". The means whereby the factory could effectively respond to this challenge was seen to be through an extensive physical restructuring of the assembly operations to meet the demands for a more flexible and responsive manufacturing system. It was for this reason that the "Modular Assembly Cascade" system was developed (and hence the DRAMA acronym: "Design Routine for Adopting Modular Assembly"). The basic cascade concept will now be described, but for more detail on the system's operation refer to Bennett and Forrester (1988) and Nagarkar and Bennett (1988).

Figure 2.1: The Modular Assembly Cascade Concept



The Modular Assembly Cascade, as its name implies, comprises a number of modules within which various parts of the total assembly operation are carried out. The modules are largely autonomous, their main constraint on the range of tasks they can tackle being the overall dimensions of the products or subassemblies they can produce. Just-in-time principles are applied both within and between modules. Modules manufacturing final assemblies "pull" their requirements from those manufacturing subassemblies, and so on; hence the notion of materials "cascading" down the various levels of assembly (Figure 2.1).

The modules derive their flexibility from ensuring the production activities and material distribution within the system is as generalised and non-product specific as possible. This has caused a re-equipping of assembly areas with more general purpose tools and the use of manual assembly rather than investing in automation.

Another important aspect of flexibility, given the human centred nature of operations, has been the development of an adaptive workforce. There has been considerable investment in an ambitious programme of training with the objectives of increasing employees' adaptability to change, extending the range of operator skills and increasing their ability to work in a less structured environment. A major part of this has centred around education and training in quality. Quality training, based largely upon the prescriptions offered by Philip Crosby (see Crosby, 1979) was provided for all employees and was seen by managers as a critical element in both process and personnel development. Direct employee training combined with a zero-defects programme, the adoption of quality circles and the introduction of other team based improvement approaches has ben geared towards developing a "quality culture" within the organization as a whole.

The Cascade was mainly implemented within the Ashton plant over a four year period between 1985 and 1989. Design and commissioning of individual modules took place incrementally starting with a final assembly module having a one-metre cubed capacity (Nagarkar and Bennett, 1988). Other modules include a larger dimensioned two-metre cube module for final assembly of larger "wardrobe" sized cabinets, and several modules for subassemblies with differing size capacities. A module dedicated to the kitting of parts to be used in assembly is located in the main stores area. Here all parts requirements are kitted into "kanban" containers. These requirements are checked and brought together according to a kitting list displayed on a VDU screen, this listing having been triggered in response to what ICL term an "electronic kanban" signal. Assembly modules have their own "input" and "output" stores where "strategic buffers" (an ICL term) are located. The main purpose of these are to provide the correct balance between holding costs, risks of stockout and to provide for process flexibility.

Automation of the assembly processes was not feasible due to the complexity of the operations in terms of manual dexterity needs, the high variety of tasks and the low volumes of manufacture per variant. However, automation was incorporated within the system for material handling and information processing. Transportation and storage equipment included computer controlled cranes, automatic guided vehicles (AGV's) of various sizes and functions, horizontal carousels, paternoster stores and combined automated storage and testing facilities. A unique feature of the material control system was the "electronic kanban" technique mentioned previously. Here the pulling mechanism of a card (as used in the original Toyota system) is replaced by the use of bar-coded containers holding kits of parts combined with computerised automatic data capture and transmission.

The system was implemented using participative teams from different functional areas in the factory, so called "working parties". These working parties comprised not only the technical specialists from the Engineering and Manufacturing Systems departments, but also user representatives from the operational and functional areas which would be affected by the changes. Incremental introduction of modules caused minimum disruption at any point in time and allowed for a continuous learning process for systems designers and user groups. This enabled subsequent developments to advance in light of the experiences and lessons learned at previous phases of development.

One notable observation in the change from push to pull operating mode was the need for new performance and control measures. These ensured that the criteria upon which operations managers were assessed would be compatible with the newly identified service and quality aspects of market and manufacturing strategy, which the new systems were trying to address. This can be compared to previous measures where measurement of operating performance was based primarily upon cost and efficiency to the detriment of other criteria. Following a time lag after systems introduction, ICL finally saw the need to raise the profile of "conformance to requirements" (Crosby, 1979) and delivery performance and to reduce the dependence upon measures of standard labour hour performance and cost performance. This, assisted by a new factory wide real-time management information system, produced a more balanced portfolio of performance measures across a wider range of indices. As a result, they were more appropriate to the new philosophy and methods of manufacture within the plant.

The results of the changes within the factory have been widely publicised in trade and academic journals (see, for example, Powell, 1985; and Kellock, 1985) giving the impression that ICL were developing the Ashton plant as their showcase factory. Table 2.1 summarises the results from these press sources. It is interesting to note that the IDOM team's review of performance from internal sources largely confirmed these figures. However, it was often difficult to extract the bases for these measures from ICL personnel and how the data for the publicised information were collected and analysed. Despite the questions surrounding the validity of the figures, it is clear that significant advances have been made within the factory compared with the methods of production prior to the installation of the Cascade and its inherent disciplines.

Table 2.1: ICL Ashton Performance and System Operation Figures (1985-1989)[3]

Criteria:	1985	1986	1987	1988	1989
Inventory turns on stock and WIP (pa)	5	9	12	17.5	20
Stock service levels (%)	92	95	98	99	99
Data accuracy (%)	90	94	98	99	99
Automatic data capture (% transactions)	0	5	10	60	80
Manufacturing cycle time (days)	40	29	22	15	13
Delivery Reliability (%)	50				96
Inventory Levels			down by 75%		
Output			up by 250%		
Output per unit area			up by 350%		
Labour productivity			improved by 450%		

A number of intangible benefits was also recognized as a result of the introduction of the Cascade and the quality initiatives within the company. Firstly, ICL managers generally acknowledged increased functional flexibility of core workers within modules. Secondly, mobility between modules was increasingly becoming the norm, enabling Ashton to cope more effectively with the peaks and troughs in demand, particularly important in a make-to-order only environment. Thirdly, there was increased willingness on the part of employees generally to participate in decision making and to cooperate in any change programmes. Finally, managers identified an increase in the level of quality awareness, attention to detail

[3] Sources: Management Today 1989, ICL Press Release 1989, ICL Ashton brochure 1989.

and customer focus so essential for an organization now requiring its operators to self inspect their work. Within ICL as a whole Ashton is now considered to be the star of the manufacturing business and the volume of positive publicity its has generated in the press and trade and management journals can only be to the advantage of the company as a whole. In 1989 it was named by Management Today as one of Britain's Best Factories and was regarded by the Director of ICL Manufacturing and Logistics, when interviewed by the IDOM team, as the "jewel in the crown of ICL".

2.3 Development of DRAMA

The original DRAMA model for production systems design was based upon research into process design within ICL Ashton. As a consequence the DRAMA methodology, as contained in the DRAMA manual (Bennett, 1990), is orientated towards the design of flexible electronics assembly systems for high variety production. It must be added, however, that the modular assembly concept was generalised and refined into a form that could be applied by a wider industrial and academic audience.

The IDOM research project was funded primarily by the Science and Engineering Research Council's ACME Directorate ("Application of Computers in Manufacturing Engineering") under a project titled "Evaluation, Design and Implementation of High Variety Assembly Systems". The project formally commenced in January 1987 with an immediate focus on the process development activities at ICL Ashton. Two full-time research staff were employed, one a management scientist (the author of this thesis) and the other an industrial engineer. The researchers were guided by principal investigators from Aston Business School and a co-opted investigator from Keele University. The team as a whole contributed a complementary range of knowledge and expertise. The team was based within the IDOM Research Unit at Aston.

The research team was allowed almost unlimited access to the ICL Ashton plant of the sort not available to most industrial researchers. This level of access was accepted as necessary by ICL so that a comprehensive and longitudinal study of process design and organizational decision making could be carried out. In order to observe the production systems design activities at first hand the full time research staff were absorbed into the ICL Ashton organization in a participative role, to the extent that they were frequently regarded and treated as fellow employees by some unknowing ICL personnel. This enabled an ethnographic investigation to be conducted whereby the research staff acted as participating observers. This was seen as preferable to involving the researchers in merely passive observation. Passive observation would have allowed for little contribution on a day to day basis and would surely have limited access and reduced the observers acceptability within the Company. The participative approach facilitated a high degree of acceptance and justification of the team's presence among the ICL personnel. It also enabled the collection of internal data of a higher quality and integrity than is normally possible with other forms of industrial research.

Figure 2.2: The Development of DRAMA

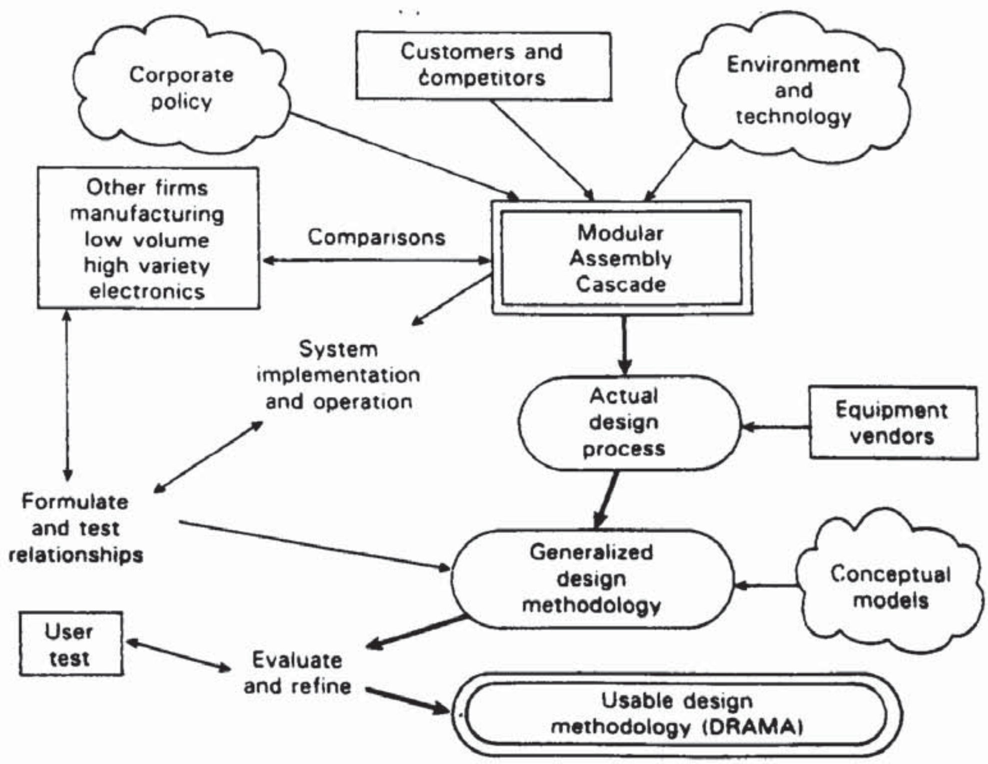


Figure 2.2 illustrates the development of DRAMA by showing the research design of the IDOM project. The design and implementation processes for new assembly facilities within Ashton were documented and reconstructed by the researchers. This reconstruction was retrospective in the case of the first assembly module, "Mercury", which was implemented prior to the commencement of the research programme. The implementation of all subsequent modules was observed in "real-time" and so reconstruction of the design process for these was performed concurrently with systems developments.

The "through-time" study of the Ashton plant was complemented by a detailed study of the ICL organization as a whole. This was both hierarchical and lateral in nature, comprising interviews with senior ICL managers and directors and including visits and interviews in other parts of the organization, including all the other six manufacturing sites (prior to the closure of three of these and the dedication of one more to distribution activities). This business study explored the strategic choices made by the Manufacturing and Logistics Division[4] within the context of the newly formulated market-driven corporate mission. It also considered how Ashton's sister plants had translated manufacturing strategy into the level of systems design and operation. Participative observation within ICL Ashton was therefore supplemented by an extensive and far reaching programme of semi-structured interviews throughout the organization, from main board directors to shopfloor personnel and administrative staff. External analyses were also performed which considered ICL's customers, competitors and suppliers. This review also considered the technological, structural and business environment within which the company was operating.

The ICL study provided an extremely detailed and comprehensive study of process design and organizational decision making within a major UK based electronics manufacturer. Despite the attractions of these participative, ethnographic and interviewing methods, the IDOM team was aware that concentrating on ICL would leave the work open to the criticism that it only involved a sample size of one company. Unless the team was careful, it might get locked into a study of "worst practice", with no means of distinguishing good from poor. In response to this criticism, and to place the ICL research into context within

[4] The Manufacturing and Logistics division was renamed "ICL Manufacturing" in 1990 and then, from 1 January 1994, became "Design to Distribution Limited" (D2D), a wholly owned subsidiary company of ICL.

the electronics sector, the researchers conducted a number of smaller comparative studies within other UK companies who were manufacturing similar products in comparable markets. This gave the research a yardstick both for the evaluation of the ICL case and for determining the relative merits of all the factories studied.

From the data provided by the ICL study and the analyses of other organizations, a number of relationships were identified, tested and incorporated within the methodology for process design, to be described later in this chapter. Existing theoretical and other conceptual models from the literature were used at this stage to assist in the analysis of the research data and to provide a framework of enquiry for the observed design and decision processes. These models, to be discussed in Chapter 4, included the "soft systems approach" (Checkland, 1981; Checkland and Scoles, 1990), the "structure of unstructured decision making" model (Mintzberg et al, 1976), and the GRAI conceptual model for hierarchical decision making (Doumeingts et al, 1986). These models also proved valuable in the later construction of the DRAMA model.

2.4 DRAMA Model

Introduction to the Model

The DRAMA model was developed by the IDOM team as a necessary precursor to developing the process design methodology for electronics assembly systems. The DRAMA model was developed in an evolutionary fashion, being very general at first, but becoming more explicit through time (Bennett, 1990). DRAMA was initially developed for use in high variety electronics assembly industries. However the DRAMA model, upon which the methodology was eventually based, offered a structure which, it is now proposed, could be used as an analytical tool for examining production systems and their design processes generally. There certainly appears to be some scope for extending the applicability of DRAMA far beyond the limits suggested by the Modular Assembly Cascade and the ICL case.

The model now formulated provides the starting point for this thesis. The case studies presented in Chapter 5 and the questionnaire used for the survey (described in Chapter 3) are constructed in such a way that they relate to the DRAMA model. This enables the testing and validation of the model and its application across a wider range of manufacturing situations than the IDOM research. The rest of this chapter provides an overview of the model as formulated by IDOM. The remainder of the thesis then concentrates on the task of testing, validating and further developing the model. The DRAMA conceptual model for production systems design will now be presented.

The Components of DRAMA

The DRAMA model separates the total production system design activity into ten identified components which require addressing in the process of decision making. These components are defined as follows:

Market and Environment
Analysis of the economical, socio-governmental, customer, competitive and technical factors to evaluate strengths and weaknesses, opportunities and threats. Determination of corporate objectives, policy and market strategy.

Manufacturing Strategy
Manufacturing's response to the market strategy including an internal audit of performance. Will involve decisions on make or buy, the degree of vertical integration and the setting of manufacturing targets.

Organization
The design of the organization, both in terms of "structure" (ie: formal recognized composition and lines of communication as shown on the organization chart) and "state" (ie: the culture, employment climate, flexibility, etc.).

Justification
Generating the case for a new, or modified, production system. Justification is normally

based upon a combination of financial arguments and strategic need in terms of qualitative advantages. Approval for new projects and capital expenditure is usually sought from senior management on the basis of this justification.

Project Management

Once capital has been granted, system design projects need to be managed within the constraints of terms of reference, timescales and budgetary constraints.

The following three components can collectively be regarded as relating to the "operating system" of the production facility:

Physical System Design

The choice of production system "hardware", plant layout and configuration at the levels of the factory, the operating unit (module) and equipment.

Control and Integration

The design of the production system "software" including operations planning and control, the computer systems and the integration of the system as a whole.

Work Design

The choice of work organization within the production system. Work design tackles such issues as flexibility, responsibility for quality and operator tasks, etc. The "humanware" of the production system.

Implementation

The drawing together of all design work conducted in 1 to 8 and converting this into the installation of efficient and effective new production facilities and their acceptance by people in the organization.

Evaluation

The "control loop" of the systems design process. Evaluation is concerned with the maintenance and improvement of production systems and the process of decision making within the organization. Production systems designs are continually evolving as a result of ongoing evaluations at all levels in the business.

The DRAMA model views the production systems design process as a dynamic combination of these interdependent components that mesh together like a set of gears which drive the organization and its manufacturing activities through time, as shown in Figure 2.3. In explaining the decision processes involved, DRAMA assumes a generally phase-wise progression through these components during a production systems design project. However, it is recognized that the components of design are interdependent and that decisions within one component will probably have an effect on a number of preceding and subsequent events in other components. Thus, as a result of evaluations and reassessments throughout the design process, there is a myriad of feedback and feedforward loops between components, too numerous to represent on any diagram of the model. This notion of complexity corresponds closely to the Mintzberg decision process model which also sought to bring structure to the complicated longitudinal process of decision making (Mintzberg et al, 1976).

Figure 2.3: The Meshing Components of the DRAMA Model[5]

[5] from Bennett (1990).

Presenting the components of system design as in Figure 2.3 provides little by way of a useful structure for either the system designer or the research analyst. Therefore the DRAMA model has been represented in a more structured and usable diagrammatical form as illustrated in Figure 2.4. This representation of the model will be more fully explained in the remainder of this chapter. It would appear to provide the basis of a tool for the structural examination and analysis of decision processes associated with production systems across a range of industrial contexts.

The Concept of Decision Making Domains

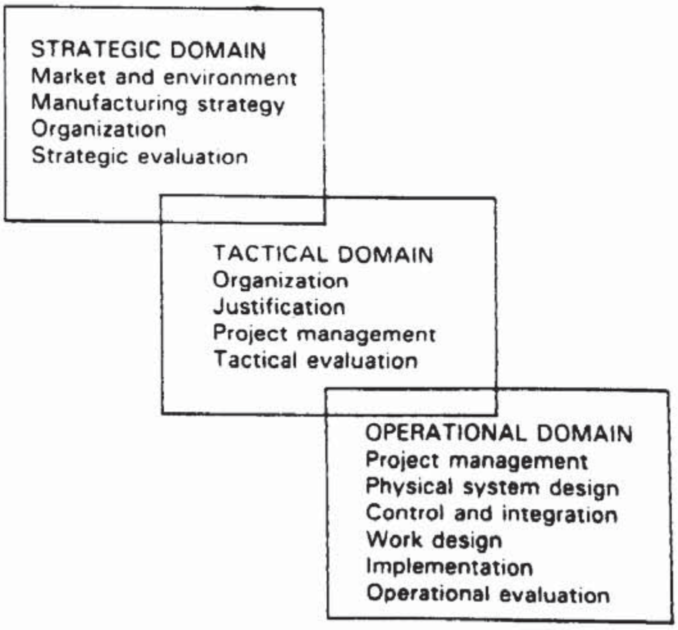
DRAMA provides a model of organizational decision making which explores the effects of participation in the production system design process at different levels of the manufacturing business. Three such "domains" of decision making are identified, "strategic", "tactical" and "operational", and these are shown in Figure 2.4.

Figure 2.4: The DRAMA Conceptual Model of Production Systems Design[6]

[6] From Bennett (1990).

The strategic domain embraces the activities of senior management down to the level of individual plant units. Market and Environment, Manufacturing Strategy, Organization and Evaluation components are identified as being within the strategic domain and can be considered together when focusing upon the strategic issues of systems design. The tactical domain spans what might be termed the "middle management" levels where senior management decisions are translated down into plant level procedures. Components within this domain are Organization, Justification, Project Management and Evaluation. The operational domain relates to the lower organizational levels where detailed production decisions and systems operation take place. The operational domain includes Project Management, Physical System Design, Control and Integration, Work Design, Implementation and Evaluation. Thus, as illustrated by Figure 2.5, Organization and Evaluation span the interface between the strategic and tactical domain, while Project Management and Evaluation span the tactical and operational domains.

Figure 2.5: Contents of the Decision Domains of DRAMA



This disaggregation of organizational decision making into domains provides a hierarchical dimension to the DRAMA model to supplement the longitudinal analysis provided by the sequential components. Design activity and decision making routines can thereby be tracked at different levels of the organization as well as laterally through time.

2.5 DRAMA Design Methodology

The DRAMA methodology evolved using the original conceptual model as a basis and is contained within a manual (Bennett, 1990). The methodology is essentially a set of guiding principles that assist the industrial user to steer through the decision sequences that must, or could, be followed when designing an operations system. It is based upon the requirements of the high variety electronics assembly industry and so relates directly to the specific design options and process choices that need to be made within this type of manufacturing activity.

Using the research design illustrated in Figure 2.2, the ICL case material and the DRAMA model were used to generate the DRAMA process design methodology for the electronics industry as contained in the manual. The DRAMA manual, the structure of which is shown in Figure 2.6, provides a flexible, user-led guide for production system designers divided into the ten components of the model. The methodology part of the manual, which forms the prescriptive part of DRAMA, advocates the top-down progression from strategy formulation to detailed facility design and operation as indicated by the model. However, linkages are identified and an evaluation of the impact of system design changes on the remainder of the components is seen as fundamental to the success of any process design activity.

Figure 2.6: The Structure of the DRAMA Manual

In understanding the structure and potential applicability of the methodology it is important to understand the purpose of "tracks" in the DRAMA manual. The empirical material gathered during the SERC funded project between 1987 and 1989 included detailed ICL data supplemented by material obtained from outside ICL. These other data comprised material collected from other manufacturing organizations, information from suppliers and customers of ICL and general facts concerning the market and environment for electronics production. Inclusion of the detailed ICL case study was considered necessary to enhance the depth and quality of examination. To allow the user of the manual to adopt a structured approach when using the manual, DRAMA is separated horizontally into three "tracks" (see Figure 2.6). These tracks were entitled: the "ICL Case", "Assessment of the Case" and the "Generalised Methodology".

This subdivision of the manual only enables the user to focus upon specific components of interest in the design process, but also allows the opportunity to follow a particular aspect of each component without the need to read completely through the manual. In this way the user, by selecting the appropriate track, is able to only read the descriptive case study, or an assessment of the case (with reference to theory, other plants and established "best practice"), or the methodology in the form of guidelines which include the design options available to the systems developer and their related positive and negative features.

Figure 2.7: Conceptual Form of the DRAMA Components

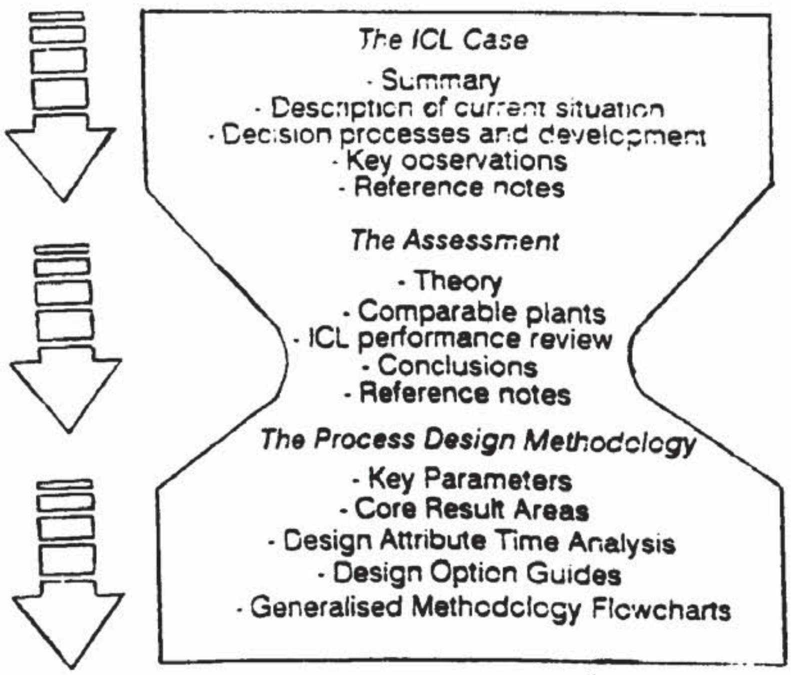


Figure 2.7 shows the conceptual form of each DRAMA component (a "vertical slice") as it progresses through the case, assessment and design methodology tracks. This method of investigating the current context and detailed activities of what might be seen as a "leading edge" manufacturing organization, and then relating this to theory and practice elsewhere in the industrial sector, appears to be a generally applicable approach to formulating principles and guidelines for future design activity in that industry. The case-to-assessment-to-methodology route would seem to have generic utility in the development of industry specific methodologies and systems design lessons for the future.

The use of DRAMA to develop methodologies for systems design has formed a major part of the doctoral study to validate the model within other situations. This issue will be considered in further detail within Chapter 9. For now the format of the components within the methodology track of the DRAMA manual will be described. As mentioned before, the methodology sections provide a detailed set of guidelines for electronics manufacturers who wish to adopt the concept of modular assembly. The methodology is suitable for the design of production facilities within the context of a market-driven corporate strategy requiring high variety, small batch manufacture.

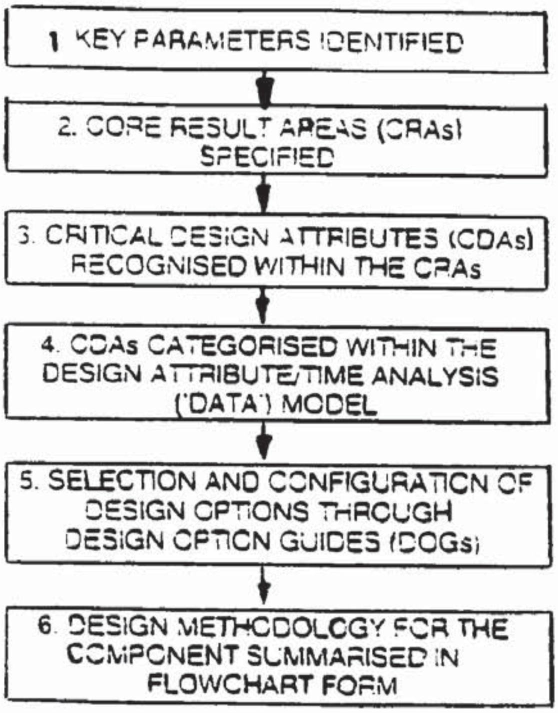
2.6 Derivation of Methodology Components

Figure 2.8 illustrates the procedures followed when using the methodology to design each component. As the methodology for each component is presented in this standard format, Figure 2.8 should be considered in conjunction with the ensuing descriptive text.

Key Parameters

Key parameters are the inputs to each DRAMA component. They are items which serve to shape the design or configuration of each component, as identified by an assessment of current theory and practice for each methodology component. As they are influential factors shaping design, they are prerequisite areas of analysis or audit prior to embarking upon the detailed design of the component under review. Within the DRAMA methodology, key parameters comprise a combination of outputs from previous DRAMA component designs or from the wider environment (eg: market, process technology, etc.) which impinge upon design decisions.

Figure 2.8: Development of a Process Design Methodology for a DRAMA Component



Key parameters are identified for each component within the methodology. There must be an agreement by all in the design team on the nature of each key parameter prior to embarking upon the design of components. This is considered essential because they serve to provide terms of reference and the scope for decision makers and system designers alike.

Core Result Areas

Core result areas (CRAs) are specific zones of performance, the combination of which the organization would seek to optimise when designing a particular component. CRAs are specified as objectives which each DRAMA component and are dependent upon the domain within which components fall. The CRAs for each domain are:

Strategic Domain:

- Goals
- Profitability
- Quality
- Service

Tactical/Operational Domains:

- Productivity
- Quality
- Inventory
- Service
- Cost
- Output
- Human Resources

DRAMA, by identifying CRAs, helps to indicate potential business drivers within each domain as a guide for systems designers. The user of the methodology decides the weight that should be placed on each. A prescription by the authors of the manual regarding weightings would have been inappropriate because the situation and strategies within which organizations operate vary considerably from one company to another, even within the same industry. Therefore, the importance, and hence weighting, attached to each CRA will vary accordingly.

Critical Design Attributes

Critical Design Attributes (CDAs) are then identified for each component. The CDAs are categorised within the specified CRA's from above. CDAs are, in effect, a brainstormed list of features which could be induced by the choice of particular design options. Again, it is within the discretion of the user to decide upon those attributes that should be emphasised through process choice and those which are less favoured.

Design Attribute Time Analysis

The Design Attribute Time Analysis (DATA) is intended to measure the variability of design attributes in relation to a time frame measure. This analysis depicts whether individual CDA's tend towards fixed or more variable configuration and whether they persist as either short or long term attributes.

The DATA model was developed by the IDOM research team while developing DRAMA. It is illustrated in Figure 2.9. DATA modelling of decisions utilises a three level disaggregation of design activity relating to the strategic, tactical and operational domains of the DRAMA model. The degree to which specific design attributes are considered long or short term depends upon the domain within which the attribute is contained. Decisions concerning the configuration of design attributes have consequently been positioned within the relevant box in the DATA model depending on whether they have low or high variability in relation to the long or short term poles of the time axis.

Identifying key parameters, determining CRA's and their associated CDA's, and categorising CDA's within the DATA model has all been by way of setting the scene for specific design choices. This method of determining and analysing each design component attempts to direct the user to critically investigate system requirements prior to making design choices. This compares with the propensity of systems designers in practice who frequently jump to explicit hardware, software and organizational choices without analysing and examining the prevailing situation. It is only when the analysis stage, outlined above, has been completed that the systems designer can make design option choices with any real confidence.

Figure 2.9: Design Attribute Time Analysis (DATA) Model

Aston University

Illustration removed for copyright restrictions

Design Option Guides

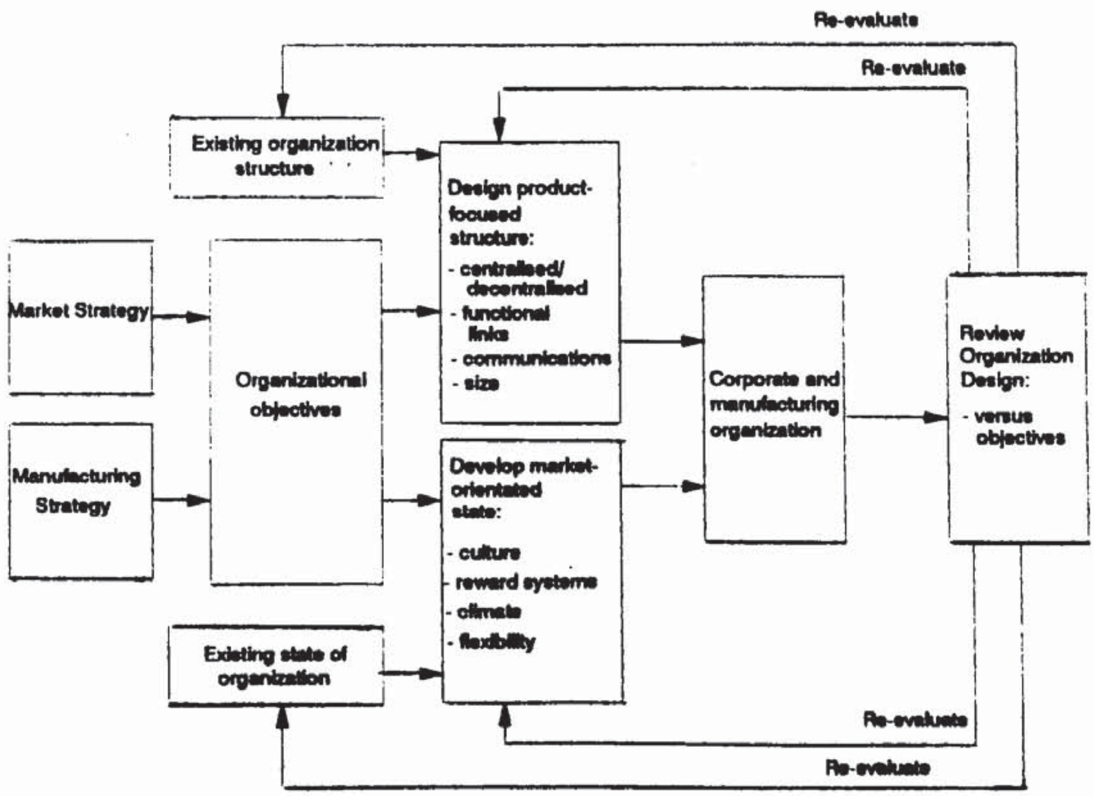
The user is now introduced to the available design options for the components. This is done through the use of "design option guides" (DOGs). An example of a DOG, in this case from the Physical System Design component, is shown in Figure 2.10. The DOG offers a list of "result criteria" from which the user selects a "principal result objective": a preferred, weighted, compilation of the criteria suggested. The design options are then presented together with their related features, grouped according to whether they are advantageous (shown as positive) or disadvantageous (negative) in relation to the result criteria. The expected result from each option can, therefore, be compared with the principal result objective developed by the user. Where there is an apparent gap between the two, the user will recycle to consider other options. The best single, or preferred combination, of options can eventually be identified.

Figure 2.10: **Design Option Guide for Transportation Systems (Utility Level of Physical System Design)**

The choice between alternatives is, therefore, an iterative procedure that permits the selection and modification of options until the preferred configuration, as governed by the user's own result objectives, is achieved. The number of DOGs varies between each component of DRAMA, but tend to proliferate as the user moves down towards the operational domain of decision making. This is what one might logically expect as operational design options, although not so far reaching in their effect as strategic choices. are certainly more numerous. The DRAMA manual comprises a total of 27 DOGs, with each representing a particular element of design.

DOGs are not in themselves a highly developed knowledge-based ("expert") system, but they do provide decision support for designers of assembly systems that allows for options to be identified and evaluated in a comprehensive and structured way. Compare this with the rather arbitrary nature of system design commonly prevalent within organizations, where decision makers and designers frequently have a myopic view of this process.

Figure 2.11: Generalised Methodology Flowchart for Organization



Generalised Methodology Flowcharts

Finally, the design methodology for each component is summarised in flowchart form to provide a succinct representation of the recommended design process and decision routines. The Generalised Methodology flowchart places the elements of design analysis and choice into context. Key parameters are indicated as inputs and the main areas of design choice are highlighted. Outcomes of the design process are also indicated where they occur and a strong emphasis is placed on the value of evaluation, feedback and the recycling of information regarding the performance of design components. This will be used for future design modifications and improvements.

Figure 2.11 gives an example of a generalised methodology flowchart, in this case for the Organization component. The flowcharts show the design of production systems to be a continual and iterative process, being influenced by persistent internal and external change and thus never coming to a permanent conclusion. The analogy of design components as meshing gears (see Figure 2.3) is still appropriate, therefore, whereby all are continually turning, sometimes at different rates, but always subject to change from other "cogs".

2.7 DRAMA as an Analytical Framework

The detailed design methodology originally developed for the electronics assembly industry has limited generic applicability and is certainly more restricted than those approaches developed on the basis of a wider source of data. However the fundamental DRAMA model incorporating components and domains offers the potential for more widespread analysis. Indeed the basic model would appear to have properties that make it appropriate as a basis of research enquiry into the link between corporate and manufacturing strategy and the development of production system designs.

Prima facie, the DRAMA model offers a framework for analysing manufacturing design activities so its validity and rigidity in this respect needs to be evaluated. This evaluation is the essence of this thesis: namely whether DRAMA is appropriate for the analysis of production systems design across a range of industrial contexts. There are a number of questions that need answering in this respect. Does the model provide researchers with a robust method of analysing decision processes for the translation of strategies at higher levels of organization into the design, implementation and operation of operational production systems? Can DRAMA benefit practitioners by being developed into industry specific methodologies generally in the same way as it was used for the design of electronics assembly systems in the DRAMA manual? The thesis will now turn to considering these questions and, in so doing, represents a break from the IDOM research team's work on DRAMA.

One final point relates to the acronym of DRAMA itself which was derived from "Design Routine for Adopting Modular Assembly". Although this was entirely appropriate for the DRAMA manual and its process design methodology for electronics assembly industry, this title is not suitable if any argument is to be made for its generic applicability. The continued use of the original model name in connection with a more generic tool is, unquestionably, inappropriate. Since it was felt the acronym itself should be retained it was decided that when used in conjunction with the development of the generic model DRAMA should stand for "Decision Rules for Analysing Manufacturing Activities". To distinguish "Design Routine ..." from "Decision Rules ..." the latter is referred to as DRAMA II.

2.8 Research Hypotheses

Having described the background to the development of DRAMA and the structure of the model, the design methodology, the contents of the manual and the potential relevance of a generic DRAMA II model, it is now appropriate to state the objectives of the doctoral project conducted by the author.

There are really two strands to the work since the completion of the SERC project. Firstly the rigidity of the model has been evaluated more broadly within the electronics industry where it was originally conceived and, furthermore, used as a framework for enquiry for three additional industrial sectors. The objective of this work was to examine the applicability of DRAMA as a model for production systems design in a range of organizational and operational contexts. The second objective was to investigate the links between strategic decision making and systems design within the context of the organization as a whole. In other words, did the research material collected provide any insight into the process of organizational decision making during the emergence and development of production systems design?

The dual objectives of the research are reflected in the formal hypotheses that have been stated for the project. These hypotheses are:

Hypothesis 1

> ***Production systems design can be represented by a generic process model across a defined range of operational and organizational contexts.***

This hypothesis turns upon the degree to which the production systems design process has generalisable properties across different applications and industrial contexts. The thesis considers this issue by adopting a number of levels of organizational analysis, from strategic choices to the more routine activities of equipment selection and deciding exact methods of work.

Hypothesis 2

> ***Production systems design is most strongly determined by market and environmental factors as reflected within corporate and manufacturing strategies.***

The research tests the commonly held assumption that market determines strategy and design, and not the other way. This assumption of top-down market determination has been questioned by Hill (1991) amongst others, but this thesis attempts to explore in explicit detail the relationship between markets, strategy and process choices.

2.9 Summary

This chapter has provided details of the background to the doctoral research project. The initial research which resulted in the development of the DRAMA model and the DRAMA process design methodology for the electronics industry was conducted by a team from the IDOM Research Unit at Aston University, of which the current author was a member. The DRAMA conceptual model has been explained in the text and was described as comprising ten components of activity divided into three hierarchical domains of organizational decision making (refer to Figure 2.4). Some detail was also given of the content of the DRAMA methodology, although for more detail the reader should refer to the source material, the DRAMA manual (Bennett, 1990).

This thesis represents the continuation of the work from the point where the DRAMA manual was completed. The IDOM team confined itself to the electronics sector, whereas this thesis attempts to consider manufacturing systems design more generally by investigating other industrial sectors. In addition the DRAMA model was written largely for the benefit of the practitioner, whereas this thesis focuses on the use of DRAMA for research enquiry. Finally, a particular theme of this project is the desire to study the links between manufacturing strategy and operational systems design, a topic which, it is argued in Chapter 4, has been neglected in the past.

Given the above, it was relevant to present the research hypotheses at the end of this chapter. Indeed, this point in the thesis represents the break-point between the research conducted by the wider IDOM team, and the research carried out by the author. Chapters 3 to 10 comprise new research and output generated as a direct result of the doctoral project.

Chapter Three
RESEARCH METHODOLOGY

3.1 Introduction

A combination of research methods were utilised for the purpose of this study into the design of production systems. These methods fit within the overall research design framework which seeks to investigate current practice and the appropriateness of DRAMA in modelling these activities. The research has involved research within the electronics industry plus three other industrial sectors where DRAMA has been tested both as a framework of analysis and validated in terms of its generic explanatory features.

A distinctive feature of the IDOM research from which DRAMA evolved was its participative nature and the employment of longitudinal observation in the accumulation of data. The doctoral study has, in large degree, been conducted in the same spirit, although there existed obvious constraints on time and resources. Therefore none of the cases presented here have anywhere near the four man years' worth of direct participation afforded in the study of ICL. Therefore research instruments have been adopted which have sought to collect data in as efficient a manner as possible. The empirical methods used include participation, observation, interviewing techniques and a survey. These have resulted in the development of a number of industrial case studies and quantitative results from the more widespread survey.

This chapter illustrates the means by which the research data has been analysed. The use of the DRAMA conceptual model is described and it is explained how the framework of the model has enabled the synthesis of the material collected, as it was, from a variety of research methods. Any research approach leaves itself open to criticism in terms of its limitations, the way in which it links fieldwork and evidence to conclusions, its susceptibility to bias and its inherent objectivity. This is acknowledged in the case of this research and so a list of advantages and drawbacks of the research design adopted is identified towards the end of this chapter and the main issues discussed.

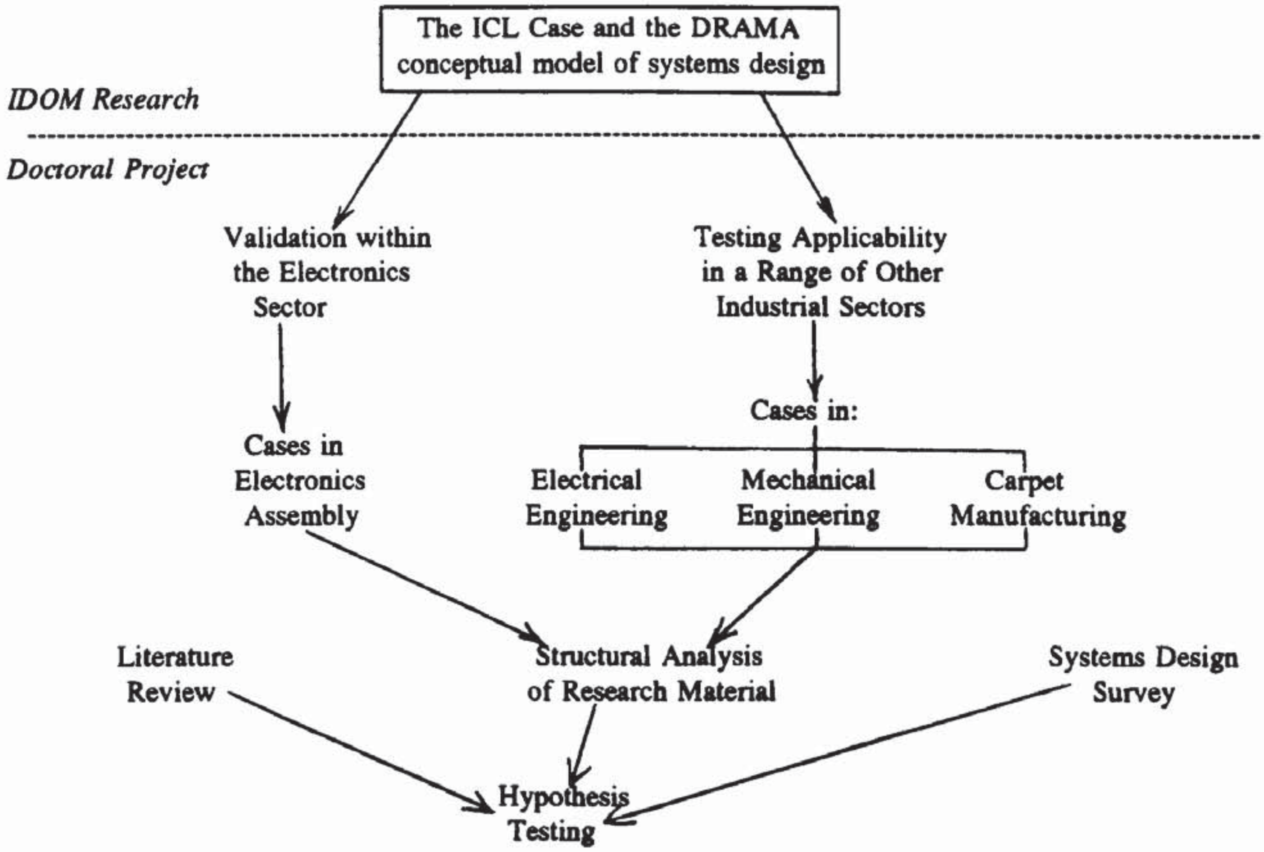
Much of the research has concentrated on a qualitative analysis of production systems design and has necessitated the accumulation of a wide range and volume of data which has presented problems in terms of analysis and assimilation. However, the depth of work has resulted in a richness of data and research material which, it is argued, would be difficult or impossible to extract using a highly structured and quantitative approach. The author, therefore, has no reservationss regarding what is often seen as the greater objectivity of the quantitative approach. The argument postulated here is that systems design is, for most intents and purposes, a creative art. Any research, therefore, studying design of an "holistic" system requires in-depth study and observation of the type adopted in this research. Otherwise it would be difficult to identify and diagnose anywhere near the full range of activities that, together, comprise the design process.

3.2 Overall Research Design

The overall research design is geared towards and dictated by the aims and objectives of the research, namely to validate DRAMA as a model of production systems design within the electronics assembly industry and, secondly, to test DRAMA as a generic model for systems design. Figure 3.1 illustrates the research design employed.

The ICL case was summarised in Chapter 2. In addition to describing the development of DRAMA from this case, it was also indicated in the chapter that a number of smaller comparative studies were conducted in other electronics manufacturing companies to contrast with ICL. When combined with a reference to theory, the cases facilitated an assessment of what constituted "best practice" in the industry (refer to Figure 2.6). The data which emerged from the other electronics companies was not utilised, however, in the form of individual case studies. Instead they were presented in the DRAMA manual in a segregated manner, broken down into the components of DRAMA. This took the form of a commentary of manufacturing strategy within Factory B, physical systems design within Factory E, etc. This thesis returns to the source material for a selected number of these cases and re-analyses the data. The cases are then presented in four case studies of production systems design in the electronics assembly.

Figure 3.1: Research Design



The second concern in the objectives was to test the validity of DRAMA for systems design across a range of industrial contexts. For this purpose a total of nine further case studies have been developed and are presented categorised into three identified sectors: the "electrical engineering", the "mechanical engineering" and "textiles" industries. Later, in Chapters 7 and 8, these cases are collectively analysed within the framework offered by the DRAMA model. This gives the opportunity to test the validity of the model as a conceptual representation of systems design in this predetermined range of industrial sectors.

The cases provide detailed descriptions of the nature of systems design within thirteen organizations. Combined with the depth of the work performed by the IDOM team within ICL, this represents a considerable bank of research material. However the combination of approaches and instruments used including observation, participation, semi-structured interviews and general discussions with company personnel does raise some questions regarding the consistency of data collection methods from one organization to another.

The research has, therefore, incorporated a survey approach, both to follow-up the cases already considered and to increase the number of organizations from which research material has been collected. The survey was deemed appropriate and complementary for a number of reasons. Firstly, on the strength of the experiences gained in the case study research and of asking relevant questions within the companies visited, the author considered that asking a number of key questions of organizations would result in answers giving a concise and important insight into the systems design process. There was a confidence that the "right" questions could be asked on the survey questionnaire. Secondly the survey would provide a means of following-up the narrative case studies for the purposes of updating progress and for verifying previous findings from the organization under review. Finally, and importantly, it was acknowledged that data from a large number of companies could be collected with relatively little effort compared with research visits and interviewing. The postal survey therefore represented an increasing of the sample size within each sector. Additionally it offered a means of quantitative analysis that, it was felt, would add value to the research. However it is recognized that the findings from a survey of this type is restricted by the specific questions asked and, furthermore, the responses are subject to errors of bias or misinterpretation with little opportunity for cross referencing of these responses.

The literature review and case and survey material was then used as a basis for a structured analysis of production systems, which is discussed in detail later on in this chapter. This analysis was used to test the research hypotheses stated at the end of Chapter 2, but reproduced here for further discussion. The first hypothesis concerns the issue of whether DRAMA can represent a generic model for production systems design. This is interrelated with verification of the second hypothesis. This thesis represents the second line of enquiry by considering the nature of strategic production decisions and the extent to which there exists a market and environmental imperative upon the formulation of manufacturing strategies and organization designs. The links between strategy and operation through the systems design process need to be explored in order to test the model and to determine the extent to which strategies translate into specific hardware and software process choices. The key to this thesis is whether any model can be supported as a generic model for production systems design and, if so, could DRAMA be proposed as that model.

3.3 Research Methods

A combination of methods were employed in the research. These included site visits, discussions with systems design personnel, interviews, participation in design, observation of the design processes and a questionnaire survey. These methods are now described.

Site Visits and Discussions

All cases presented are based upon a detailed site visit of three hours or more and discussions with systems design personnel as a minimum requirement. An initial "Comparative Survey" questionnaire was used as the basis for investigation and synthesis of the material gathered. The standard pro forma for the comparative survey is reproduced in Appendix A, whilst Appendix B gives an example of how site visit data was collated within the structure of this form for one of the organizations visited. Whilst this method appears to be resource intensive in terms of travel and visit time (at least a day for each visit) and costly, it in fact proved to be a highly efficient means of generating research data as a result of using the questionnaire. The structured information generated from each organization provided the foundation for writing the case studies in Chapter 5. Indeed, when one considers the depth of information illustrated in Appendix B one can see just how much relevant material can be generated on the basis of a three hour visit.

Interviews

Interviewing, in combination with participative observation, provided the backbone of the methodology in the IDOM study. During the course of this project over sixty tape recorded interviews were conducted within ICL over a three year period. Interviewing techniques were also employed in this research and has proved useful not only in developing the case material, but also in providing an insight into some of the major issues in manufacturing strategy formulation and production systems design to be covered in Chapters 7 and 8. All interviews were of a "semi-structured" type, by which it is meant that a written agenda of questions and issues were prepared beforehand from a "data-base" of research questions accumulated over time and appropriated to the organization and/or individual respondent. Interviewees were allowed to deviate from this agenda should they or the interviewer deem this necessary during the course of the interview. An example of an interview agenda is shown in Appendix C.

Participation and Observation

Participative observation was a key feature of the IDOM study but, by its very nature, is extremely time consuming as it requires the researcher to be within the company's operations and on site on a day to day basis over a prolonged period of time. Despite the attractions of the approach, it was simply not feasible to adopt this method within all organizations studied. Two of the cases described in Chapter 4, however, did involve a degree of participative observation. One of these was on a twenty days per year basis over a three year period, where the author as contracted as a consultant in Operations Management and computer systems development generally. The second organization where participative observation continues at the time of writing is a company collaborating in another research programme with the author, but where the opportunity has been taken to extract data relevant to this research. Involvement in this second company has been on a two to three days a week contact basis over a period of twelve months to date. The author sees these periods of direct involvement as critical in his understanding of the deep rooted issues of production systems development in practice. Certainly the two collaborating organizations in this research plus the experiences gained on the ICL project have given the author a detailed insight into process design, its problems and the typical sequence of decisions encountered in practice. This practical knowledge of design in what is a pragmatic piece of research is seen as a critical attribute of this work.

Questionnaire Survey

The value of the widespread and habitual use of survey approaches in research is viewed with some scepticism by the author. Whilst its advocates point to its merits of covering a large sample size and, through the intelligent design of questionnaire forms, its ease of quantitative analysis, it does not represent more than a snap-shot of any one organization or individual at a point in time. It is also questionable as to whether the researcher can ever expect to have the depth of knowledge necessary to develop appropriate questionnaires, those that ask the "right" questions and open up the relevant issues. Without some detailed work and background investigation into the subject, how effective is the survey technique in truly furthering the bounds of knowledge in a research sense? The author, therefore, takes issue with those researchers who habitually see the questionnaire survey as the starting point in research. Rather it should be seen as the end-point, where one seeks to clarify issues and ideas across a wider population following more detailed investigation in a smaller number of cases. The purpose of the questionnaire was two-fold. Firstly it was to be distributed to all the case study organizations as a follow-up to the detailed work. It could, in effect, be used to cross check the responses, assessments and impressions obtained in the research from above. The second reason to perform the survey was to increase the number of organizations considered in the research and therefore increase the sample size used in the research. Otherwise it would be difficult to justify that a generic model is valid based upon a small number of studies, however detailed these might be.

3.4 Case Studies

Selection of Industrial Sectors

Four case study sectors were chosen for the research. Electronics assembly was a necessary industry to include, particularly as the research was to validate the DRAMA model within this sector which includes ICL. The other three sectors have been adopted from a combination of the researcher's expertise and experiences on the one hand and the need to provide a wide range of operational contexts on the other. The three other sectors are electrical engineering, mechanical engineering and textiles. Four sectors seemed an appropriate number. Fewer than four and the range of industries would not seem broad enough. Many more than four, however, and the depth of research within each of these, given the constraints on time and resources, would be diluted considerably and lack depth of analysis.

Selection of Cases

Selection of cases within the sectors was again a combination of opportunity and appropriateness for the research. Much of the case material for electronics assembly was collected by the author during the IDOM research project and, although some of this was used in addressing specific issues as part of the comparative studies in the DRAMA manual, the majority has never been published before. Certainly none of the case studies have been presented as a whole in a section to itself. Cases for electrical engineering, mechanical engineering and textiles, with two exceptions, have been researched and developed solely as part of the doctoral project. Cases have been chosen where a requisite level of access has been provided to allow for a detailed site visit as a minimum requirement. Cases also needed to be appropriate and representative of their industry and care has been taken to choose valid research sites. This has resulted, in two instances, of excellent access to organizations being left uncapitalised, the first because the firm in question did not fit neatly into a sector and the second because of the unique characteristics of the business making it unrepresentative.

Synthesis and Analysis

The method of data collection and analysis from the case study companies was somewhat problematic. An obvious means was to use the structure of the DRAMA model and to categorise lines of enquiry into its components and domains, thus making for ease of analysis. The danger in doing this, in the view of the author, would be to run the risk of biasing the analysis. The true test of any model is that it can represent situations and synthesis research information that have not used the model in their design or collation. To have collected data and have written cases up in the DRAMA structure would have been self defeating and left the research open to accusations of bias. Case study material was therefore collected using the form in Appendix A as a structure and then developing a case report using this structure as in Appendix B. These reports then formed the basis of the case studies in Chapter 5, which have been developed and written outside the confines of the DRAMA model. The cases, together with the questionnaire survey results, are only analysed at a later date in a collective manner within the DRAMA model in relation to strategic issues (see Chapter 7) and with reference to production design and operation (the tactical and operational domains) in Chapter 8. The intention of this approach is to remove bias and to enable as unconstrained an analysis of the cases as possible, the DRAMA structure only being imposed at the later stage of analysis. In this way it is considered that a true qualitative test of the model's validity has been performed.

3.5 Survey of Production Systems Design

Rationale

The development of the DRAMA model and methodology from the IDOM research, the author's involvement in this on a full time basis over a three year period, and the parallel development of case material in this research, has generated a framework of enquiry for production systems design activity. A long and categorised list of questions, the "database", has been developed which have been proved to be valid and appropriate in exploring production systems design processes. This research is concerned with validating the DRAMA model over a wide range of situations so, as a consequence, the survey approach seemed appropriate for this study. The reason for conducting the survey is to increase the coverage of the research to encompass a wider range of companies in the four selected industrial sectors. Despite the findings from the survey being more limited in depth than one gets from a detailed case study, the survey approach was deemed necessary to increase the sample size of those organizations studied. The research was at the point where a concise questionnaire, covering the main aspects of systems design, could be developed. The feedback from this questionnaire would then increase the confidence of the research findings, the sample size having been raised from 24 (including ICL, the IDOM comparative companies and the case studies in this research) to around 50.

Questionnaire Design

The questionnaire used (shown in Appendix D) has been developed on the basis of detailed empirical fieldwork, analysis and contains some of the major questions and issues emerging from the research. The design of the questionnaire reflects the components and domains of the DRAMA model and is used in Chapters 7 to 10 to develop cross referenced discussions, to evaluate the potential of DRAMA as a generic model, and to test the stated hypotheses in the research. Many of the questions on the form require an answer in points weighting. This may appear complex and time-consuming for the respondent, but its value is that it makes respondents think in detail before giving an answer and forces them to prioritise and order their responses rather than merely ticking a box saying it is important. The weighting also lends itself to a structured and quantitative analysis, presented within Chapter 6. The questionnaire was piloted with four managers, one in each of the sectors surveyed, for its clarity and possible ambiguity. Only minor changes resulted from this exercise, the pilots having few concerns about the questionnaire, the main criticism being that of time to complete (an hour in one case).

Survey as a Follow-up to the Case Studies

The survey also had a supplementary purpose in addition to increasing the industrial coverage of the research. The questionnaire would be sent to all those companies visited whilst developing the case study material. The responses from these companies, therefore, would act as a follow-up to the case study work. The survey returns from these companies could be used to test the accuracy of the cases and to validate the research findings within them. If any major discrepancies were found, the companies would be contacted and the anomalies discussed. A section in Chapter 6 is devoted to discussion on the survey follow-ups to the case studies.

Coverage and Response

The initial intention was that a total of forty survey responses should be aimed for, ten from each of the targeted sectors. Realising that the return rate from survey questionnaires is notoriously low, a number of steps were undertaken to increase the probability of returns. Firstly, and most obviously, more forms were sent out than were required, a total of 55 in all. However, this in itself was not considered sufficient. Therefore, as a second guarantee, potential respondents were telephoned and told that they would be receiving a questionnaire and the purpose for this. This, it was hoped, would increase the chances of individuals returning the forms. A number of "fliers" (ie: survey questionnaires to companies where there were no known personal contacts) were also sent out in an attempt to increase the numbers of responses, although it was recognized that the chances of these being returned would be small. Thirdly, respondents were promised receipt of the survey results when complete in return for their time in completing the form.

Analysis of Survey Data

The results from a questionnaire survey must be considered with some trepidation. The old saying of "there are lies, damn lies and statistics" was held uppermost in the mind of the author when analysing the survey data. Whilst survey responses are interesting in showing differences in emphases as well as similarities between company to company and sector to sector, the research has not attempted to link responses to any grand conclusions on production systems design. Rather the survey has added a further dimension and enabled a degree of quantitative analysis to take place to complement and add value to the qualitative analyses conducted on the "rich and deep" material provided by the case studies. Thus, whilst Chapter 6 presents the survey results, the main body of research analysis contained in Chapters 7 to 9 uses a combination of the case material and the survey results. Analysis of the survey data has been divided into two parts. Firstly the responses as a whole have been analysed to give some overall statistics on the production systems design process, the variability of responses received and the differences between sectors. Secondly the responses for those companies in the case studies have been separately analysed and the results compared to the qualitative findings in Chapter 5.

The survey results were analysed one question at a time and, as a result of the weighting system used for question answers, the results can be summed and averaged, etc. Thus some revealing relationships are disclosed in the results sections on such matters as what are the main stimuli in strategy formulation, what are the market and competitive forces at work within the sectors, how do the operations of different organizations vary in approach, and what are the major influencing factors on production systems design. With particular reference to the systems design process, the results are illustrative of such personnel are involved in the decision sequence, whether this concerns the formulation of manufacturing strategy, the justification and approval of new systems, or the detailed design of systems. Finally the survey covers aspects of systems operation which as performance measurement, operations planning and control and labour management.

3.6 Structural Analysis of Material

The majority of analysis is contained within Chapters 7 to 9. These sections bring together the empirical fieldwork and survey results to be compared with the DRAMA model in order to develop a generic model of systems design, DRAMA II, and to test the hypotheses concerning whether such a model is feasible and the effects of market and strategic factors on design.

The analysis is structured in the following way. First the strategic decisions of production are explored in Chapter 7. The framework of analysis here is provided by the components contained in the strategic domain of the DRAMA model. Thus areas such as market and environment, manufacturing strategy, organizational decisions and strategic evaluations of manufacturing operations are considered here. In addition to the DRAMA model, this analysis makes extensive use of the established literature in the subject and relates this to the empirical and quantitative evidence as contained in the case studies and the survey.

Chapter 8 considers the design and operation of production systems. This analysis uses the tactical and operational domains of the DRAMA model as its framework and a particular theme of the chapter is the way in which strategy is translated into systems configurations, if this process occurs at all. The DRAMA model dictates that area such as organizational decision making, justification, the management of projects, the design of physical systems, control systems and work designs, implementation and systems evaluation are the areas to review.

Finally, Chapter 9 pulls together the work outlined in the previous two chapters to describe the development of the analytical model: the transition of DRAMA I into DRAMA II. It also suggests the merits and shortcomings of the model for use by researchers as an investigative framework, its potential use for developing industry specific methodologies, where the model stands in the context of production management theory and its use to explore organizational decision making.

The conclusions of the research are detailed in Chapter 10. The conclusions relate directly to the hypotheses formulated at the start. The first hypothesis turns on whether any model of production systems design is worthy of the title of generic. Obviously any findings on this will only be applicable across the predetermined range of activities studied, although this in itself increases evaluation of the DRAMA from ICL to a total of 37 companies in four sectors. The second hypothesis relates to the influence of market and environmental pressure on production systems designs and the findings from the research in this respect will be articulated.

3.7 Advantages and Caveats of Methodology

Any methodology for research will have its advantages, but also a number of caveats. No research design is infallible and all are subject to false interpretation by the unwary. This should not deter the researcher, however. The main issue here is that the advantages should be promoted whilst, at the same time, any potential difficulties are recognized. This enables boundaries to be identified around the research, within which the findings hold and outside of which would require further investigation. Statement of the advantages and disadvantages of the methodology reduces the risk of criticism in the researcher's approach and exhibits the realization that the approach is always open to question and debate. The advantages and caveats of the research methodology adopted are as follows[1]:

Advantages

- The combination of the qualitative case study approach and the quantitative survey brings with its the advantages of both and addresses their individual weaknesses.
- The case study approach has the advantage of providing a high quality and richness of research material.
- The survey enables the sample size of organizations and operations studied to be increased, thus increasing levels of confidence in the research findings, and also enables a quantitative evaluation to take place.
- Participative observation in two of the case studies (plus ICL) has enabled the real time

[1] These are adapted from those shown in Bennett et al, 1992, p.36-37.

longitudinal mapping of production systems decision processes.

- The degree of access secured within a number of companies has enabled a continuous exchange of information and comment between the researcher and these organizations, including the validation of the model.
- The findings of this research, as a result of its design, are expected to have more generic applicability than the case specific DRAMA methodology developed on the basis of the ICL case in the original IDOM study.

Caveats

- Both the case study and the survey approaches have their own separate disadvantages. Case analyses are criticised as having only limited generalised applicability, whereas surveys are static and lack detailed observation of the real system. The approach adopted in developing this thesis has attempted to balance out these two extreme criticisms.
- Responses to questions may vary depending upon the method of delivery, whether in general discussion, as part of a formal interview, or in written form on a questionnaire. To address this, where discrepancies do occur from the same organization or respondent, the author has checked back to see whether this was as a result of the instrument used or whether it was due to different interpretations or changes over time.
- Bias may occur when seeking to validate and test a model. Despite attempts to the contrary, the researcher may be confined to thinking within the model's terms and analysing the data to fit the model. This was a particularly thorny aspect at the start of the research, the issue of force fitting the data and a lack of objectivity in so doing. The survey questionnaire approach was therefore chosen as a means of providing quantifiable and objective data that could be used to support or repudiate the model.
- In using a questionnaire survey, the respondents may be an unrepresentative sample. They may be those who best associate with the structure and type of questions and phraseology of the form designer. Those who do not readily associate with the issues are more liable to not return. Again a difficult problem, but by contacting as many respondents as feasibly possible, including those who did not respond, the author hopes to have gleaned some insight into this caveat.

- Finally the participative method raises a number of issues[2]. Firstly, care must be taken that the researcher is not too "drawn in" to the organization and loses objectivity. Secondly, in participating the researcher may be influencing the course of events. Finally, this form of research is time consuming and reduces the amount of time available to visit other organizations; it may also inhibit access to other organizations for reasons of confidentiality. However, participative observation has formed a far smaller proportion of data gathering in this research than in the original IDOM study. Therefore the issues outlined above are not so pertinent to this study. Also the researcher and the doctoral supervisor have held regular project reviews whereby the supervisor has questioned the work conducted and has ensured that objectivity and impartiality is not being compromised.

3.8 Summary

This chapter has detailed the precise methodology employed for the validation and testing of the DRAMA model. The research design comprises three main strands. Firstly a literature review has been performed into production systems design and its associated issues, the results of which is presented next in Chapter 4. Secondly a series of detailed case studies in four industrial sectors have been conducted in which organizational decisions and systems design practices have been explored. These form the content of Chapter 6. Thirdly a survey amongst a larger number of manufacturing companies has been performed, the results of which are summarised in Chapter 7.

The results of the research generated from the various instruments have then been analysed using the structure of the DRAMA model. A major issue to be addressed was how the material should be analysed without constraining evaluations by the imposition of the DRAMA model. It was thought necessary to use the model to give the analysis some structure, but the convergence of the research data with the model was delayed until the end of the investigation process.

[2] As suggested by Bennett et al, 1988

Structural analysis of the data was split into the strategic issues of production, relating to the strategic domain of DRAMA, and production design and operation (the translation of strategy into operation), the tactical and operational domains of the model. This evaluation has enabled not only the testing of the hypotheses, but also provides an insight into the theory and practice of contemporary production systems design.

Finally the advantages and caveats of the research methodology employed have been suggested. It is necessary to do this so that the limitations of the research findings can be recognized and the scope and utility of the thesis determined. Particular attention has been paid in this section to describing how the potential pitfalls of the research have been avoided.

Chapter Four

REVIEW OF PRODUCTION SYSTEMS DESIGN THEORY AND PRACTICE

4.1 Introduction

This chapter provides a review of contemporary production system design and the influences upon theory and practice over recent years. An historical imperative in the developments of production systems design is identified, specifically that both changes in the nature of physical systems and in the process of design have been closely associated with major industrial events and the emergence of difference schools of management and their impact on management practices in the twentieth century. It is beyond the scope of this thesis to review the historical development of production systems, but a short indication of the major influences on the process of system design is useful here[1].

In the 1800's the prime focus in the management of manufacturing was the management of the factory, but as scientific management practices became more widespread in the early twentieth century the discipline changed from general Factory Management to Production Management, including a new groups of specialists including systems designers, industrial engineers and method study personnel (Taylor, 1911; see also review of scientific management in Huczynski and Buchanan, 1991). New perspectives on the design and operation of production systems were evolved under the influence of the Human Relations and Sociotechnical Schools (Roethlisberger and Dickson, 1939; Trist et al, 1963). These paradigms are often seen as the antidote to mechanistic forms of scientific management in that they recognize people and human behaviour as a major, if not the most important, influence on the efficiency and effectiveness of production operations. The wider operational perspective brought about by practitioners of Operational Research following

[1] For a full description of the history of manufacturing systems and associated management and engineering practice see Bennett, 1986; Gaither, 1992; and Ayres, 1992.

the Second World War encouraged a more holistic view of the transformation system whereby operations such as transportation, logistics and supply where encompassed and considered in the design of production systems (Moskowitz and Wright, 1979; Urry, 1991). Now, with the development of computers and the emergence of Japanese approaches based upon *continuous improvement* (Imai, 1986; Suzaki, 1987) including just-in-time management (Harrison, 1992) and lean production (Womack et al, 1990), the theory and practice of production systems design continues to develop under the influence of a number of different, and often conflicting, schools and paradigms.

Companies today are required to meet the increasing competitive and market pressures impinging upon them with the design of competitive manufacturing systems. Whilst maintaining the cost-effective manufacture of products, such systems are also expected to provide high levels of product quality, range and response flexibility[2], incorporate the latest technology, and address and account for the social and organizational demands made by the people working in the company. Production system design is, therefore, a complex process with determining influences and so the literature drawn upon in this thesis is, as a consequence, necessarily wide and varying in nature. There is no single identifiable body of literature providing a full understanding of all aspects of production systems design. The intention of this chapter is, therefore, is to provide an overview of the development and current state of relevant production systems theory. This involves collating the views of specialists from numerous, often conflicting, paradigms and consolidating the varied arguments into a contemporary view of the system design process.

4.2 Changing Perspectives on the Nature of Production Systems Design

Since the introduction of assembly flowlines within Ford's High Park factory and the dissemination of the principles of mass manufacture, the production system design activity has been closely associated with the various engineering functions of the manufacturing

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[2] "Range" and "response" are the two basic dimensions of flexibility possessed by a manufacturing system as identified by Slack, 1983; 1986.

enterprise. The methods of design were therefore chiefly contained within the literature of one profession. In addition, production systems prior to 1960 were relatively easy to categorise. They tended to fall neatly into three generally accepted groups: job, batch or flow[3]. Historically the process of production systems design has been largely retained within the domain of the engineering and concentrated upon the technical aspects of production in the quest to increase productivity, raise efficiencies and lower costs.

Manufacturing companies in the 1990s are facing many challenges from their environment which, it is argued, has induced new perspectives on the role of the production system within the organization and, correspondingly, the process of designing production systems has changed, as has the participants in the decision process for new systems. So what are the changes in the environment that have prompted such a radical change in emphasis? Boer (1990, p13) concisely sums these up as:

- more stringent market demands;
- increasing (global) competition;
- the need to simultaneously satisfy demands for efficiency, quality and flexibility;
- the growth of new computer-aided technologies; and
- the development of new management techniques.

In response to the first two items, increasing competition and changing market demands, many observers have identified a reorientation from manufacturing managers who now adopt a more *market-focused* approach to production system design (see for example Bessant, 1988; Bennett et al, 1992; and Bennett and Forrester, 1993). The third factor has seen a gradual change away from more traditional Western manufacturing management methods which seek to *optimise* performance from production systems to ones where *satisficing*, then *continually improving* in order to meet multiple and often conflicting requirements are the order of the day. This approach is perhaps best exemplified by the work of Imai (1986) on *Kaizen* which describes the improvement approach employed by Japanese companies and which, in Japanese, literally means "continuous improvement".

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[3] The classification of systems into job, batch and flow, and their characteristic features are considered in detail in Section 4.3. A full description of the rationale for this categorisation of production system types are given in Bennett and Forrester (1993), Hill (1991) and Muhlemann et al (1992).

The growth of new computer-aided technologies has brought with it the development of highly flexible reprogrammable production systems able to react quickly to changing market and customer demands, and control a variety of product manufacture not previously envisaged. The terms *Flexible Manufacturing Systems* and *Computer-Integrated Manufacturing* came to the fore in the 1980s as a direct consequence of the flexibility and potential for systems control and integration afforded by computer technology (see Boer, 1990). Finally the dissemination of new management practices, most notably as *Total Quality Management*, heavily influenced by Japanese models, has had a considerable impact during the 1980s. This shows no signs of let-up given the current level of interest in the 1990s in *Business Process Re-engineering*. Market-focused operations, the improvement approach, new technology and new management techniques are now considered in turn.

Market-Focused Operations

The 1980s and 1990s has seen the emergence of a new philosophy towards production systems design and management. This new philosophy is generally based on the responses required to meet the ever increasing demands of customers and the constant threat of competition. Different names have been given to the type of organization that has emerged but the term *market-focused* was adopted by Bennett and Forrester (1993) since it embraces the twin concepts of customer orientation and competitiveness. The idea of companies responding to market requirements is, of course, not new. From the perspective of production system design, however, market-focus means more than simply having a manufacturing function that is subservient to marketing. Market-focused production means restructuring the physical system and the associated planning and control systems in order to equip production with the means of deriving a greater customer orientation and competitive edge, thereby having a *proactive* rather than a *reactive* manufacturing function. To understand the way the philosophy achieves its objectives it is necessary to compare market-focused production with the more traditional *technology-led* approach.

Market-focused production is the name given to a philosophy based on the response required to meet the ever increasing demands of customers and the constant threat of competition. Traditional *technology-led* production is orientated towards maximising product and system performance and minimising cost whereas market-focused production also acknowledges the importance of quality and customer service. In market-focused production, volumes are usually lower and *economy of scope* through the ability to economically produce a high variety of products replaces economy of scale in a Fordist sense. There is also a tendency towards greater customisation. The management of market-focused production differs from the technology-led approach in a number of ways. Systems normally operate in a *make to order* environment and material ordering is facilitated using the *pull* rather than *push* approach[4]. Production control in market-focused production is based on the just in time principle where the supply of materials and parts at each stage of production takes place at precisely the time and in exactly the quantities required. As well as minimising inventory costs this enables the production systems to operate with maximum flexibility. Finally, a new approach to quality management is required based on creating a culture which is customer-orientated and sees quality as an asset rather that simply in terms of costs which must be minimised.

Technology-led production systems have, for many years, predominated in the established industrialised economies and, consequently, the design of production systems has often remained in the hands of technical specialists. A technology-led system is one in which product and process technology determines manufacturing strategy. It is based on a presumption that customer choice is influenced by two main factors, namely product performance and price. The result of such an approach is that production is of highly standardised products which are manufactured in large volumes to achieve economies of scale and reduce cost. Such products then 'look' for markets, that is to say they try to attract potential customers by using their price advantage and technical performance as the main competitive factors. The technology-led approach was appropriate when markets were less discriminating; when customers had less buying experience, disposable income was lower and financial credit not so widely available. The main objective, therefore, was to provide value-for-money expressed as a function of technical performance and price.

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[4] For an explanation of, and distinction between *push* and *pull* inventory control systems see Bennett and Forrester (1993).

A good illustration of market-focused production can be provided by the case of the electronics industry which provides one of the industrial sectors used for analysis in this thesis. Electronics is a relatively young industry which originally developed in the West where most of the major players until the 1980s relied on technological advances and production volumes to achieve and retain competitiveness. Their main focus was therefore on process and product innovations in order to provide high technology products at the lowest possible cost. As the industry grew and matured, however, the major Western manufacturers became subject to increasing competition from the Far East, and Japan in particular. They found that 'clones' of their products could quickly be produced by companies at greatly reduced cost and, therefore, the basis on which they were competing was rapidly being eroded. Faced with this situation the response among the traditional Western manufacturers has been dramatic, perhaps no where better demonstrated than in the case of ICL, and its corporate turnaround from near insolvency in the early 1980s to continued success and profitability in the late 1980s and into the 1990s. There have been efforts to reduce costs and to keep ahead technologically; however the most significant response has been to change the basis of competition where the emphasis lies in providing solutions rather than merely pushing products on to the market. Although different in their specific emphasis, many companies' objectives and manufacturing performance measures now represent an articulation of market-focus rather than technological dominance. They illustrate a desire to bring production closer to the customer and to 'provide solutions' or 'satisfy needs' rather than simply 'selling products' (see, for example, Bessant, 1988). In manufacturing terms it places an emphasis on the organization's interface with the customer which implies a shift in concentration from 'upstream' to 'downstream' activities.

The Improvement Approach

The conventional categorisation of production systems, and the logic underlying their choice, centres around the notion of *optimisation*: profit generating potential, costs, inventory holdings, etc, are optimised subject to a number of recognized and predetermined constraints. However a notion of *trade-offs*[5], where the decision maker acknowledges the limitations of each system type and takes a more holistic view of its benefits/deficiencies, has come to the fore over more recent years, both in the manufacturing management literature and in practice.

A different philosophy is necessary when designing production systems that overcome the deficiencies of conventional systems. This can be termed the *improvement* approach, which based on the idea of deliberately exposing constraints and finding ways of reducing and removing them rather than simply optimising within them. An essential part of the improvement approach is the development of new types of transformation system which allow the limits on system performance to be extended. The objective here is to design transformation systems based on combinations of work organization and facility arrangement which will exhibit the beneficial features of conventional systems while having fewer of their drawbacks. In this way many of the intrinsic constraints of conventional production systems can be removed and the improvement approach can thereby be facilitated[6].

New Technology

The role of new technology and, in particular, computer-aided technology, in the manufacturing organization has been an important theme of management research for some time. Gerwin and Kolodny say that new technology "is both a response to and a generator of uncertainty for a firm" (1992, p3). It is a response to the market and competitive demands that now demand highly responsive, flexible and cost-effective production, but is often the cause of tensions within the organization, many of which are not foreseen prior to implementation. Reporting on the social and organizational implications of the development of Computer Integrated Manufacturing (CIM) systems within UK companies, Forrester et al (1992) have said the following:

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5 See Hill's (1991) discussion of trade-offs. Also see New (1992).

6 See the work on *Kaizen* by Imai (1986).

> "The adoption of CIM brings with it new demands for interdisciplinary working and the sharing of information. However in most traditionally organized companies this in itself yields a host of difficulties, not least of all in trying to break the barriers that exist between different parts of the business: trying to effect organizational, as well as technical, integration. Design engineering modules within CIM encompass those activities traditionally performed by designers and engineers, whilst computer-aided production management often replaces the manual activities of production scheduling, control and operation, historically within the domain of production management. The integration of systems in many organizations is currently being hindered by the resistance to a converge these parts of the business. Organizational integration and the elimination of departmental barriers are proving to be more difficult to achieve in practice and will in turn hinder the technical development of the *seamless* integration required."
>
> (Forrester et al, 1992, pp321-322)

So, whereas many of the new computer-aided and associated technologies are supposed to provide adopters with the opportunity to respond adequately to competitive and market forces, they often result in internal organizational difficulties where companies have difficulty in effectively implementing these technologies to their full benefit (see Bessant, 1991). This has been identified by Boer (1990) as a major factor explaining the limited growth of Flexible Manufacturing Systems (FMSs) in the 1980s and has led to calls for the parallel consideration of technical systems and organizations, an approach defined as *simultaneous design*[7] by Ettlie (1988). However, a word of caution here. Rowlinson et al (1993), using the example of CIM, suggest that a major problem in the introduction of new technology is that design is seen as a technical project which runs into "organizational difficulties" at a later stage. These authors criticise much of the work on the management of new technology as still having a technological determinist emphasis where introduction of the technology is seen as paramount to organizational success. They suggest that the introduction of new technology should be treated not as a determinant of organizational

[7] Ettlie's concept of *simultaneous design* is distinct from the rather more pragmatic approach known as *simultaneous design engineering* meaning the concurrent design of products and processes.

change, but as "organizational change in itself" where technology is introduced when, and only when, it matches the needs and prevailing conditions within the organization.

New Management Techniques

New management techniques have stemmed in no small respect from the need to respond to the competitive, market and technological factors identified above. It is not the purpose of this thesis to consider the broader management techniques and approaches in any great detail as they are covered intermittently at the appropriate points throughout this chapter. However it is useful at this juncture to identify some of the more important techniques and management philosophies that influence the production system design process.

One of the most popular management approaches adopted by companies in recent years is that of Total Quality Management (TQM), although the precise content of a TQM programme can vary considerably from one organization to the next. TQM has evolved under the influence of the writing of a number of distinguished authors who, collectively, are often referred to as the *quality gurus*[8]. In general terms TQM can be seen as an organization-wide commitment to quality achievement and customer service. The focus is on ensuring high levels of quality performance through continual improvement, inducing customer satisfaction, developing an ethos within the organization of dedication to quality, and encouraging people within the business to assume individual responsibility for the quality of their own work. This would obviously be expected to permeate the production system design process whereby participants would be expected to develop as effective a design as possible[9].

Just-in-time (JIT) management has also had a profound effect on the process of system design. At one level JIT can be seen as a production control technique, but its broader philosophy of waste minimisation, low inventories and synchronised production means that

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8 See the work of Crosby (1979), Deming (1982; 1986), Feigenbaum (1983), Ishikawa (1972), Juran and Gryna (1980) and Taguchi (1986).

9 For more information on the concept of TQM refer to Oakland (1989) and Logothesis (1992).

production systems need to be designed with these requirements in mind. Schonberger (1982; 1986) has been foremost in promoting the advantages of production operations managed under the principles of TQM and JIT and the broader implications on design of the widespread adoption of the Toyota Production System are described in the lean production thesis by Womack et al (1990).

The spread of TQM and JIT practices can be traced to Japanese management approaches and the desire to emulate the economic success of Japanese companies in the West. Indeed some people go so far as to suggest that the development of new management techniques can be seen in terms of a second industrial revolution (see for example Gaither, 1992). Invention in terms of process technology was the catalyst of the Industrial Revolution in the eighteenth and nineteenth centuries. Invention, the argument runs, is once again the catalyst for a new manufacturing revolution which began in Asia and the countries of the Pacific Rim in the 1970's and 1980's. However, the inventions this time are not of a technological type. Rather it has involved the development of alternative production theory and practice. New concepts such as "just-in-time" management and new approached towards quality and design management (such as Total Quality and Kaizen) were introduced and evolved, in Japan particularly. This served warning of a new challenge to the traditional Western manufacturers (Hayes and Wheelwright 1984, Schonberger 1986, Womack et al 1990).

Having reviewed some of the challenges now facing the manager of manufacturing, and the system designer in particular, the types and characteristics of production systems will now be considered prior to exploring the design process for new facilities.

4.3 Classification and Characteristics of Production Systems

Job, Batch and Flow Production Systems

The classification of job, batch and flow derive from distinct combinations of three parameters which influence system design choices. Their features are shown in Table 4.1. Despite the recognition of three influencing parameters on the development of this classification there has been a tendency for two factors to dominate in the decision making process for new production systems design. These are:

Inertia

There has tended to be a lack of innovative thought at the overall systems organization level in the mind of the engineer who has in the past had primary responsibility for system choice. Compare this with the innovation often shown in the selection and development of individual "stand-alone" machines and equipment.

Table 4.1: Parameters Shaping Choice and Characteristics of Process Designs[10]

Parameter	Job	Batch	Flow
Organization of Work	Product orientated	Process orientated	Task orientated
Physical Layout	Fixed Position	Functional	Sequential
Level of Demand	Low/Unique	Medium/ Intermittent (or Prodn > Demand)	High/ Continuous (or Prodn ≈ Demand)

[10] A fuller explanation of the parameters shaping design and the characteristics of each conventional system type is to be found in Chapter 2 of Bennett and Forrester (1993).

Table 4.2: Features of Conventional Systems[11]

Type of Production	Benefits	Drawbacks
Job	• product flexibility • low fixed costs • job enlargement • simple planning	• low resource utilisation • duplication of facilities • high training costs • no benefits from specialisation
Batch	• specialisation (of operational tasks and supervision) • process flexibility • isolation of processes where necessary • ability to make priority changes	• high working capital costs • frequent set ups • high material handling costs • long delivery lead times
Flow	• few set ups • low working capital costs • low material handling costs • low direct training costs • specialisation • more easily automated	• human problems: (recruitment, high absenteeism, high labour turnover, etc.) • physical problems: (high capital cost, product and process inflexibility, interdependency can cause unreliability)

11 Adapted from Bennett and Forrester, 1993.

Demand Level and Nature

This has tended to dominate over the other two shaping parameters, organization of work and layout. Generally the rule-of-thumb adopted by engineers and managers alike is that if demand should be high and continuous the choice should be flow, low and unique, job, etc. This one can see as the capacity versus demand dilemma, where decision makers aim, first and foremost, to balance rates of production with aggregate demand over the range of products they produce with the minimum of risk.

It is important that the development of alternative innovative systems should take into account a wider number of factors and variables than those outlined above. A useful starting point in identifying the range of other factors is to recognize the inherent benefits and drawbacks of job, batch and flow systems. The features associated with each system type are given in Table 4.2.

Work Design Issues

The consequences of systems design choice on the job design of people working in the system has also had a profound effect on process decisions in the latter part of this century. Human and organizational problems of conventional system types were recognized during the Hawthorn Studies (Roethlisberger and Dickson, 1938), and the changes made to their processes by Volvo in the 1970s and 1980s were of a direct result of labour problems (Gyllenhammar, 1977). The job design features for each type of system identified above will now be discussed in turn.

Job Systems

A job system has traditionally been seen as appropriate were demand is low or unique ("one-offs"). It is based on layout by fixed position, where resources and materials come to a single location and products are then manufactured complete. The product-orientated organization of work means that the job contents of people within the system are centred upon the concept of the "make-complete" manufacture of the product. Job systems therefore normally require people with a range of skills and the ability to cope with the wide range of tasks demanded of them. Thus there is ample scope for job enlargement in work design. Additionally, the planning activities are simple, with all materials and resources coming to one point of use. However, job-type work designs demand a highly skilled workforce, so training needs and their associated costs tend to be high. Where volumes increase, the only way that job systems can cope is through duplication of facilities with the danger of low resource utilisation. Thus, despite the attractions of work design normally associated with job production, other types of organization usually need to be adopted for higher demand situations.

Batch Systems

A batch system normally uses a functional layout whereby similar machines or processes are grouped together and materials move between those processes during the manufacture of individual products. Batch systems are generally used in medium or intermittent demand situations, or where production rates exceed the rate of demand. The main justification for moving from a job to a batch system is the increased utilisation of resources, which are now laid-out on a functional basis. The resultant "process orientated" jobs within batch systems reflect the functional area within which the operator is working. Traditionally a major argument for the use of batch production is that it offers a high degree of specialisation, both in terms of manufacturing tasks and supervision. It was recognised as early as the eighteenth century that the development of functional specialisation and expertise in restricted operational areas leads to increased output (see Smith, 1776). However, more recently, the argument for functional specialisation has been thrown into doubt. From an organizational viewpoint, it is regarded as leading to restricted practices, a lack of interaction between functions and political difficulties between the different functional areas. Additionally, from a strategic and marketing perspective, the division of the manufacturing process into discrete and separate areas causes problems for market focus, with people who are working upstream in the system finding difficulty associating with, or even identifying, the requirements of the end-customer.

Flow Systems

Flow systems are used for situations where production volumes are high, or continuous, and the rate of production matches that of demand (capacity can be balanced against demand).

Processes are normally laid-out in operation sequence and the organization of work is generally task orientated, with operators performing a small or restricted number of tasks on a repetitive cycle. Much has been written in criticism of flow systems, but the logic underpinning the system (high specialisation and the opportunity of balancing the line) enables products to be produced quickly and efficiently with a minimal number of set-ups and materials movement. In terms of work design, the benefits frequently quoted include the ability to use less skilled labour, economies of scale through a high specialisation of tasks and, more recently, ease of automation of the simple and repetitive tasks performed. In addition to the criticisms of task specialisation outlined above, flow systems have also been seen to experience many human problems through monotony and boredom at work. Specific difficulties have included problems associated with "line-pacing" for workers, recruitment, high staff turnover and absenteeism, poor quality through a lack of commitment, and, as a result, a high incidence of industrial relations problems (Gyllenhammar, 1977; Womack et al, 1991).

Mixed- and Multi-Model Lines

A major problem with conventional line configurations is the difficulty of achieving flexibility in terms of product variety and range. This is because, traditionally, products being manufactured on a line have needed to be highly standardised and of a restricted range in order to maintain line balance and operational efficiency. Mixed and multi-model lines have been developed to deal with the problem of variety and are still widely used in manufacturing companies today (Wild, 1995). A mixed-model line is one which is configured so that a number of different (but broadly similar) products are manufactured simultaneously. A multi-model line is one where batches of the same product are produced and the line is periodically reconfigured or "set-up" each time the line changes over from one batch of products to the next (Aneke and Carrie, 1986). Mixed- and multi-model lines, in addition to coping with product variety, have the added advantages of enabling job enlargement and reducing the monotony of repetitive work for employees. However, these alternatives to the conventional line do have considerable drawbacks. Most significantly, demand for each product variant must be known and fixed in order that the line can be properly balanced across all the product range. However, even when demand has been accurately forecasted, the line is still forced to operate at low efficiency due to line losses caused by the variations in work content associated with each model produced (Bennett and Nagarkar, 1988). In practice the use of mixed- and multi-model lines is an option restricted to situations where total demand for assemblies is high and predictable over a relatively long period and product variety is relatively low. Such configurations have been utilised in the assembly of motor vehicles where a range of optional features and variations are available on what is fundamentally a basic model.

To overcome the drawbacks associated with the conventional systems it may be necessary to adopt alternative approaches using different combinations of work organization and facility arrangement. If such production systems can extend the limits on the efficiency of material flow there will be clear strategic benefits and the control system will not be constrained by the previous restrictions imposed. The ideas behind how such alternatives can be developed are discussed in the next section.

Job, batch and flow can be regarded as the three conventional production system design options and their implications for work organization and design are generally accepted. Over the last thirty years, however, there have been considerable efforts, by theorists and practitioners, to develop alternative approaches to fixed position, functional and line layouts. These include "mixed-" and "multi-model line assembly", "group technology" (otherwise known as "cellular manufacturing") and "autonomous group working", which are now described below.

Redesigning the Transformation System

Within the context of market-focused production there is an additional and complementary objective of improving the system's customer orientation. This is usually achieved by developing production systems with a greater product orientation, normally only associated with "job" production. The answer often lies in the use of *cellular* or *modular* organization. There are two types of cellular organization:

i for batch production of components; and

ii for continuous production (via assembly) of end products.

They are based, respectively, on the established principles of *group technology* and *autonomous working*. The place of these within the context of production system design theory will now be explained.

Cellular Organization for Component Production

Cellular organization for the production of intermittent batches of components is based on the principles of 'Group Technology' (or GT), (Snead, 1989). Group Technology has three aspects: grouping parts into families; grouping processes or machines into cells with the aim of reducing material movement; and creating groups of multi-skilled operators.

Grouping parts into families has the objective of reducing the amount of setting time between batches and thereby avoids the need to produce in large batches to minimise the unit ordering and setting cost. Parts family formation is based on the idea of grouping parts together according to geometrical or processing similarity. Sometimes 'composite component' is conceived which has all, or most, of the features of the constituent parts. The composite component may be 'real' although more often than not it will probably be hypothetical. If the process is set up to produce the composite component the setting time between all its constituent parts can, by definition, be minimised.

Processes or machines are grouped into cells with the intention of reducing material movement. Whereas a functional layout involves extensive movement of material between departments with common processes, a cell comprises all the processes or machines required to manufacture a family of components. Material movement is therefore restricted to within the cell and throughput times are thereby reduced.

Creating groups of multi-skilled operators enables increased autonomy and flexibility on the part of operators. This enables easier changeovers from one part to another and increases the job enrichment of members of the group. This in turn can improve motivation and have a beneficial effect on quality.

An additional feature of group technology is that cells can be a single planning point rather than individual machines. Production control need therefore only plan down to level of the cells and becomes more simplified. Planning within the cell is carried out by the group members themselves which enables them to apply their detailed knowledge of process capacity, capability etc. Work organization is product orientated which is in common with job production. Facility arrangement is by operation sequence so in this way it is similar to flow production. Group Technology is therefore able to derive the advantages of these two types of production system while still being suited to intermittent batch production.

The concept of group technology or GT ("Cellular Manufacturing") was developed as an alternative to the production systems normally used for batch manufacture (Bennett, 1986; Edwards, 1974; and Mosier and Tanbe, 1985). Parts and/or products are grouped into "families" on the basis of similarities in appearance, product type or, processing requirements. Human and/or machine work centres (cells) are then established for their manufacture based on operation sequence or product layouts. In essence the items are produced on small lines of machines or operators. GT can, therefore, be seen as a hybrid of batch and flow manufacture which seeks to achieve the benefits of flowlines (eg: low WIP, minimal materials movement, reduced setting/changeover times and shorter throughput times) in the batch production of parts or products.

A group technology cell can be regarded as a type of flexible manufacturing systems (FMS). It can achieve autonomy for separate operations within the manufacturing process whilst at the same time satisfying overall production objectives (Heyer and Wemmerlov, 1984). However, in certain situations there is a problem of deciding upon the precise arrangement of facilities and the categorisation of parts necessary to enable an appropriate segregation of the overall process into cells. As a consequence of this, GT has tended to be most widely used in the component processing industry where large numbers of very similar parts are produced which can be grouped into identifiable families (Burbidge, 1978).

Cellular Organization for the Assembly of End Products

The general approach to cellular organization for end product assembly is based on the principle of Autonomous Working, (Sandberg, 1982). This is an alternative to conventional flow production systems and, like flow production, it is associated with high (continuous) demand. Autonomous working addresses both the 'human' and 'physical' problems associated with conventional flowlines. To implement autonomous working in a practical environment the broad options available are either parallel assembly cells, or cells based on line assembly. Each type can be based on assembly being carried out by individual operators or groups. Both approaches change the work organization from being task orientated to being product orientated. Parallel assembly, however, uses a fixed position facility arrangement while line assembly retains the operation sequence arrangement usually associated with flowline working, (Karlsson and Bennett, 1991).

The benefits of autonomous working include the fact that the balance and system losses associated with conventional flowlines are reduced or eliminated with the longer cycle times of autonomous working. Also different products can be produced at the same time in different cells or modules, and response and volume flexibility is greater than with flowlines because model changes can be effected more easily. The autonomous nature of assembly cells means there is no work station interdependency meaning that job enrichment and autonomy lessens the human problems associated with flowline working. Finally quality tends to improve because responsibilities are more clearly assigned.

Autonomous Working was developed as an direct attempt to overcome the human and sociological problems associated with flowline production and short cycle tasks where little opportunity exists for job rotation and enlargement (Bennett, 1986; Gyllenhammar, 1977; and Aguren and Edgren, 1980). In autonomous working operators work independently of one another or are arranged into a number of small groups which, to achieve high volume production, may be duplicated and identical within the factory (Bowey and Connelly, 1975).

Like GT, autonomous working can be defined as a hybrid system. Whereas GT is an alternative to batch production, autonomous group working is an alternative to flow manufacture which seeks to achieve some of the human benefits frequently linked with job production operations. Group working is based on abandoning the idea of long flowlines in favour of a "make complete" approach. Thus, tasks are performed in independent work areas rather than at a series of positions along a line which are dependent on one another.

In autonomous working employees are allowed greater freedom to organize their own activities. Often the only constraint attached is that a certain volume quota is expected to be achieved by the group in a set time period (usually a week) (Sandberg, 1982). This inevitably leads to opportunities for the rotation of tasks or, if the operators choose, to more radical changes in the way work is performed. Responsibility for planning and local management is devolved from functional specialists and managers to the group level, therefore affording a significant degree of job enrichment. Finally payment schemes within autonomous group working usually take account of factors other than merely output, and a large proportion of earnings are normally calculated on the basis of group, not individual performance.

Autonomous working, however, does have its critics including the authors of the "lean production" thesis on the world automobile industry (Womack et al, 1991). Firstly, the productivity of organizations, such as Volvo, who have widely adopted group working is frequently questioned in comparison to the most efficient Western and Japanese producers. Secondly, there is an argument that job rotation, enlargement and enrichment can still be achieved in conventional and Japanese influenced manufacturing operations. Finally, it is widely accepted by advocates of autonomous working that it does not necessarily function satisfactorily in every labour market and social context.

Implications of Cellular Production

Some of the implications for production control of adopting cellular organization have already been addressed in the discussion on the benefits of Group Technology. The greater complexity of autonomous work systems for assembly necessitates a control system that can monitor products and sub-assemblies as well as guide them to the correct work places at the correct time. The reduced setting times, more efficient material flow and modular nature of cellular organization facilitates 'just in time' production using 'kanbans'. Materials Requirements Planning (MRP) can be used for longer term material purchasing where procurement lead times are too long for 'just in time' ordering.

One of the most important requirements for successful implementation of cellular organization is that the design of the product lends itself to the 'completeness of task' principle. With complex products this principle may require the design of modularised products which enable the complete production of a module to be assigned to an individual or group. Product design is one of the keys to successful implementation of cellular organization. The potential benefits of both Group Technology and Autonomous Working are often restricted when products have been designed to be manufactured on conventional systems.

Conventional payment systems, particularly those based on an individual financial incentive, are usually inappropriate for cellular organization. A more relevant payment system would probably comprise several components depending on the nature of work organization and the motivational and reward factors being emphasised. Some of the features of a payment scheme for autonomous work groups might be as follows:

Conventional versus Cellular and Group Systems

Summarising this discussion on conventional and alternative systems, it can be seen that production organization and its effect on work design has historically been a topic of intense debate and interest to systems designers and social scientists alike. The relative features of the established forms of batch and flow process designs have been questioned for some time and, as a result, alternative system designs have emerged. In terms of work design, however, there still persist doubts as to the superiority of these forms of manufacturing over conventional methods.

Cellular organization of processes has a number of important implications for work design within manufacturing. Firstly, the use of cells enables discrete parts of the business to be dedicated to the manufacture of products serving distinctive markets or goods for individual large customers. It has been found therefore that cellular organization can significantly increase the market focus within a business and, importantly, in the people working within the cell who can now identify and relate to their own external customers and markets. The result of this is that the introduction of cellular manufacturing is increasingly driven by a need to be more market focused rather than merely to achieve the performance benefits through the GT engineering approach.

Secondly it has become recognized that cellular and group organization can achieve numerous advantages by virtue of the fact that it breaks the manufacturing process into a series of small autonomous production units. Products or parts are made on a "make-complete" basis instead of being routed around a functional layout or along a line. The advantages of such working are two-fold. Firstly, it enables greater accountability across product lines within the manufacturing process and in some cases has resulted in "business managers" taking responsibility for product design, marketing and production for the items produced in one or a restricted number of cells. Secondly, it is argued that the multi-skilling requiring and the opportunity for job rotation frequently result in more varied and interesting jobs for workers. Converse to this, however, has been the counter claim that job satisfaction can fall due to the reduced variety of parts processed in a dedicated cell compared to the general functional department.

Flexible Manufacturing Systems

Manufacturing facilities with finite capacity need to be flexible within the modern operations systems where product variety is high (Slack, 1986; Buzacott, 1982; Bessant and Haywood, 1982; and Zelenovic, 1982). The techniques of FMS to respond to this demand are now relatively well developed (for discussion see Gustavsson, 1984; and Vonderembse and Wobser, 1987), but its application has mainly been directed towards component processing industries where production systems invariably incorporate advanced machining equipment operating in conjunction with automated handling devices (Bennett, 1986; Lim, 1986; Lim, 1987 and Hartley, 1984).

Flexible manufacturing for assembly is less well developed than for component processing since automation is frequently not feasible or cost-effective where product variety is high (Foyer and Drazon, 1986). An additional factor is that automation cannot respond to major design changes for products whose life cycles are inherently short and the volumes per design type are never great enough to justify robotics and the like (Bennett and Forrester, 1988). Mixed and multi-model lines are a step towards increasing the variety of products assembled (Aneke and Carrie, 1986) but there are a number of drawbacks associated with them. Most notably the periodic resetting of lines for new models causes distribution and, when running, there is often low efficiency in operation due to balancing losses (Bennett, 1986). The development of autonomous working based upon the principles of "make-complete" production, can enable a greater variety of products to be assembled in parallel systems (Sandberg, 1982; and Zelenovic et al, 1987). However the desire to attain high levels of manufacturing flexibility should be balanced against the fundamental requirement in manufacturing of maintaining productivity levels (Beaton, 1983; and Galonek, 1987).

The Design Process for Production Systems

Traditionally, the activity of designing a physical system for production was considered to only be the concern of engineering function within manufacturing companies (Forrester and Hassard, 1992). On two counts the approach was, typically, of a "closed systems" nature: there was little interpretation of the business needs of the organization and few efforts to link these with system specification and design; and there were only limited attempts to properly learn from the experience of other organizations in the area of process technology and design, and little collaboration with external systems vendors.

Current theory and best practice indicates a shift in this type of approach to one where the specification and design of an production system is linked very closely with the strategies developed by senior managers and the demands of the customers. Additionally, technical systems designers are actively encouraged to survey the environment to ensure that the best available or most appropriate process technologies are utilised in the design of any new production system. System design and development work is also increasingly being subcontracted to external suppliers and vendors who are often regarded as having greater technical expertise or more experience in the field of designing new production facilities.

4.4 Modelling Decision Processes

Systems theory forms an important part of the theory of organizational decision making and constitutes the basis of many of the models representing these processes. The systems approach derived from a desire to structure processes in an easily understandable and relatively standardised format. The basic systems model is that of the simple input/output model, and the systems models described below build upon this fundamental concept. Despite its somewhat "mechanical" appearance, systems theory has become an important part of organizational theory, with behaviouralists realizing the benefits and flexibility of the approach. Some of the applications of systems modelling are now explored.

In the analysis of business organizations a distinction is frequently drawn between conceptualising the firm as an "open" or "closed" system. Whereas the open system perspective analyses an organization in terms of the way it maintains a steady state through interactions with the environment, the closed systems perspective accounts solely for intraorganizational factors. Developing upon the pioneering work of Ludwig von Bertalanffy (von Bertalanffy, 1950; 1968), contemporary wisdom in organizational analysis suggests that we should, primarily, conceptualise the activities of work organizations in open systems terms (Checkland, 1972; Hall, 1962; Mitchel, 1968). The dominant perspective in organizational analysis has long been that of the open systems approach (eg: Katz and Kahn, 1975; Kast and Rosenzweig, 1970) and many writers talk of an open systems "orthodoxy" in research and conceptualisation (Silverman, 1970; Reed, 1985).

The analysis of organizational decisions, including those in production systems design, has led to the development of models which suggest that decision making processes can usefully be researched through reference to partially-open or, in some cases, closed systems perspectives (Silverman, 1970), that is to say approaches that focus firmly upon the interaction of decision processes and events internalised within the organization. Advocates of this approach to decision modelling, whilst recognizing the limitations of closed systems approaches, suggest that such perspectives are fruitful for directing attention to the existence of structural similarities and in the identification of key internal relationships in decision processes (Jaffe, 1967). The decision to apply an open, partially-open or closed systems methodology should, it appears, always be based upon the level of conceptualization's required by the system designer.

Peter Checkland's work at Lancaster University has drawn a distinction between what he calls "hard" and "soft" systems (Checkland, 1972; 1981). He argues that orthodox systems thinking concentrates on the solving of "well-defined" problems by the use of structured methodologies. He feels, however, that a "softer", more generic, approach is necessary for the analysis of "purposeful human activity systems", by which he implies the unstructured problems most commonly requiring decision making and solutions in industry. What is required, he argues, is a systems view which accounts for the solution of such unstructured problems, what is termed an "action approach".

Checkland's soft systems model involves a series of stages and the transfer of the thought processes of the system designer between the "real world" and the "abstract world of systems thinking". Thus problem situations are expressed and structured in the real world prior to the identification of "root definitions" of those systems that might seem applicable through systems thinking. Existing methodologies and systems thinking are used to develop and test conceptual models, which are then compared with the expressed situation in the real world. Having determined whether changes are both "feasible and desirable", they are then implemented and their effect in the real world monitored with a view to further calibration if necessary.

Systems approaches provides techniques for analysing the design and decision processes within manufacturing and other organizations. Whereas specific situations can be tackled using closed or partially open systems analysis, for higher levels of analysis it would seem more appropriate to utilise soft and open systems models. Despite their attractions in terms of structuring the problem situation and the decision making process, there remain many problems associated with the systems approaches. The more general and open the model, the more conceptual is the form of analysis produced. In general open models would appear somewhat detached and less applicable in terms of practical production systems design. Closed systems, however, tend to be limited in their scope, whereas soft systems are limited to conceptualisation and do not readily provide the systems designer with the techniques for more detailed analysis. Additionally, methodologies derived from systems theory tend to be more problem oriented in their rational. Thinking as all stimuli to the decision making process as being problems tends to neglect wider influences upon design such as strategic opportunity for the introduction of new systems. It is with such problems in mind that we need to turn to other forms of decision modelling.

The decision process model developed by Henry Mintzberg, Duru Raisinghani and Andre Theoret at the University of Montreal (Mintzberg et al, 1976) is regarded by a significant proportion of social scientists as state of the art for comprehending complex strategic decisions (for example Hickson et al, 1985). The model overcomes the problem orientation criticism of systems modelling by categorising stimuli to the decision process as "opportunity, problem and crisis". The Mintzberg et al model emphasizes decisions made within organizations as opposed to the decision making behaviour of individuals described for example by Newell and Simon (1972). It is superior to previous instruments for modelling organizational and group decision making, as developed for example by Cyert and March (1963), in that it considers a greater number of decisions across a wider range of contexts.

In essence the Mintzberg model separates the decision process into seven steps, what were termed "routines". Despite a largely phase-wise progression, it is recognized that one routine does not necessarily follow another in adherence to a strict sequence. In reality, decision processes are liable to move forwards and backwards between routines in a sporadic manner due to the incidence of "interrupts", "speedups" and "delays" in the decision process which together cause a delineation of the basic steps.

Structuring the decision process in this way is an invaluable aid for leading the practitioner or researcher through the stages of decision making in a concise and comprehensible fashion. The model's applicability to manufacturing system design has been demonstrated and the model has been used in a number of situations as a tool for analysing the decision processes inherent in a large scale project (see Bennett et al, 1990). If organizations could conceptualise their decision making activities in this way, it could enable greater understanding of the rationale behind design projects and, therefore, increase the effectiveness of future systems design projects.

The Mintzberg model, however, has a major shortcoming in that implementation is not recognized as a distinct phase. It is argued that the addition of an implementation phase to follow the seven previous routines is necessary to fully capture the entire decision process (Bennett et al, 1990). The omission of implementation is a criticism that also applies to most other decision models since few offer a detailed analysis of how solutions are developed from conception through to systems installation. Considerable scope exists for future research which seeks to analyse the implementation of complex design projects and how this process may be better understood and improved.

The GRAI Laboratory at the University of Bordeaux has developed a conceptual model for total system design in tandem with a more specific technique for designing production control systems (Doumeingts et al, 1986; Roboam and Pun, 1989). In terms of practical application it is the production control system design methodology that has been widely adopted and used as a control aid, particularly under the funding of the EC ESPRIT programme (see, for example Buenz and Huber, 1988). However, the lesser used conceptual model of decision making could offer the greatest potential for the future development of generic, higher level methodologies.

The hierarchical decision model is most commonly known as the GRAI conceptual model, it disaggregates manufacturing organization into three components, the "physical system", the "decision systems" and the "information system". The decision and information systems, which together comprise the "production control system", are then split into levels of decomposition to propose an organizational model with a hierarchical structure of decision centres. The interaction of the information system with the external environment initiates the open systems nature of the model.

To gain a methodological balance in the appreciation of systems design activities both processual and structural aspects must be taken attention of. The Mintzberg et al model of unstructured decision making can be used to map out the various stages of the decision process involved in systems design, and to recognize the extent to which feedbacks and multiple iterations affect this process. The GRAI model, on the other hand, can be used to structure and show the common decision interactions that occur between the various hierarchical levels within an organization's information and decision systems.

4.5 Corporate and Manufacturing Strategy

Contemporary best practice in production systems design demands considerable attention in associating the business and market needs of the organization with the requirements of the system. The need to develop a manufacturing strategy, detailing the objectives for production and long term targets, is seen as prerequisite before embarking upon the design of effective systems. A large body of literature on approaches to the development of corporate policy and business strategy has evolved over during the period since 1970. So, before discussing recent trends in the development of market-focused corporate and market strategies, three established theories of strategic analysis will be discussed. These are The "Boston Consulting Group Matrix" (see Shanklin and Ryans, 1981; and Daft, 1991), Porter's model for marketing strategy (Porter, 1986; and Miller, 1988) and the method of strategic analysis and policy formulation developed by Johnson and Scholes (1989).

The Boston Consulting Group Matrix

The Boston Consulting Group (BCG) Matrix is the most widely adopted form of portfolio strategy analysis. Portfolio strategy is that part of corporate strategy which plans an organization's mix of products and businesses. It attempts to fit together parts of the company, its "strategic business units" (SBUs), in such a way as to produce synergy and competitive edge. It identifies that companies usually require a balanced mix of SBU investments with some being high risk but with growth potential, some having low risk but guaranteed returns, and so on. The BCG matrix considers SBUs across two dimensions, their market growth and their share of the overall market for the products they produce. Market growth is the rate at which the industry is growing, whereas market share defines the size of the SBU in the industry within which it operates. The combinations of high and low market growth and market share generate a two by two matrix with four categories for a company's portfolio. Each of these types will now be considered.

Stars

A "star" is an SBU within the organization which has a large market share in a rapidly expanding market. The organization should consider investing funds in this business because of its potential for future growth and the consequent opportunity for future income and profit generation. If market share is maintained or increased, the star will generate positive cash flows even when the industry matures and growth slows down.

Cash Cows

The "cash cow" is where a high market share is held in a mature industry. Heavy investments in production facilities, research and development and marketing are no longer required, so the organization should "milk" the cash cow SBU for the money it can invest in its star and question mark businesses.

Question Marks

The "question mark" (or "problem child") is an SBU in a rapid growth industry, but with a relatively small share of the overall market. The question mark is a high risk business: it could become a star if the proceeds from cash cows are invested in them, but could also fail. Alternatively the business could be divested to another company if thought too risky or not key to the organization's overall future plans.

Dogs

The "dog" is a poor performing SBU: it has a small market share in a slow growth market. The dog is unlikely to yield large profits or any potential for future cash generation for the organization. As a result their should be no investment in the business and should only be kept by the company if in profit. Otherwise the business should be sold off.

The BCG matrix provides a means for companies to map their range of SBU and so provide a visual representation of the state and portfolio of the overall business. It is usual for SBUs to be represented by circles within the matrix, their position representing the growth and market share and the size of the circle indicating the relative size of each SBU. Using the BCG matrix, then, companies are able to evaluate which businesses should be milked for funds, which have future potential and should be invested in, and which should be divested as high risk or loss making businesses.

The Porter Categorisation of Marketing Approaches

Porter has identified four types of business strategies adopted by companies, namely those of "differentiation", "cost leadership", "focus" and "stuck-in-the-middle". The first three of these he identifies as effective strategies, whilst stuck-in-the-middle represents a poor strategy where a business is "master-of-none" of the three effective strategies. In fact "stuck-in-the-middle" represents no real strategy at all, with the organization generating no distinctive competitive advantage. The effective categories of strategy are now discussed.

Differentiation

This type of strategy represents an approach that attempts to distinguish the products offered by an organization from that of its competitors. The product is advertised and presented to the customer as being unique and different in terms of quality, the features offered or in some other way. Organizations adopting a differentiation strategy are commonly categorised or should seek to develop strong marketing abilities, good coordination between functions, creative flair and innovation, strong skills in research and development, and a reputation for quality and technical leadership.

Cost Leadership

This type of strategy occurs where the organization seeks to provide the product to the customer at a lower price than its competitors. Thus, in its operations, it pursues a strategy of developing highly efficient facilities, aggressive cost controls and reduction programmes, and economies of scale in production. Such an organization is characterised by tight financial management, close supervision of labour, process engineering skills and product design for ease of manufacture.

Focus

The third type of effective marketing approach identified by Porter is really a subset of the differentiation and cost leadership strategies. It occurs where the organization pursues one of the above strategies in a distinct geographical market or for a limited target group of customers within the overall market. Thus the focus strategy can invoke any of the organizational and operational circumstances discussed above for differentiation and cost-leadership depending on the type of focus strategy being adopted.

The Porter categorisation provides a potentially useful and easily understandable framework for companies formulating their competitive strategies. They are able to analyse their current position and determine the type of strategy they are currently pursuing. If this is of the "stuck-in-the-middle" category, the strategy can then be adapted to one of the effective types. There are areas of similarity between Porter's work and the classification of strategic approaches put forward by Miles and Snow (Miles and Snow, 1978). The differentiation strategy is similar to the "prospector" trait of Miles and Snow, cost-leadership can be akin to the "defender" and the focus approach is like the "analyzer" type. Miles and Snow's fourth type, the "reactor", is not a proactive strategy at all and so can be compared with the "stuck-in-the-middle" approach.

The Porter categories are very general, but are useful not only when considering corporate and marketing strategy as they give some insights into probable manufacturing objectives. Manufacturing strategy must be developed so that systems operate to reflect the requirements of the identified market. Similar products are liable to be manufactured on quite different production systems if competing organizations adopt different market strategies. For example a cost leadership strategy usually requires economies of scale in manufacture and production in higher volumes on fairly rigid systems, whereas strategies of differentiation, particularly those where the customer is offered a range of features or customisation, will need a more flexible operation.

The Johnson and Scholes Framework

The Johnson and Scholes framework is intended to assist in the analysis and development of corporate strategies. Whereas the BCG matrix and the Porter classification provided typologies of strategic approaches and their associated characteristics, the Johnson and Scholes framework is more concerned with the process of strategy formulation. The framework comprises three main stages: strategic "analysis", "choice" and "implementation". Each of these will now be considered in turn.

Strategic Analysis

Analysis involves the collection of data and information from the environment plus an internal evaluation of the organization. Environmental analysis includes evaluation of the market and customer requirements, the collection of competitor information for benchmarking and other analyses, an appreciation of the prevailing social conditions including the labour market, and familiarisation with legal and government aspects. The internal analysis involves consideration and understanding of the multiple values, expectations and objectives that reside within the organization and the capital, labour and other resources that are available.

Strategic Choice

Following from the analysis stage, the choice of strategy for the organization must be made. There are three steps identified for this. Firstly strategic options need to be generated and so a high degree of lateral and novel thinking is required a this stage. Secondly these alternatives must be evaluated and screened so that the most feasible and appropriate strategic options can emerge. Finally the strategy must be selected from these preferred options.

Strategy Implementation

Once a decision on a particular strategy has been made, this must then be implemented and put into practice within the organization. Three main considerations are identified within the framework. Firstly implementation must take into account the existing human resources, corporate culture and organizational processes and these should be adapted and modified where necessary to align with the new strategy. Likewise the organizational structure should match and appropriate to the strategic direction of the organization. Thirdly implementation must include a high degree of resource planning on the part of the strategist to ensure that plans and policies are put into operation with the minimum of disruption and resistance.

The Johnson and Scholes model provides a pragmatic framework to assist in the formulation and implementation of strategies and the overall management of this process. It also offers a means of evaluating existing strategies for the analyst and practising manager alike.

Manufacturing Strategy

Within manufacturing companies today there is little argument that an effective and efficient production system delivering products to customers at the requisite quality and cost and on time is a critical element in ensuring corporate success. The strategic importance of operations with the manufacturing company is now widely accepted, as is the need to link the approach to production with the corporate objectives and marketing strategy. However, this view has not always been held by senior executives within companies. This section traces the evolution of the manufacturing strategy paradigm from its inception and acceptance through the work of Wickham Skinner and thorough the various influences upon the development of its theory. The contribution of leading scholars will be described and, finally, its current state will be discussed.

Early Developments and the Work of Skinner

An interesting keynote address was given at the 6th UK Operations Management Conference at Warwick in 1990 by Wickham Skinner, regarded by many as the pioneer of the manufacturing strategy paradigm. He reported that the term "Manufacturing Strategy" was first used at the Harvard Business School in the late 1940s where, at that time, he was a young research student. For twenty years his use of the term was considered the be a contradiction in terms and he had frequent disputes and arguments with those who saw manufacturing as having little or no consequence in competitive terms. The words "manufacturing" and "strategy" were seen as incongruous. Surely it was the intelligent strategic use of marketing and finance that gave an organization its competitive advantage and manufacturing operations simply got on and produced goods as cheaply and fast as they could. Indeed, using Skinner's words, manufacturing was typically seen as a "millstone" around the corporation's neck: a function that used up substantial quantities of the company's resources, always seemed to be on the defensive when requests were made or changes required, and never providing marketing with what they needed.

The idea of formulating manufacturing strategy, however, has gained momentum since the publication of Skinner's article in the Harvard Business Review in entitled "Manufacturing-Missing Link in Corporate Strategy" (Skinner, 1969). Skinner argued that manufacturing could and should be linked to corporate objectives and marketing strategies. He suggested that the links between manufacturing effectiveness and corporate success go far beyond merely ensuring high efficiency and low cost and should include other considerations such as quality, product and process focus, service and delivery, etc. He was strongly critical of conventional methods of operations management which were based upon the principles of scientific management and Taylorism and advocated a top-down rather than a bottom-up approach.

Skinner concluded that manufacturing operations can be either a "competitive weapon" or a "millstone" for a company, and seldom neutral (see Skinner, 1978; 1985). He argued that by adopting a strategic approach to managing operations the organization can achieve competitive edge over its rivals. By not paying sufficient attention the manufacturing and its links with corporate objectives, however, the production operations can impede corporate success even when corporate objectives have been well stated and a effective marketing strategy has been formulated.

Restoring Competitive Edge in the 1980s

The late 1970s and early 1980s saw the realisation in the USA and Western Europe of the emergence of global competition, particularly that from Japanese companies. Many reasons have been cited for the success of Japanese and, more recently, of other manufacturers around the Pacific Rim, but one of the most publicised is that of their effective manufacturing operations. The Harvard Business School took up this cause and published many papers which attempted to identify why the Japanese had attained manufacturing superiority (see, for example, Hayes, 1981; Wheelwright, 1981; and Abernathy et al, 1981).

A key issue in these (and other) works was one of how to extract the lessons from the successful manufacturing economies of the world so as to apply these and rejuvenate the competitiveness of American companies. Robert Hayes and Steven Wheelwright carried their ideas forward and, in 1984, published their book entitled "Restoring Our Competitive Edge: Competing Through Manufacturing" (Hayes and Wheelwright, 1984). Rather than merely stating the malaise of Western manufacturers, this book attempted to provide guidelines for senior executives wishing to compete through manufacture and so achieve levels of corporate effectiveness comparable in the best in the world.

An important contribution to understanding Western manufacturing decline was provided by Terry Hill in his thesis on the strategic management of the manufacturing function (Hill, 1985). Writing at the same time as Hayes and Wheelwright, Hill also drew international comparisons in the management of manufacturing. His conclusion was that the pressure on the manufacturing function in many businesses was such that the emphasis has been upon how "to manage reactively, and to be operationally efficient rather than strategically effective" (Hill, 1985, p27). He argued that manufacturing executives must begin to think and act in a strategic, not reactive manner. "The purpose of thinking and managing strategically is not just to improve operational performance or to defend market share. It is to gain competitive advantage ...." (Hill, 1985, p27). Hill went on to provide a framework for analysing and linking production and operations decisions within corporate objectives, which will be described in Section 3.

World Class Manufacturing

The term "World Class Manufacturing" (WCM) has now come to the fore to describe the operations of the most successful companies. Foremost amongst those authors spreading this term was Richard Schonberger. Firstly Schonberger had attempted to reveal that Japanese excellence in manufacturing was not culturally bound and gave some insight into the methods adopted by Japanese companies (Schonberger, 1982). Picking up on his theme of blending Total Quality Control and Just-in-Time management approaches, Schonberger then attempted to show how companies could achieve world-class status (Schonberger, 1986). In the "World Class Manufacturing" book Schonberger gave a 17-point action agenda for managers to follow in developing "manufacturing excellence"[12]. These were:

" 1. Get to know the customer
2. Cut work in progress
3. Cut flow times
4. Cut set-up and changeover times
5. Cut flow distance and space
6. Increase make/deliver frequency for each required item
7. Cut number of suppliers down to a few good ones
8. Cut number of part numbers
9. Make it easy to manufacture the product without error
10. Arrange the work place to eliminate search time
11. Cross-train for mastery of more than one job
12. Record and retain production, quality and problem data at the work place
13. Assure that line people get first crack at problem solving - before staff experts
14. Maintain and improve existing equipment and human work before thinking about new equipment
15. Look for simple, cheap, moveable equipment
16. Seek to have plural instead of singular work stations, machines, cells and lines for each product
17. Automate incrementally, when process variability cannot otherwise be reduced"

(from Schonberger, 1986)

[12] The number of points had increased from the "nine hidden lessons in simplicity" that Schonberger had presented in his 1982 book.

Schonberger's work has been criticised as being highly prescriptive and not providing adequate framework for the analysis of production operations to enable the development of manufacturing strategies in given situations. However "World Class Manufacturing" as a concept has found favour and caught on widely amongst practitioners as a goal to be attained. In this respect, the following provides a useful definition of what WCM status means:

1. *Becoming the best competitor*

   Being better than any other company in your industry in at least one aspect of manufacturing.

2. *Growing faster and being more profitable than competitors*
3. *Hiring and retaining the best people:*

   Having workers and managers who are so skilled and effective that other companies are continually seeking to attract them away from your company.

4. *Developing an excellent engineering staff*
5. *Responding quickly and decisively to markets changes:*

   Being more flexible than one's competitors in responding to market shifts or price changes, and getting new products into the market faster than they can.

6. *Practising "simultaneous" or "concurrent" engineering:*

   Being able to develop products and processes in parallel and so cutting time to market down below that of competitors.

7. *Continually improving facilities, systems and people skills:*

   The emphasis on continual improvement is probably the ultimate test of a world class organization.

(adapted from Hayes et al, 1988)

4.6 Frameworks and Methodologies for Manufacturing Strategy

This section reviews four structured approaches for the analysis and the development of manufacturing strategies. A particular feature of the frameworks and methodologies presented is the way they link manufacturing facilities and production control choices with corporate policy and marketing strategy, and so with the markets and environments within which organizations operate. The two approaches reviewed are Skinner's model of the "Process of Manufacturing Policy Determination", Hayes and Wheelwright's typology of the "Stages in the Evolution of Manufacturing's Strategic Role", Hill's "Framework for Reflecting Manufacturing Strategy Issues in Corporate Decisions", and the Cambridge Group's "Methodology for Developing Manufacturing Strategy".

Skinner's Process Model

As was described in the last section, Skinner called for the need for a more strategic and top-down approach to the management of manufacturing operations. He then went on to provide a fifteen step model providing guidelines for the process of formulating and implementing manufacturing strategy (Skinner, 1969; 1978; 1985). The first eight steps of the process attempt to form the link between corporate strategy and manufacturing operations. These are:

1. Analyse the competitive situation
2. Audit the company's existing skills, resources, facilities and approaches
3. Formulate corporate strategy
4. Define the manufacturing task in accomplishing corporate strategy
5. Study economic constraints and limitations within the industry
6. Study technical constraints and limitations within the industry
7. Evaluate resources available within the company
8. Specify manufacturing strategy

Steps 9 to 15 then consider the implementation and ongoing evaluation of the new manufacturing strategy. They are:

9. Consider the implementation requirements of the manufacturing policies
10. Determine and develop manufacturing systems and procedures
11. Determine and develop manufacturing controls
12. Select manufacturing operations components relating to labour skills, equipment, etc
13. Measure performance of elements in 10, 11 and 12

14. From the results of 13, evaluate changes in competitive situation and review corporate strategy where necessary
15. Analyse and review manufacturing operations and strategy

Skinner's views of manufacturing have been very influential in the development of the manufacturing strategy paradigm and, increasingly, in the linking of production systems design and operation with markets and corporate objectives. However his process model, although innovative in nature at the time, is very general in nature and, other than conceptually, provides the manufacturing practitioner with very little detailed guidance on how to formulate strategies and translate this into system design choices. We therefore turn to other frameworks and methodologies that have since been developed.

Hayes and Wheelwright's Effectiveness Framework

This framework presents four stages identified by the authors in improving manufacturing effectiveness in global markets. As well as being descriptive and explanatory, the effectiveness framework is intended to provide guidance to managers when attempting to evolve their manufacturing strategies and operations (Hayes and Wheelwright, 1984; Wheelwright and Hayes, 1985).

The stages identified in the framework are as follows:

Stage 1: Minimise manufacturing's negative potential - "internally neutral":

This is where senior managers view the manufacturing function as neutral, that is to say it is incapable of influencing competitiveness success. The emphasis here is to minimise any negative influence that manufacturing may have upon corporate and market developments.

Stage 2: Achieve parity with competitors - "externally neutral":

Senior managers see manufacturing as important only in so much as it matches the effectiveness and efficiency of competitors in the same industry. Here the emphasis is upon following industry practices in managing the workforce, avoiding large step innovations in product or process technologies, and viewing economies of scale and efficiency as the most important factors in production.

Stage 3: Provide credible support to the business strategy - "internally supportive":
Senior managers expect manufacturing to support and strengthen the company's competitive position. They see the contribution of manufacturing as deriving from and dictated by corporate objectives. They ensure decisions made in manufacturing are consistent with corporate and marketing strategies, that strategy is translated in terms meaningful to manufacturing personnel, and are proactive in developing longer term manufacturing strategies at the functional and factory levels.

Stage 4: Pursue a manufacturing-based competitive advantage - "externally supportive":
This is where senior executives see manufacturing capabilities as a significant influence upon overall competitiveness. So manufacturing strategy is not merely determined by internal corporate and marketing strategies, but allow manufacturing executives to have a meaningful role in contributing to the development of the company and its strategies as a whole. In some cases this will result with the realisation that manufacturing is the key competitive weapon within the organization.

Managers can identify at which stage their companies are in this framework and therefore identify changes that need to be made within the organization to progress to the next stage. Thus, to improve manufacturing effectiveness, companies should progress from one stage to the next with Stage 4, in the opinion of the authors, representing "world class manufacturing". Hayes and Wheelwright also comment that in some cases companies can move more than one step at a time, but that the largest step is from Stage 3 to 4: the "big jump". Useful as it as a positioning tool for comparative and/or benchmarking purposes, the Hayes and Wheelwright framework provides little or no guidance describing how exactly one might move from one stage to another.

The Hill Framework

An early attempt to provide a structure for the practitioner in developing a manufacturing strategy was provided by Wild (1980). In his book, Wild considers the role of manufacturing within overall business policy and then sets up a "policy framework" which laid particular emphasis on the need for the operations management function to interact with the rest of the organization and the external environment at all levels, particularly during the process of investing in new production facilities.

The work of Terry Hill builds upon and goes further than this by considering how to strategically manage operations (Hill, 1985). As his starting point Hill compared manufacturing management and performance in an international context through the extensive use of economic statistics. Following consideration of manufacturing practice, he then provides lessons for the translation of corporate policy and market strategy into "process choice" and the development of the manufacturing "infrastructure". Process choice and the installation of the infrastructure can be viewed as the two essential components of production systems design, so the work of Hill is most relevant for this thesis.

Hill summarises his arguments and discussion within his "framework for reflecting production/operations strategy issues in corporate decisions". This framework is reproduced in Figure 4.1. Based upon his work upon the manufacturing management task and the role of the production manager, Hill provides lessons for the development of manufacturing strategy within an overall framework (Hill, 1985). The framework focuses upon the translation of corporate policy and market strategy into "process choice" and the development of the manufacturing "infrastructure" and is based upon the following premise:

> "The need for strategic difference in production/ operations is, therefore, a prerequisite on which to build a sound and successful business. To accomplish this, it is necessary for business to recognize relevant issues at two levels:

Figure 4.1: Framework for Reflecting Production/Operations Strategy Issues in Corporate Decisions (from Hill, 1991)

1. How to develop relevant production and operations functional inputs to the corporate strategy debate.

2. To be aware of the different approaches at the operational level within manufacturing management so that appropriate consideration can be given to alternatives."

(Hill, 1991, p21)

Fundamental to the framework is an understanding of "how products win orders in the market-place", step three in his framework. These include price, quality, delivery, service, responsiveness to change, and technical performance. In turn it is argued that the mix of these comes from two major sources, originating from the customer or market as reflected in corporate strategies on the one hand, or generated from the inherent features of the production system on the other. The manufacturing organization must identify the order-winning criteria for its products; ie: the correct balance between the factors detailed above, and then reflect these in corporate objectives, market strategy and production systems design.

The five steps in the framework are defined as:

"1. Define corporate objectives
2. Determine marketing strategies to meet these objectives
3. Assess how different products/services win orders against competitors
4. Establish the most appropriate mode to manufacture these sets of products or provide these sets of services - process choice
5. Provide the infrastructure required to support the production/operations process."

(Hill, 1991, p25)

Hill sees nothing unique about this process which, he says, are essentially the "classical steps in corporate planning". However, he regards the current situation as one where corporate decision makers see only the first three as an iterative process with feedback loops at each stage of development. Process choice and infrastructure, the production systems design issues, are simply seen as linear and deterministic by most senior executives. It is argued that manufacturing strategy (ie: steps four and five) should also interact in an iterative manner with the first three steps: that manufacturing managers should enter the "corporate debate". Also he sees manufacturing facilities as possibly providing areas of advantage which are frequently overlooked in strategic formulation, hence the arrow from steps four and five back to step three. This notion fits well with the view of manufacturing as a "competitive weapon" (Skinner, 1985) and the concept of "competing through manufacturing" (Hayes and Wheelwright, 1984).

The Hill framework demonstrates how market and competitive decisions are, and should be linked with decisions on production systems design. Moreover it explores the relationships from the "bottom-up" and illustrates how excellence in manufacturing can provide order-winning characteristics for products which may not have been recognized as winners by corporate decision makers and marketing managers. The framework can be used in two ways. It can firstly be utilised for the assessment and evaluation of the effectiveness of manufacturing operations in relation to corporate objectives and product markets. Secondly it serves as a guide for developing new, market-focused strategies and systems in manufacturing. As such it represents a significant contribution to the study of manufacturing strategy and process decisions.

The Cambridge Group Methodology

A methodology for developing manufacturing strategy has been devised by Gregory and Platts at Cambridge University and has been widely publicised by the UK Department of Industry (DTI) under its "Enterprise Initiative". The methodology provides guidelines for practitioners in developing their objectives for manufacturing (DTI, 1988). It covers such issues as determining market requirements, competitor threats, performance of existing systems, and how to combine all these into a comprehensible and meaningful blueprint for production.

The objective of the Cambridge Group's methodology was to provide a practical approach for the development of manufacturing strategies for use by industrialists and so complement the more theoretical frameworks described above. A key feature of the methodology is that, through the use of worksheets which the user completes, it not only performs an analysis of the market and competitive environment within which an organization operates, but also conducts an audit of existing manufacturing facilities and competencies. In this way it looks for areas in which system performance may be improved to better align operations to the market needs.

The methodology involves three main phases:

Stage 1: Understanding Your Market Position:

This involves generating basic data on product families which indicates the importance of the family to the business and the strength within current markets. The competitive criteria for each family is then determined (eg: price, delivery performance, etc) and the organization's current performance against these criteria is assessed. Finally potential areas of product profitability and vulnerability within the business are identified.

Stage 2: Assessing Your Manufacturing Operation:

Involves an assessment of current manufacturing strategy and analyses this in nine areas, namely:

Facilities	- the manufacturing factories, including number, size, location and focus.
Capacity	- the maximum output for each factory.
Span of process	- the degree of vertical integration.
Processes	- the transformation activities and the way they are organized.
Human resources	- the people-related factors.
Quality	- the means of assuring products, processes and people operate to specification.
Control policies	- the operations planning and control guidelines and philosophies of manufacture.
Suppliers	- Relations and methods to ensure delivery of input materials.
New products	- The mechanisms and processes for managing new product introduction.

Stage 3: Developing Your New Strategy:

The results of the analyses conducted in Stages One and Two are used to develop a new manufacturing strategy linking manufacturing activities with corporate strategy and market needs. The process in this strategy formulation are identified as:

1. Select the most important product families, based upon assessments of the relative contributions to profits, growth potential of market share or overall market size, and current strength within markets.
2. Taking each family in turn, compare the market competitive criteria with the achieved performance.
3. Identify the manufacturing policies which contribute to any mismatch between the competitive criteria and the actual performance.
4. Identify the weaknesses of the policies.
5. Consider opportunities and threats.
6. Identify possible actions and strategic choices.
7. Repeat for other families.

The originators suggest that the methodology can be used in two main ways, both for auditing existing manufacturing activities in order to identify current strengths and weaknesses, and as a framework for reviewing manufacturing strategy and developing a new one if need be. As such, it not only provides a useful insight into the process of manufacturing strategy formulation, but also suggests a practical approach by which organizations might arrive at appropriate strategies for production and market-focused systems development. The Cambridge Group methodology thus incorporates the ideas of academic writers on manufacturing strategy and the role of manufacturing, but provides detailed guidance upon how to audit and develop strategies within a business environment.

Summarising Work on Manufacturing Strategy

This section has provided four frameworks to assist in the analysis and development of manufacturing strategy. Each has its own novel features and uses. The Skinner model was an early attempt to provide guidelines upon how to link manufacturing operations with corporate strategies which was further developed by Hill who provides a more analytical and less prescriptive framework. Hayes and Wheelwright provided some insight into the stages which a company must pass through on the route to "world class" status. Finally the Cambridge Group provide a more practical, detailed and complex methodology to assist organizations in the analysis of market and competitive factors and so develop an appropriate framework.

In summary, the literature on manufacturing strategy therefore suggests that a strategic (ie: top-down) and market-oriented approach to manufacturing strategy should be taken. This is not to say, however, that the development of this strategy and its linked decisions on process choices should be a deterministic process and lead on linearly from corporate and marketing strategies. Increasingly, as manufacturing are becoming more involved in shaping their own strategy, the opportunity for increased flexibility and responsiveness to market needs is being identified and effected. It is to this flexibility debate, which has direct consequences for production systems design, that we now turn.

4.7 Manufacturing Flexibility

The issue of manufacturing flexibility has been the centre of a wide ranging debate both in the manufacturing strategy and labour management literatures. It is now widely acknowledged that manufacturing flexibility means far more than merely flexible machining as was the case with early installations of so-called flexible manufacturing systems (FMS). Flexibility is now treated as having a number of dimensions in both the manufacturing strategy and labour management literature but, for some reason, these two paradigms on flexibility have never really been integrated. This section considers both areas in the literature: it is suggested that by jointly considering these manufacturing managers and academics alike would improve their understanding of the concept of flexibility in manufacturing systems.

In the manufacturing strategy literature Gerwin and Kolodny (1992) and Zelenovic (1986) have put forward to basic premise that manufacturing flexibility is needed so that organizations can adapt effectively to changing circumstances. But what exactly is flexibility? Slack (1987; 1991) has picked up on this and has suggested that in examining flexibility we must identify the forms and dimensions that it takes.

Table 4.3: Dimensions of Manufacturing Flexibility as Identified in the Literature[13]

Reference	Range Flexibility	Response Flexibility
Mandelbaum, 1978	-	State Action
Zelenovic, 1986	-	Design Adequacy Adaptation
Gerwin, 1982	Mix Parts	Design Change Volume Routing
Buzzacott, 1982	-	Job Machine
Browne et al, 1984	Process Routing Production	Machine Product Volume Expansion Operation
Bessant and Haywood, 1986	Product Routing	Volume Operation Machine Process
Slack, 1986	Product Mix	Volume Delivery

13 Some similarly titled dimensions appear as both "range" and "response" flexibility. This is due to variations in the definitions attached to these by the different authors.

Slack suggests a basic distinction between *range* and *response* flexibility. Range flexibility is defined as the operations system's ability to adapt by facilitating the scope for a range of products to be produced, whereas response flexibility is the system's ability to react quickly and effectively to changed requirements. Other writers have suggested what dimensions manufacturing flexibility might comprise, but all can be categorised within the Slack concepts of range and response (see Table 4.3). In summarising the various views on flexibility Nilsson (1995) suggests that flexibility should be considered as a concept in manufacturing management which links production operations with the strategic concerns of the organization. Nilsson argues that organizations, by increasing the flexibility of their production systems, can greatly enhance their strategic flexibility (defined as the ability to continuously align the organization with its environment). Furthermore Nilsson argued that although sometimes deemed to expensive to incorporate within a production system, flexibility can have positive synergic effects upon other competitive priorities such as cost, quality and dependability in delivery. Its incorporation therefore has long term benefits for the organization as a whole.

In labour management theory, labour flexibility has been one of the most influential contemporary concepts. Building on the organizational concept of the "core" and "periphery" (see Handy, 1983), the model of the "Flexible Firm" was evolved by Atkinson (1984). This model has been widely acknowledged as describing the emerging employment patterns of U.K. companies in response to the pressures of the 1980s, such as increased foreign competition and shrinking captive home markets. Atkinson argues that companies will seek three forms of flexibility in its employment policy:

i "Functional": the ability of employees to accomplish a range of tasks;

ii "Numerical": the ability to adjust employee numbers as required by demand; and

iii "Financial": the ability to vary the amount paid for labour (which is linked to numerical flexibility).

This type of approach is articulated in the emergence of a group of core workers who, in return for providing functional flexibility, will receive stable employment and single status conditions of work. Numerical and financial flexibility, however, is seen as being achieved either through a pool of peripheral workers (for example temporary and part-time employees) who gain little by way of job security, by an increase in subcontracting work, or a combination of both. These actions result in increased labour flexibility for the organization, and the production systems in particular, but clearly they have consequences for the labour market and society in general.

Much of the labour management literature therefore takes a more critical perspective towards flexibility (see for example Rowlinson et al, 1991). The issues of core and periphery and the model of the flexible firm have been linked to the more wide- ranging debate on flexible specialisation which envisaged a fundamental restructuring of employee relations, social relations and the work itself. Flexible specialisation involves increasing the flexibility of labour by using what amounts to a revival of craft forms of production with multi-skilling being normal practice (Piore and Sabel, 1984). Flexible specialisation has, therefore, become one of the cornerstones of the "Post-Fordism" movement which, because of the need for flexibility and to satisfy changing markets, considers that the era of mass manufacturing is now approaching its end (Murray, 1989).

4.8 Manufacturing Organization

Theory and knowledge is now relatively well advanced on the subject of technical aspects of production systems design. However the organizational issues associated with new technology is more confused and, in many cases, conflicting. One notable piece of work in this area is that of Ettlie who calls for an adoption of "appropriate" as opposed to merely "advanced" product and process technologies to correspond with the development of organization design (Ettlie, 1988). Despite the attractions of Ettlie's concept of "simultaneous design", he provides little by way of guidelines for the manufacturing decision maker wishing to take advantage of new technology, but is also aware of the importance of maintaining and developing the "right" organizational form.

This section now considers the wider body of management literature and writings on organizational behaviour which seem applicable to the debate on manufacturing organization design. Three areas of the literature are identified, these being organization structure, innovation, organizational culture, and employee participation and codetermination.

Organization Structure

The major debate in organization theory has been in response to the vexed question of what exactly determines structure. Clearly there are many influences upon organizations and these differ between companies, but if the most important determinant or determinants could be identified and proved, then this would provide a means of reorientating structures and production organizations towards the market. The five most widely proposed determinants are corporate strategy, size, technology, the environment and power/control. Each of these will now be explored (the five determinants of structure are considered in detail in Robbins, 1990).

The Strategy-Structure Relationship

Strategy represents the most traditional view on what determines structure in that decisions on structure are merely seen as rational responses to the stated objectives of the organization. However, more recently, strategy is seen more as just one of a number of influences. Some important pieces of work have studied the relationship between strategy and structure. Chandler, in a major study of the US's largest companies concluded that structure does indeed follow strategy (Chandler, 1962). Considerable support remains for this position, although more recently the generalisation of his findings has been questioned as a result of his definition of "strategy" and the sample of very large companies that he studied (Grinyer et al, 1980). More latterly Miles and Snow have analysed the strategy-structure relationship (Miles and Snow, 1978). They developed a typology which distinguishes between four types of corporate strategy: "defenders", "prospectors", "analyzers" and "reactors". They argue that classifying organizations as one of these strategy types does have predictive properties in the range of industries they have studied. Despite these claims a number of criticisms have been voiced concerning the strategy imperative. Most notably it has been argued that, contrary to Chandler's argument, strategy might be determined and constrained by structure and not the other way (Keats and Hitt, 1988).

The Size-Structure Relationship

Despite difficulties in defining what exactly is meant by "size", is has been argued that size can be a major determinant of structure (Blau and Schoenherr, 1971; Hickson et al, 1969; and Meyer, 1972). The general theme of the argument is that the larger an organization becomes, the more specialised and formalised the constituent parts of the business become. However this assertion has been criticised and it has been argued that size may be related to structure, but does not cause it (Argyris, 1972). Also the size-structure relationship could be merely a tendency and does not necessarily represent best practice in the way organizations should design structures (Peters, 1988).

The Technology-Structure Relationship

A major contribution to the technology imperative was the contribution of Woodward who firstly identified three types of production technology (unit, mass and process) and then identified relationships between these three types and the organization structure of the company (Woodward, 1965). Other advocates of the link between technology and structure are Perrow and Thompson (Perrow 1967; and Thompson, 1967). Recent evidence seems to support some form of technological imperative within smaller organizations, but the effects are less pronounced in larger enterprises where there appears to be very little relationship between technology and structure (Hickson et al, 1969).

The Environment-Structure Relationship

Different organizations face varying degrees of environmental uncertainty. It has been said that structural design and change can be used as a means to reduce this (Robbins, 1990). Burns and Stalker entered the debate on environmental influence by proposing two types of organization: "mechanistic" and "organic" (Burns and Stalker, 1961; also see Oakley, 1984). They argued that those organizations facing stable environments should adopt mechanistic structures, whereas those in uncertain and dynamic situations should be organic in nature. Other notable authors have identified the existence of a complex relationship between the organization structure and the environment (Emery and Trist, 1965; and Lawrence and Lorsch, 1967).

The Power-Structure Relationship

There is an argument that strategy, size, technology and environment represent only a small part in determining structure. Child in his work on strategic choice recognized that managers have considerable scope in the decisions they make concerning organization and argued that power and control are the main determinants of organizational structure (Child, 1972; and 1984; see also Clegg, 1979). It has been said that rational influences, namely those four factors mentioned above, account for only fifty to sixty percent of the variability in structures (Robbins, 1990). The remainder are as a result of the power network and political factors within an organization.

Views are mixed, therefore, regarding the major influence upon organizational structure. However, Peters and Waterman in large part turn much of these arguments upon their heads by saying that we should be investigating the actions and major determinants in those companies seen as successful rather than passively observing structure determination in companies generally (Peters and Waterman, 1982). The argument runs that those companies with superior performance possess structures that are adaptive to change and closely track developments in the market and environment. This view coincides with the theme of this book on the development of market-focused production systems. However, it is maintained here that consideration of the five influences above should all be borne in mind as potential and probable influences upon the organization of production systems and management structures.

The general theme in the structure literature is that any companies wishing to develop market-focused operations systems should seek to base their organization around some form of "product-focused" or, if resources are limited, a "matrix" organization as opposed to the more conventional organizational forms based upon functional or process differentiation. Additionally the use of "flatter" organization structures is widely advocated to replace the hierarchical and multiple level designs historically used by conventional organizations. However there appears not to be complete agreement on all the issues and, if one considers the organizational forms prevalent in manufacturing companies today, there seems to remain a reticence to change to more radical structures. The question remains whether this is as a consequence of inertia, or whether it represents a conviction held within companies that control is better achieved through conventional designs. Until this question is resolved, process orientated, functional and other traditional forms of structure will remain as feasible organizational options.

As already mentioned, adaptability and flexibility are key concepts in the design of organizations and are particularly important considerations for companies wishing to reflect market trends in tastes and requirements. It has been argued and widely accepted that organizations should be willing and able to adapt to any new circumstances. Ackoff suggests that matrices of responsibilities should be used for this purpose and offers a method of "multi-dimensional" organizational design (Ackoff, 1977). Flexibility is the other key concept, but this is open to many different interpretations. Some commentators have considered flexibility as meaning few rules and little structure (Hemphill and Westie, 1950), whereas others understand it as the ability to change existing rules and structures (Pugh et al, 1968). On a practical point, Trist et al provide a number of methods for the creation and evaluation of effective flexible structures (Trist et al, 1963). Furthermore, Atkinson sheds considerable light on organizational and labour flexibility in the modern company (Atkinson, 1984) in his model of the "flexible firm".

Innovation Theory

The second area of concern in the organizational literature is that of innovation theory. Much of the work in the field of innovation arises from the work of Everett Rogers and concentrates on the diffusion of innovations within society and throughout organizations (Rogers, 1983; and see Clark, 1987). Recently there has appeared some more prescriptive literature which offers ways in which companies can mobilise their resources in order to be responsive to innovative new ideas and able to adopt them quickly (Boer, 1990; Bessant, 1991). The work of Kanter (1984; 1989) is a case in point. She argues that for companies to be successful they must be innovative in a number of ways. Firstly they should be able to pull resources together quickly on the basis of short term recognition. Secondly they should have a host of "exterior sensing mechanisms" and, thirdly, they should have more surface exposed to the environment. Kanter goes on to say that for managers to be able to initiate new ideas, organizations must have a participative management style, loosely defined jobs that require people to stretch for power and resources, and collaboration (not suspicion) across functions. She advocates more widespread use of what she terms "integrative" organization structures to achieve this. The integrative approach is where multi-disciplinary groups, matrix organizations and team working are the norm and replace the "segmented" structures and practices most frequently present in functionally differentiated companies.

A number of models have been proposed that enable the change process within organizations to be analysed and evaluated. Of particular significance in this respect is the dynamic model of innovation proposed by Utterbeck and Abernathy (Utterbeck and Abernathy, 1975). This model is founded on the premise that innovations and manufacturing .systems design should be evaluated and categorised using a three part classification: product, process and work organization. By understanding the type of innovation and its process, it is argued that managers are better able to understand the full extent of their implications. A number of studies have adopted the Utterbeck and Abernathy model and provide an interesting insight into organizational development and design innovation within manufacturing companies (see Abernathy, 1978; and Whipp and Clark, 1986).

Organizational Culture

The third area of organization studies to be reviewed here this that of corporate culture. Interest in the culture of different organizations is not a new phenomenon (see Jaques, 1951). However the prescription of cultural cures for organization and process design has struck a popular chord in the 1980s and 1990s, with writers quoting and advocating the lessons learned from successful US, Japanese and British companies (see respectively Peters and Waterman, 1982; Pascale and Athos, 1981; and Clutterbuck and Goldsmith, 1985).

The work of Peters and Waterman deserves particular mention here because this, more than any other contemporary management research, has been seized upon by senior executives and instilled within their style of management (see Peters and Waterman, 1982; and Peters, 1988). They claim to have identified those policies that successful companies adopt and which lead to superior performance. These are a bias towards action rather than analysis, simple organization with the minimum of staff, autonomy to encourage innovation, and a climate of trust enabling the development of consensus building.

The central argument of Peters and Waterman is that those successful companies strive towards achieving excellence in their decision making and activities. This goal of perfection fits well with the Japanese inspired goals of Total Quality Management and Just-in-Time manufacturer (see Schonberger's discussion on World Class Manufacturing techniques, Schonberger, 1986). The evidence from these and other texts suggests that companies with unified, strong and quality orientated cultures tend to be those that exhibit flexible and adaptable organization structure (see for example Crosby, 1979).

Employee Participation and Codetermination

In many countries, and within specific industries, employment agreements and legislation have facilitated the introduction of novel forms of work organization and working practices which otherwise would have been considered impractical (Bennett, 1986; and Lindholm, 1979). In Sweden, where many of the contemporary developments in autonomous working have taken place, examples include the Act of 1972 introducing mandatory labour representation on the Boards of Directors of corporations and the 1977 Act on Co-determination. The Codetermination Act granted employees the right to be given extensive information, through their unions, on the activities of the company. In addition companies were compelled to consult the unions before making decisions involving major changes. In 1982 the legislation was supplemented by an industry-wide development agreement laying down the procedures by which the legally established principles could be upheld (SAF-LO/PTK, 1982).

A similar situation exists in Germany where for several years worker representatives have had participative rights. An Act of 1972 extended works councils' rights for information and consultation to include job design, work operations and the working environment. Again, as in Sweden, the legislation has been supplemented by collective agreements on co-determination and "work humanisation" (Spieker, 1979).

The Swedish and German examples provide an indication of the changes that have taken place in the industrial world in relation to industrial democracy and codetermination. They demonstrate a growing and important trend which differs from country to country in its rate as a direct consequence of the extent to which governments have been willing to seek to influence and legislate for changes. The US and UK governments, for instance, have deliberately not sought to control directly the course of industrial democracy, preferring rather to encourage agreements at a local level. However it is becoming increasingly the norm for workers to be involved in designing their own jobs and participating in company-wide decisions. Also, the consequences of the European Community's "Social Charter" for workers is expected to accelerate this process in its member states into the future.

4.9 Investment Appraisal and Justification

New production systems requiring substantial investment need to be justified in the light of strategic objectives in order that capital can be released for their development. The justification process greatly influences subsequent developments because it is here that decisions are made whether to accept or reject proposed system developments. Proposals for new manufacturing systems therefore need to be presented in a favourable light if they are to be sanctioned by senior management, and the more a case for investment is directed toward the achievement of corporate objectives the greater its chances of success.

Investment Appraisal Techniques

Production systems designers and managers may see the need for investment in new manufacturing facilities, but a case for this investment expressed in financial terms will still need to be made within most organizations. Usually companies adopt some form of investment appraisal technique for this purpose. The basic methods for economic justification have not really changed significantly over recent years. Appraisal techniques are normally based upon comparing the initial and subsequent outlay for a capital project against the estimated financial benefits of the project in the future. Five such methods are reviewed here, these being the "payback period", the calculation of "return on investment", the discounted cash flow techniques of "net present value" and "internal rate of return", and finally the "life-cycle costing" method. Each of these will be described and their relative merits discussed. Arnold and Hope (1990) and Lumby (1988) provide a detailed and comprehensive review of capital investment procedures, whilst Harrison (1990) gives a review of financial appraisal in relation to advanced manufacturing technology including a useful section on risk and sensitivity analysis.

Payback Period

The payback period technique is based on the time taken to recover the initial capital outlay through the cash flows generated. Essentially, the payback period is calculated according to the time into the future when the predicted income resulting from the investment pays back the initial and any subsequent capital expenditure. Companies using this method will normally have a target payback period within which time all investments will be expected to have been repaid. It is the simplest and, historically, the most commonly used method, and is useful as a first rough check to judge whether a new project is likely to be financially sound. The method has its limitations, however. Firstly, it ignores income accruing from the investment after the payback (ie: breakeven point) has been reached. Secondly, it is inadequate as a rigorous and systematic means of comparing alternative project investments. Finally, it tends to be biased against high capital investments such as advanced manufacturing technology where the benefits are viewed in terms of long term flexibility and responsiveness, rather than as a quick financial return.

Return on Investment

An alternative to payback period is the "Return on Investment" (ROI) method of capital appraisal (see Bennett, 1981). ROI is more normally used in the analysis of the overall business, but it would seem to make sense to adopt this approach in the assessment of individual investments, linking the decision of whether to approve expenditure with the wider business objectives. ROI involves calculating the ratio of average annual net benefit against the capital employed and is usually expressed as a percentage. However, it is probably better as a yardstick for judging the success and return of past projects rather than assessing future projects. ROI does not take into account the life of the project nor the expected useful life of the investment. The timings of when benefits are expected to accrue are also excluded.

Net Present Value

In contrast to those techniques described above discounted Cash Flow (DCF) methods take into account the life time of the investment and the times of expected benefits. One technique using DCF is that of "net present value" (NPV). The NPV is the value of an investment expressed in present day terms, taking into account items such as inflation and the opportunity cost of capital which could have been employed elsewhere. The method acknowledges, therefore, that an amount of money spent or received in the future is worth less than the same amount of money today because money can be invested and used to generate interest in the future. In calculating NPV, negative values (ie: capital outlay and costs) must be included to offset the income expected (revenues and returns). So the basic rule is that if NPV is greater than zero it is a worthwhile investment as it yields contribution for the organization, provided there are no projects competing for the same funding that have a greater NPV.

Internal Rate of Return

Another calculation often used within DCF analysis is the "internal rate of return" (IRR). This is rather similar in principle to the ROI method, but takes into account the discounting factor over the expected life of the new system. The company will normally select a rate of return, normally expressed in percentages which equates to the lowest rate of return it will accept from its capital investments. Any projects with an IRR lower than this will not normally be accepted. The IRR method is now widely favoured by companies and more commonly adopted than NPV. It gives a concise figure for an investment which can be compared to other projects or investment options within the business. However it only gives an overall figure which, whilst taking into account the rate of inflation and costs of capital, does not show the timings of such returns.

Life-Cycle Costing

Based upon the concepts of "terotechnology", life-cycle costing is an alternative means of investment appraisal. Tero-technology involves "a combination of management, financial, engineering and other practices applied in pursuit of economic ends" (HMSO, 1977). Life-cycle costing investigates the "total costs" connected with an investment including those associated with feasibility studies, research and design, maintenance, recruitment, training, and the like. These items are not normally accounted for separately in other methods and are assumed to be part of general overhead costs. Using this method, the preferred investments will be those that provide the greatest NPV once all costs included have been taken into account (Sizer, 1979). This method aims to more realistically represent the full costs and financial implications associated with an individual project. However, it is in reality often difficult to obtain realistic figures for some of these other tasks, such as the proportion of systems designers' time spent on developing the proposal. Additionally there is the argument that many such costs are already spent and "sunk" into the expenditure of the organization, and so should not be taken into account when assessing future values and worth.

Contemporary Views of Justification

The advent of advanced manufacturing technologies has coincided with a growing awareness that the established financial justification methods outlined above do not represent the full benefits liable to accrue from the development of manufacturing systems (see for example Meredith, 1986; and Cooke, 1986). Considering projects merely in direct financial terms may not be the best way to judge the wider business benefits to the company. For example, increasing response to customers in terms of reducing design or manufacturing leadtimes may produce benefits in terms of increased sales. Likewise, the enhanced organizational image, favourable publicity and improved product quality likely to result from the development of an advanced manufacturing system may also yield unforeseen benefits. It appears, not surprisingly, that measuring capital projects merely in financial terms may not be the best or only way to determine the likely success of a market-focused production system (Bower, 1985; Marsh et al, 1988). Hayes et al point out that conventional methods of justification are now quite commonly seen not as the most appropriate or sole means of assessing the worth of large projects to the organization (Hayes et al, 1988). Harrison, however, adds the proviso that we should be careful that the procedures and rationale of financial appraisal are not undermined by a collusion between design engineers and accountants and advocates a balanced approach to justification (Harrison, 1990).

Quantitative calculations of, for example, labour and inventory cost savings and increased customer satisfaction are important. However, the intangible benefits offered by these, though difficult to quantify, also need to be assessed because they are likely to be significant in the longer term. A number of alternative ideas on capital appraisal and justification of advanced manufacturing systems have therefore been developed with the objective of providing improved procedures for justification. Conventional methods tend to overlook some of the intangible or non-quantifiable benefits liable to accrue from an investment. The nature of these intangible benefits depends on the manufacturing environment and the type of technology adopted, but can include factors such as quality improvements, improved manufacturing control, reduction in delivery leadtimes, opportunity costs, flexibility for accommodating new product designs, different mixes and volumes, and the marketing advantages of having a "showcase" factory (see the discussion on these points in Kaplan, 1984; and Bhattacharyya and Gibbons, 1992).

The contribution of Primrose and Leonard at UMIST in Manchester is worth mentioning here. They have advocated supplementing traditional cost saving measures with a quantification of the perceived intangible benefits (see for example Primrose et al, 1985; and Primrose and Leonard, 1984). The intangibles they considered include:

i improvements in product quality and the reduction in rework and scrap;
ii shorter leadtimes causing a better response to customer demand and a consequential increase in sales; and
iii faster introduction of new products giving a technical lead in the market and better economies of scale through an increase in market share.

In order to assist the systems designer in justifying new production facilities for which a number of intangible benefits have been identified, Primrose and Leonard have developed a computer-based tool which enables a well-structured case for investment in appropriate systems to be developed.

Kaplan also points to the need to justify new manufacturing facilities on more than an "act of faith" basis (Kaplan, 1986; 1990). He argues that many managers have abandoned the use of conventional accounting and justification procedures because they are not seen as applicable in the case of advanced manufacturing systems where the business benefits are apparent, but difficult to precisely quantify. However, to make critical decisions on investments without financial information seems to Kaplan to be a very risky approach. He puts the case for the intelligent use of financial appraisal techniques in the justification of new systems. Inherent in this is the need for common sense to prevail in the mind of the decision maker in considering both financial analyses and the business issues such as increased flexibility and shorter throughput times.

From a practical perspective it now appears as though most companies use only an outline design concept for a new system, together with an analysis of the reasons for choice, when running through the justification procedure. These capital approval papers normally contain estimates of the times to perform activities and the relevant budgetary plans for such development. In addition, some companies are coming to a realisation that there are virtues in spending more time and effort prior to the submission of a capital approval paper in carrying out detailed design work, so obtaining better estimates of the timescales and benefits (for further discussion on some of these issues see Slagmulder and Bruggeman, 1991).

Standard justification techniques based on payback periods and DCF methods are widely employed by industry in the justification of new manufacturing systems. They provide a sound foundation on which to quantify the expected savings by means of financial cost-benefit analysis. However, in industries where labour costs are relatively low in comparison to material cost, greater emphasis is placed on working capital savings from reduced inventory levels. There is also a growing awareness that the benefits from adopting advanced manufacturing systems are not confined to the short term (Cooke, 1986; McLean, 1988). Account is also being taken of the intangible benefits likely to result from the proposed development, although difficulty still exists in their quantification. It is nevertheless realised that the inclusion of intangible benefits means there is a better chance of the proposal gaining approval. Close cooperation between engineers and accountants is also considered to be essential in order that the proposal can provide a concise description and analysis of both the financial and engineering benefits expected.

The degree of systems design detail included within the justification proposal normally depends on the level of investment involved. Alternatives are first screened and analysed and, in order to give weight to the case, reasons are given for their selection. In some cases, due to the requirement to submit proposals against tight deadlines, the degree of design detail can be low, but the proposed development can still be concisely presented, with a projection of timescales and budgets. Experience shows that, although approval may be gained by this method, the project may then suffer from the development team being pressurised to conform to a projection which may not be realistic. This can have adverse consequences on the design and implementation phases. Some companies are beginning to realise the virtues of spending extra time in carrying out detailed design work, allowing more realistic projections of the time and budgetary plans to be estimated. This may minimise the degree of pressure encountered at the post-approval stage.

So, the justification process not only involves seeking approval to proceed with systems design, but also provides a "capital paper" to serve as a "specification" for design. Justification within DRAMA is seen as occurring with the tactical domain of organizational decision making: it involves a high degree of interaction between middle and senior management. The procedure requires acknowledgement of corporate objectives, together with a determination of both tangible and intangible benefits.

4.10 Managing Systems Design Projects

Effective project management is the key to success or failure in any production systems design programme. It represents the translation of strategies and plans into practice and operation. Project Management, however, is not only the organizational interface between higher levels of management decision making and the operational domain, but also determines to what extent the technological design is effectively converted into a working system. This section considers the process of project management. After giving an insight into what comprises the process of project management, the techniques available to assist in the planning, scheduling and control of projects are presented. These include "Gantt charts" and the network analysis techniques of "Critical Path Method" (CPM) and the "Program Evaluation and Review Technique" (PERT). The role of the project manager within the organization and his responsibility are discussed and then project management in practice and the concept of the simultaneous engineering of product and process designs are covered.

Perspectives on Project Management

Project management is critical in establishing whether a project will be a success. Areas of management responsibility have been defined as planning, control and implementation. The initial stage of project management consists of a feasibility study (Morris, 1983), where a clear definition of the goals and ultimate benefits need to be established. Top management support for project management is important for giving authority and direction and to ensure that the goals of the organization are achieved at the end of the project. The form of support can also influence the degree of resistance the project encounters (Manley, 1975).

Effective project planning and the adoption of adequate monitoring and feedback mechanisms are critical in establishing whether the implementation of a new production system will be a success. The literature advocates the need for user consultation during the design and implementation process, where the degree of user involvement can influence the ensuing support for the project. Knowledge, skills, goals and personalities are all characteristics that must be considered in assessing the environment of the organization (Boer and During, 1987). The project team should possess the necessary technical skills as well as having access to adequate technology to allow them to perform their tasks.

Project Management

Effective project plans, which detail the stages of implementation are important for successful development. Nutt has proposed that the stages of project management should be seen as those of formulation, conceptualisation, detailing and evaluation (Nutt, 1983). More commonly, however, the three stages of project planning, scheduling and control are seen as comprising the process of project management (see for example, Cleland and King, 1983; Moder et al, 1983; and Heizer and Render, 1988). Each of these three stages will now be considered in turn, together with the tools and techniques appropriate for use at each stage.

Project Planning

Project planning is the set of "front-end" activities that precede commencement of a project. Once the need for a new production system has been identified, the planning of the design project should start. This involves the setting of project objectives, organizing the project team, the development of a clear project brief which defines the project's scope and the responsibilities of team members, and a rough estimate of the time and cost of anticipated project activities. The project planner makes use of a number of sources of information during this process including budgetary and cost data, strategy and justification documents, personnel records and engineering diagrams. Often the first estimate of project duration and activities is done using a Gantt chart (commonly known as a milestone plan) which are in effect horizontal bar charts and provide an easy to develop means of representing the project in a form that can be readily understood by all involved in the organization.

Project Scheduling

Once general agreement on the overall plan has been reached the project manager can proceed to develop more accurate schedules for those activities that need to be carried out. Project scheduling involves the allocation of resources in the form of people, finance and equipment to individual activities. As the project commences there will be developed a more detailed relationship between activities. This will involve setting more accurate and realistic times for activities and a regular updating of the schedule as the project itself commences.

The tools appropriate at this stage include cash flow estimation and, once more, Gantt charting. However these techniques are somewhat limited for more complex projects of the type one might expect for the introduction of new production systems. For this reason the network analysis tools such as the "Critical Path Method" (CPM) and "Program Evaluation and Review Technique" (PERT) were developed in the 1950s to provide project managers with a more powerful and flexible means of first scheduling and later controlling projects. The development of a project network diagram is common for both the CPM and PERT methods whereby the "earliest finish" and "latest start times" for the following activities are calculated and so the route of critical activities through the project can be identified. A more detailed appraisal of the use and benefits of CPM and PERT can be found in those references quoted so far in this chapter plus others (including Kerzner, 1984; and Meredith and Mantel, 1985). It is, therefore, to the third phase of project management that we now turn, project control.

Project Control

The aim of project control is to ensure that the project proceeds according to the overall plan and the more detailed schedules that have been developed. It involves monitoring costs, time achievements, resource usage and human performance, revising and changing schedules as and when necessary. It may also concern shifting resource allocations over time to meet the time, cost and design objectives set for the project. Project control requires adequate monitoring and feedback mechanisms at each stage of the project by which key personnel can compare progress with initial projections. This enables the project manager to anticipate problems, take corrective action, and ensures that no deficiencies are overlooked (Pinto and Slevin, 1987; Toft, 1988). For less complex projects use of Gantt charts and a review of milestone attainment may be sufficient for control, but increasing use is now being made of computerised CPM and PERT packages. PERT in particular offers a powerful means of controlling projects and can be used to give probability-based estimates of completion time as the project proceeds, details of costs of the project on an ongoing basis and information regarding the additional costs of completing activities in reduced times, and a post-audit of projects both as a means of evaluating individual design processes and for improving project management techniques within the organization in the future.

The Role of the Project Manager

The responsibilities of the project manager have been identified as follows (Bowenkamp and Kleiner, 1987):

1. To plan thoroughly all aspects of the project, soliciting the active involvement of all functional areas involved, in order to obtain and maintain a realistic plan that satisfies their commitment for performance.

2. To control the organization of manpower needed by the project.

3. To control the basic technical definition of the project, ensuring that technical versus cost trade-offs determine the specific areas where optimisation is necessary.

4. To lead the people and organization assigned to the project at any given point in time. Strong positive leadership must be exercised in order to keep the many disparate elements moving in the same direction in a cooperative manner.

5. To monitor performance, costs and efficiency of all elements of the project and the project as a whole, exercising judgement and leadership in determining the causes of problems and facilitating solutions.

6. To complete the project on schedule and within cost, where this is the overall standard by which the performance of the project manager is evaluated.

The role of the project manager is therefore a key determinant in the outcome of a project. The manager must be carefully selected and, once in post, must act as a champion and facilitator for the rest of the project team and the eventual users of the new system. The project manager must coordinate designers and users to ensure that the eventual system design matches those objectives explicitly stated at the justification stage.

Project Management Practice

Approaches adopted in the project management of new manufacturing systems vary considerably, but can be categorised broadly into either "autocratic" or "democratic" in style. Most companies surveyed during the course of the authors' research in developing this book adopted a fairly autocratic style of project management. An autocratic style usually influences the traditional, and most popular, approach where a project team is established comprising system design specialists who bring in expertise when necessary from other parts of the business or come from external sources such as consultants or equipment vendors. User requirements are commonly checked on an on-going basis, but users themselves often do not participate in the design process. User requirements are usually articulated at the outset and checked on an ongoing basis. Once the new production system is designed, the autocratic style will normally lead to it being "imposed" on the production area, although this is often preceded by presentations of the system and its operation and purpose to the end users.

In contrast, there has been a growing awareness of the importance of user involvement in the design process, especially for the introduction of advanced manufacturing systems due to their potentially wide ranging impact. Thus, efforts towards a "democratic" style of project management have been attempted through the involvement of users on a regular basis during the design phase. This can increase the development time but experience has shown that imposition of a solution can result in a reluctance for it to be accepted. It may also lead to complaints and suggestions for change thereafter. A more democratic style, through participation, does not necessarily mean that everyone will always get their own way. However, it does allow users to have a say in the design, as well as having a better understanding of what is going on. This type of approach is useful in breaking down any barriers that may exist. Thus, although a participatory approach may mean that the design process takes longer, it can result in a shorter implementation time, being more readily acceptable by production personnel. The result is also likely to be closer to the "optimum" design. So the design of an "optimal" manufacturing system involves not only the use of functional specialists, but also complete consideration of user requirements. Although a total participative approach is desirable in project management, a balance must be achieved between obtaining an consensus and a degree of design imposition.

Simultaneous Design Engineering

A key issue in the product design process is the management of the interface between the design and manufacturing function. All too frequently these work in isolation, with product design engineers designing the product from the marketing department's specification and then passing this on to the manufacturing and process engineers who will incorporate into existing systems or develop new processes as appropriate. This approach, "sequential engineering", can often be very time consuming with a high number of design iterations between the design and production functions. "Simultaneous engineering" (otherwise known as "concurrent engineering"), however, involves the parallel development of products, processes and production organization (Riedel and Pawar, 1991; and Sweeney, 1992). This, it is argued, can not only dramatically cut time to market for new products but my also develops a "right first time" (quality by design) attitude in the product design process.

Simultaneous engineering of product and process is becoming increasingly common in manufacturing companies. This is especially so where early and continuing involvement in new product design by process engineers and production and materials management is seen as essential in ensuring products are properly managed throughout their life cycle and that the most effective systems designs are evolved and implemented. Simultaneous design implies continual interaction and parallel developments and decisions throughout the product and production system design processes.

4.11 Implementing Production Systems

The rate of technological change in production processes is high and accelerating. The investment costs involved in the development of new systems is very high and, with the consequences of systems failure on business performance, the stakes are high. Given the above one might expect to see a wealth of literature concerning the implementation of manufacturing systems. In fact, the opposite is true, with only a few texts exploring this process.

The book edited by Ed Rhodes and David Wield from the Open Business School is rare in that it seeks to address this neglected area in the literature (Rhodes and Wield, 1985). The book contains a number of case studies written, in some instances, by industrial practitioners. There is a high analytical content in the contained papers and the discussions centre in the main upon the implementation of large scale projects. Personnel and organizational issues score highly in the papers as the chief factor to be addressed during implementation, the inference being that without the acceptance of the users and a sense of ownership, even the best designed process or facility will have its chances of success severely impaired. There are also examples of implementation being treated from a functional perspective, an example being David Asch's exploration of the financial implications of implementation and the links between implementation and strategy (Asch, 1987).

The writings above, however are subject to some criticism. Whereas they provide some enlightenment on the process of implementation, they tend to be linear and unidirectional in nature and do not capture well the reality of the complex and interaction process of implementation. Richard Whipp and Peter Clark redress this, however, in their excellent study of the design, development of implementation of the Rover SDI project of the late 1960's and early 1970's (Whipp and Clark, 1986). "Implementation" is seen as one of four major stages which follows "conception" and "development", but precedes "operation". The strength of this thesis is the way in which the elements of the production unit of product, process and work organization (as identified in the Utterbeck and Abernathy, 1975, model of innovation) are developed in parallel and linked together through the four stages of systems design. Table 4.4 illustrates the Whipp and Clark framework of analysis.

Table 4.4: Whipp and Clark Framework for Examining Innovation in Production Organizations[14]

Elements of the Productive Unit	*Stages of Design*			
	Conception	Development	Implementation	Operation
Product				
Process				
Work Organization				

Whipp and Clark show, through analysis of the Rover case study, that implementation is a generally phase-wise and linear progression. However, and most importantly, they suggest that a myriad of delineating factors and complications occur that serve to blur the logistical sequence of events. This fits well with the Mintzberg notions of feedback, feedforward, delays, speed-ups and political influences which all serve to destructure the decision making and design process (Mintzberg et al, 1976). Nowhere is this more in

14 Developed from Whipp and Clark (1986) *Innovation and the Auto Industry*, Pinter.

evidence than at the implementation stage, as evidenced by Bennett et al in their study of production systems design in the electronics industry (Bennett et al, 1990).

The studies above stand out as rare attempts to explore and understand the implementation of production systems. Indeed, it is surprising that so little literature is in evidence particularly when one considers the depth of writings concerning strategy formulation, systems design and development. Much effort on developing appropriate strategies and designs can be wasted through poor implementation and subsequent insufficient performance of systems. The literature is, therefore, of only limited use to the practitioner and there remains considerable scope for research aimed at analysing the implementation of complex system design projects with a view to offering guidelines for the improvement of this process. It is to the practice of implementation, therefore, that we must turn to establish any general guidelines. In industry a phased approach to implementation is now frequently recognized as having advantages over implementation of the whole system as a single project. Obviously, the degree to which implementation can be phased is largely dependent upon whether the physical system proposed is of a modular design, or whether its functional control is designed to allow easy separation into discrete segments for operation (eg: installation under manual control, implementation of automation and computer control systems, followed by integration of design elements).

Bennett (1986) considers that installation of a new production system can be divided into five stages:

i Gaining acceptance of the change by the departmental supervision;
ii Gaining approval of the change by the management;
iii Gaining acceptance of the change by the employees involved and their representatives;
iv Retraining employees to operate the new methods; and
v Maintaining close contact with the progress of the implementation until satisfied that the new system is running as intended.

The desirability of gaining the acceptance of people who will need to operate and work in the new system becomes stronger where changes are proposed which affect the number of direct and indirect operators. This is often the case if the changes are aimed at improving manufacturing efficiency. In some organizations such consultation is routine where it has been discovered that a failure to involve the workforce can cripple a new production system through disputes and grievances.

There are very few guidelines for implementers of new manufacturing processes. However, on the basis of their research Bennett and Forrester (1993) identified a number of issues that emerge in the implementation of production systems which, it is argued, offer some insight to success or failure factors. These are now considered in turn.

- Phasing of the design and development process offers the potential for implementing solutions in incremental stages. This enables resources to be distributed more evenly over the time period for installation and allows new facilities to be introduced and accepted by users in small, less radical increments. If planned effectively, this approach can also reduce disruption to manufacturing where new systems are replacing established operations.

- The successful implementation of major operational changes requires that their implications are recognized early and an accurate evaluation should be carried out into their full impact upon all parts of, and people within, the organization. Where this is not done, costly time delays will probably be incurred and the confidence of system users together with their enthusiasm for the approach taken and the final objective will be reduced.

- A balance must be drawn between the time taken to develop a solution by user-consensus and the extent of "design imposition" on the part of the system designer. The former will usually result in a more acceptable decision for all parties, but the time taken to obtain a consensus may cause the project to overrun or, if constrained by rigid completion timescales, will reduce the time available for system implementation. Design time may be reduced where the design is imposed on the user with less consultation, but this may cause significant difficulties at the implementation stage with the emergence of unforeseen problems. Somewhere on this continuum between consultation and imposition is an optimal point for the situation in question where total project time is sufficiently short and an effective and generally acceptable solution is accomplished .

- A frequent occurrence in the design and implementation of successful production systems is the emergence of one or more "project champions". A champion is a person who promotes the project and its design from an early stage and follows it through to implementation. Project champions frequently exert an heavy influence upon the project and expedite it towards a conclusion. Organizations should, therefore, not only consider carefully the appointment of a project leader or manager, but should also realise that their choice of leader is critical in ensuring good progress towards implementation.

Summarising this account of the issues in implementation, it is apparent that few publications have focused on the nature of the implementation process. This manifests itself by the fact that the various design and decision models and methodologies described in Chapter 3 disregard the detailed question of implementation and, as a consequence, tend to treat it as a "black-box" area. It is to industrial practice that we must turn to find guidelines and these have been listed as the need to phase implementation, to conduct an analysis of the impact of the new system within the organization, to maintain a balance between imposition and consultation, and the identification of potential project champions to support the new system from its conception to introduction.

4.12 Evaluation of Production Systems

The evaluation of a new production system will take many forms and, consequently, there exists a wide range of literature dealing with the subject from a number of different perspectives. As indicated by the DRAMA model, evaluation occurs at all levels of the business and so this section reviews the published literature in three different areas which could be equated to these separate levels of the organization. The areas considered are the evaluation of operating performance, of systems design and, at the higher level, the post-audit of high investment capital projects.

Evaluation of Operating Performance

Recent literature indicates a sea-change in the types of operational performance evaluations used as a result of trends towards the adoption of market-driven and customer focused corporate policies. This has provoked a radical review of the performance measures used to assess production systems operation (Bowen et al, 1989). The development of appropriate control and performance measures is now seen as vital in the implementation of market-driven corporate strategies at the level of operations (Bennett et al, 1992). The inference in these texts is that evaluation procedures are widely in a process of revision in manufacturing industry in order that they might adequately reflect the flexibility, quality and delivery, as well as cost, requirements of the customer.

Measures of "output", such as quality, service and delivery have come to the fore in response to the need to change performance measures from those the which are based solely on resource "inputs", such as cost and standard hour performance (Kenny and Dunk, 1989). Traditional measures of input are still appropriate in almost all instances, particularly where resource utilisation is a key factor, but most organizations are striving to achieve a more balanced measurement and evaluation of performance. However, input measures alone will not, argue Bowen et al, reveal many of the features of manufacturing most in need of evaluation (Bowen et al, 1989).

With regards to systems design, the design models and methodologies described earlier in this chapter provide the decision maker some assistance in the evaluation of existing, or newly introduced, systems by providing a conceptual framework of analysis. For example IDEF can be used for the analysis of system design using flowcharting techniques which link design considerations and information flows at the various levels of the system architecture (see, for example, MicroMatch, 1990). Likewise the GRAI model can be used by offering a structure of the organization which links decision making activities and information flows to the physical system (Doumeingts et al, 1986). The more specific GRAI methodology for the design of production control systems can also be used to provide an assessment of the current state of an organization's systems through the use of "GRAI-nets" (Roboam and Pun, 1989).

More conventional computer simulation offers an alternative method for the analysis of the design and operation of production systems. Simulation provides a dynamic representation of the real system and its operation in the form of a purpose built model. These simulation models can be used to test the effects of changing elements and parameters within existing facilities without tampering with the real system (for a basic description of simulation methods see Moskowitz and Wright, 1979 and Moore, 1982).

The use of methodologies, modelling and simulation infers a rigidity in evaluation. This is not to say that subjective analyses are not still important. However, the complexities of advanced manufacturing systems and dynamic nature of the environmental and competitive factors impinging on them causes current theorists to advocate the adoption of structured design and analysis techniques. These are intended to supplement the qualitative evaluative work traditionally conducted in companies.

Turning to strategic evaluation, the theory of planning and selection of capital projects is relatively well developed in the capital budgeting and general accountancy literature. John Arnold and Tony Hope provide an excellent and readily understandable description of these techniques in their management accounting textbook (Arnold and Hope, 1990). However the process of the post-implementation evaluation of systems is not well documented which reflects, perhaps, the lack of evaluation of projects in practice. This lack of theory or prescription has been recognized by Sackett and Williams who call for further research in the area (Sackett and Williams, 1988). Bennett et al claim that even models in organization theory, which purport to capture the realities and complexities of decision making, give scant regard to the process of evaluation following implementation (Bennett et al, 1990).

Probably the most useful contribution to the strategic evaluation of operating performance is the work by Kaplan (1990) which, first and foremost, sees the purpose of evaluation and performance measurement as being the improvement of the organization towards manufacturing excellence. In addition to exploring the limitations of conventional management accounting approaches to evaluation, Kaplan continues to show how the adoption of appropriate measures can facilitate organizational learning and assist in making both product and process design improvements. The main argument made by Kaplan is that whereas companies are keen to adopt largely Japanese-inspired approaches such as TQM, JIT and FMS, they have been slower to react in terms of changing their traditional accounting and performance measurement systems to suit their new operating environments. Kaplan prescribes a wider range of performance measures to supplement the traditional budgetary and variance accounting systems. He argues that measures to encompass response times, delivery performance, product design cycle times and return on investment often provide a more realistic yardstick by which to measure performance within the organization against its objectives and the expectations of its customers.

A recurrent theme of recent reports dealing with the practice of operational evaluation of manufacturing systems is the development of market-driven corporate policies and the increased customer service orientation in manufacturing (for more discussion on this see Bennett et al, 1992). This has provoked a radical review of performance measures used to assess the effectiveness of operation of production systems (Bowen et al, 1989). The development of appropriate control and performance measures is now seen as vital to the implementation of market-driven corporate policies at the operating level, with evaluation procedures needing to be reviewed and possibly revised if they are to reflect the flexibility, quality and delivery requirements demanded by the customer.

Means should be developed for measuring output from the operating system in terms of customer satisfaction and which replace the traditional measures based solely on factors such as cost and standard hour labour performance. Customer-orientated measures of output incorporate such factors as quality, service and delivery. Increasingly these are being adopted to provide the primary assessment of operating systems (Kenny and Dunk, 1989). That is not to say that more traditional methods of manufacturing systems assessment are not appropriate in all circumstances. Such performance measures may be suitable where resource utilisation remains a key factor. In most situations, however, cost and efficiency measures used in isolation will not reveal many of the aspects of the operating system performance most in need of evaluation. System performance, therefore, should be viewed in totality; there should not be an over-dependence on a single measure and there should be regard to factors such as quality, delivery and levels of inventory to supplement values for manufacturing cost, output and productivity.

Evaluation of System Design

The evaluation of a production system should take place at two stages. Firstly, the proposal must be evaluated prior to any decision being made to proceed with the project. Secondly, the actual system should be evaluated after implementation to ensure that the planned benefits, as stated in the capital justification paper, are being achieved.

At the first stage, evaluating the proposal, a number of design methodologies have recently been developed whose primary aims are to assist the decision maker in the design of production systems and to help in the choice of the arrangement and configuration of facilities. These can also be viewed as conceptual frameworks for system evaluation and used to provide an assessment of existing, or newly installed production systems. For example, IDEF can be employed for an analysis of system design using a structured modelling approach and flowcharting techniques to link design considerations at various levels in the organization (see, for example, Sackett and Williams, 1988). Likewise the GRAI conceptual model can be used as a structure to analyse hierarchical decision making linking operating systems with information flows throughout the organization (Doumeingts et al, 1986). The GRAI methodology for production control systems can also be used to provide an assessment of the current state of an organization's systems through the use of "GRAI-nets" (see Roboam and Pun, 1989; Roboam et al, 1989; and Chapter 3).

Increasingly computer simulation is being used as a method of analysing the design and operation of production systems prior to their introduction. This provides a dynamic representation of the real system and its operation in the form of a purpose built computer-based model. Simulation models can be used to test the effects of changing elements and parameters within existing systems without the need to disrupt them by conducting live experiments (for more information on simulation see Moskowitz and Wright, 1979; Moore, 1982; Urry, 1991; and Pidd, 1988).

When eventually the new system is installed and, following a period of "running-in", has reached its planned level of activity, the second evaluation can take place. The objective of this to confirm that the system is providing the returns, both financially and operationally, that were predicted. In practice many organizations spend considerable amounts of money on new systems yet largely neglect the post-project evaluation, relying instead on the rather limited productivity measures that were described in the previous section of operating performance (Bennett, 1986). It is true that to monitor all the relevant factors requires time and effort, and itself incurs further costs in employing staff to conduct the necessary studies. Nevertheless these costs can often be negligible compared with the total cost of the system and the benefits of a thorough evaluation will often be more than justified. The precise list of factors which should be monitored in this post-implementation evaluation will depend on the particular type of system under consideration. However, for the market-focused organization, factors such as customer service, quality, manufacturing throughput and set-up times should receive a high priority as well as machine utilisation, costs, output and labour efficiency. Such factors can be assessed using an "audit checklist" which the organization can develop over time to specifically test the effectiveness of new systems (for further details see Skinner, 1978; and Richardson and Gordon, 1980).

Post-Audit of Capital Projects

In the capital planning and general accountancy literature the theory of planning and selecting large scale projects is relatively well advanced (a review of the various techniques is given by Arnold and Hope, 1990). When one considers the post-implementation evaluation of capital projects, however, there is little to assist or guide manufacturing companies in assessing the success of implemented production systems. It has been recognized that post-auditing and evaluation of capital expenditure has, until recently, received little attention (Sackett and Williams, 1988). Even models developed in the field of organization studies, which claim to capture the realities and complexities of decision making, give scant regard to the process of evaluation following the implementation of decisions (for further discussion of this point see Bennett et al, 1990).

As the importance of the need for post-completion audits of design and implementation projects has gained increasingly recognition more serious attention has been paid to evaluation (Norgaard, 1979; Ghobadian and Smyth, 1989). The problems associated with the process of evaluation have also been explored, and conclusions have been reached upon the value or otherwise of post-audit programmes. The benefits and advantages of post-audit (from Neale and Holmes, 1988) are:

- improved quality of decision making;
- greater realism of project appraisal;
- improved corporate performance;
- identification of key variables and success factors;
- timely modifications of under-performing projects;
- increased frequency of termination for inappropriate projects.

The problems with post-audits can be listed as follows (developed from Ghobadian and Smyth, 1989; and Neale and Holmes, 1988):

- post-audits can be resource hungry, so difficult to justify in organizations suffering a lack of available resources;

- there is often an absence of accurate and relevant data with which to carry out the audit;

- there is a feeling in some organizations that conducting post-audits can interfere with the operational control systems;

- management and engineering personnel resist to audits because of a reluctance for personal failures to be identified.

Post-audit of capital projects would appear to be essential for any organization wishing to derive the complete benefits of the high investment incurred in the installation of new production systems. However, in practice, there are a number of reasons why intensive audits are not carried out, not least of all the perceived costs of conducting the study coupled with the types of resistances against detailed capital audits outlined above. Structured programmes of post-implementation evaluation for new systems, where actual results are compared with those predicted, are not frequently adopted by manufacturing companies. The reason often cited is that the dynamic environments within which businesses now operate demand that more importance is attached to continuous improvement of existing facilities and the design of new systems than to retrospective analyses of past investment decisions. So, post-audits of newly installed manufacturing systems are not normally considered important enough to be carried out. This is not a view that can be supported, so the DRAMA component for evaluation provides a means for organizations to perform such an analysis.

4.13 Summary

The chapter commenced with a review of current perspectives on the nature of the process of production systems design. Particular attention was paid to the changing competitive environment within which companies operate, mostly notably the impact of the Far Eastern boom of the 1980s and 1990s, and the increased recognition that companies must view their marketing and, increasing, manufacturing operations in a global sense. The conventional types of job batch and flow production systems, along with their associated features were then reviewed. It was then explained why, recently, innovative forms of production systems based around cellular principles have emerged as viable alternatives. The chapter then proceeded to review the literature and contemporary practice in a number of pertinent areas for the process of production systems design.

In Section 4.4 techniques and approaches used for the modelling of production systems were examined and it was explained why modelling of the operations system, and of the decision making process for its design, has received so much interest from practitioners and writers alike. Sections 4.5 to 4.12 then considered theory and practice in the strategic and tactical domains of those components that comprise the DRAMA model. Following a more general review of the corporate and manufacturing strategy literature four frameworks for the formulation and analysis of manufacturing strategy were presented and reviewed. The issues of manufacturing flexibility and organization were then examined, following which contemporary factors in the justification, project management, implementation and evaluation of production systems are discussed and analysed.

The aim throughout the chapter has been to indicate how writers have informed practice over the recent past and, secondly, to indicate how practice has tended to influence the literature. Literature, research findings and practical issues relevant in the development of production systems design theory have all been discussed in some depth . The focus has necessarily been one of advocating the need to consider the strategic as well as the technical and systems development issues. This reflects the influence of contemporary manufacturing environments where manufacturers are subject to competition on a worldwide basis and need to pay great attention to the ways and means they operate so as the remain as players in the market-place. The key issues of flexibility and contingency in decisions concerning production systems design have been stressed throughout. These are frequently the ways by which organizations can evolve their systems so as to react to changing situations and requirements. With theory and contemporary practice in mind, therefore, it is to the case studies of production systems design that we now turn.

Chapter Five
CASE STUDIES IN PRODUCTION SYSTEMS DESIGN

5.1 Introduction

The case studies presented within this chapter have been developed on the basis of detailed empirical research and synthesis of the author's own personal experience in industry. The thirteen cases are in addition to the ICL investigations and have been collated and qualitatively analysed within the DRAMA framework. The cases, therefore, go some way towards validating DRAMA as a model of production system design within the electronics industry where four additional company studies are presented, but also test its applicability in other manufacturing contexts - a further nine cases are therefore presented from the electrical engineering, mechanical engineering and carpet manufacturing industries. For each sector, a description and overview of the industry and its market and environment is given prior to the cases, the cases then being brought together in a synopsis on production systems design for each industry.

Finally the overall conclusions drawn from the case studies are summarised at the end of the chapter to show the current status of production systems design in the four UK manufacturing industries selected. The research material presented in this chapter provides the basis for the structured analysis in Chapters 7 and 8.

5.2 The Electronics Assembly Industry

Industry Overview

The electronics industry is characterised by high rates of product and process innovation, discerning customers and intense worldwide competition. This serves to intensify market dynamics and suggests that there still exists a degree of technological drive for new products within what remains predominantly a nascent industry. Product technology and new product introduction remains an important area in which companies can achieve competitive edge: one only has to consider the success of companies such as Sony and Compaq and their corporate performance during the 1980's to realise this is the case. However there are doubts as to how many companies can adopt this approach over a sustained period of time especially as most products can be quickly cloned (particularly evident in the computer industry) and when one considers the exorbitant R & D investment entailed in being a product innovator. As a result the leading edge product technology strategy is increasingly being restricted to a relatively small number of very large companies and the rest of the industry, albeit that they need to respond to technological advances, tend to be followers.

One can dissect the electronics industry into two identifiable parts: the first being the manufacturers of consumer electronics, such as domestic appliances and automotive products, as distinct from manufacturers of industrial and commercial information technology equipment such as larger computer systems, industrial testing and monitoring devices, etc. The consumer electronics industry tends to be led by large Japanese manufacturers who are able to produce a restricted range of products in relatively high volumes with very little requirement for specific customisation. The mass manufacturing, assembly line techniques are seen as the most appropriate production systems design in this case. When one considers the information technology (IT) segment, however, one can depict a different phenomenon. Here customers frequently have an input prior to the manufacturing of the product in order to specify their own, often unique, requirements so that the product can be produced in line with the customer's own configuration needs. The result of this is that manufacturing can be characterised by the phrase "high variety, low volume" and often flexibility and delivery performance tend to be the critical success factors rather than price and technology as is common for consumer electronics. In this part of the industry increasing customer discrimination and demands for more product customisation means that the approach of "pushing" technically sophisticated products on to the market in large volumes is no longer a viable option for all but the multi-national (usually US parent) giants in the sector. Hence there has been a widespread adoption of market-driven strategies, ICL being a typical case in point.

The industry structure for both consumer electronics and IT products is quite similar. Both are dominated by very large worldwide operators, although in consumer electronics these tend increasingly to be from Japan and other countries on the Pacific Rim, whereas US giants such as IBM, Hewlett-Packard and Digital Equipment (DEC) remain dominant in the IT market despite increasing competition and growth from Far Eastern companies such as Fujitsu (ICL's parent since 1990). Most of these large companies have UK subsidiaries, or have set up transplant plants within Britain in addition to other countries as well. Beneath these large players, there exist a whole plethora of predominantly national companies, especially in Europe, the largest proportion of whose business tends to be domestic. Most of these medium sized companies have tended to be proactive in seeking collaborative deals or trading agreements with one or more of the larger manufacturers in order to safeguard their future.

The scenario then for the electronics industry is one providing huge potential for those companies who can foresee the direction of technological change and international business trends, but one that has many threats. The business environment for electronics is particularly dynamic when one considers the rate of technological change and the fierce competition which results from differences in corporate size in an industry for which competition is at a global level. The words of a senior executive of ICL, responsible for monitoring worldwide manufacturing trends, sum up well the demands upon companies in the electronics industry:

"The most important thing in this industry is that you have up to date knowledge of what is going on in the world in the manufacturing scene, because the ...... industry is a very dynamic one."

Company A

Company A is a large multi-national manufacturer of a wide range of computer related products and operates as a one of the major players in most of the world's IT markets. The company does not possess a reputation for being innovative in its design of products and relies instead on well proven technology. However, the company sets the standard for many of its markets and so any new models its develops are soon copied by large numbers of its competitors to retain compatibility. Thus, the company are constantly redesigning in an attempt to keep one step ahead of its competition: if it were to stand still it would run the risk of having substantial market share eroded by smaller manufacturers.

The worldwide company is, in total, a very high volume producer per product type. This has led to a "centre-of-excellence" policy for the location of manufacturing plants, such that each factory can concentrate upon the volume production and assembly of a restricted number of products. The company has a UK subsidiary which manufactures on two sites. The case refers to systems design within one of these plants which is concerned with the manufacture and assembly of two types of products: electronic cash-point machines as used by banks and building societies and hard disc drives which it supplies to the company's computer assembly plants worldwide. The majority of the case concerns the disc drive manufacturing facilities and the influences upon systems design.

A key part of the manufacturing policy for the factory studied is the use of just-in-time principles and special vendor relations with the aim of making deliveries direct to the production lines. In addition the company has a well developed total quality improvement process, with targets for quality achievement being a significant feature of the formulated strategy.

The management of the design to manufacturing link for new products is a major concern for the company and, as a consequence, the plant's managers are now developing a structured approach to new product design and introduction. There is an explicit policy concerning product life cycles: they should be planned to be three years in length. Manufacturing facilities and the assembly lines, as a result of knowing there will be no major design change for three years and as a consequence of the high volumes, can therefore be designed in a fairly rigid, product-specific manner. Very little variety in the product mix means that the company can afford to invest in automated assembly and materials handling equipment which can be expected to pay back in well under three years.

The production facilities indeed exhibit a high degree of automation both in parts processing and materials handling. Low product variety, a planned product life cycle and high volumes enabled the adoption of an FMS cell for the processing of disc drive covers and the use of flowlines for assembly featuring stage build, short cycle operations.

The cell incorporated a total of five DNC machines programmed to cut, grind, form, drill and clean the covers used for the disc drives, taking in metal sheets at the start of the process and producing covers ready for use in the assembly area at the end with no manual interaction at all. Materials were moved within the cell using a robotic arm and tool change (which, due to dedication to the one product, only occurred on their wearing out) was totally automatic. FMS, the systems designer explained, was a bit of a misnomer in this case. The cell was capable of producing different machined parts, but the company only envisaged a single product being produced within it for the foreseeable future. So the cell could be flexible, but only after considerable additional programming effort.

The assembly line was based around a conventional conveyor located within a very tightly controlled "clean-room" environment. The line operated in conjunction with an automatic crane which dealt with parts transfer from the buffer zone between the FMS cell, stores and the assembly area, as well as materials movement within the clean-room.

There was a strong emphasis throughout the process in establishing JIT in its entirety, from vendor deliveries right through the FMS cell and assembly to despatch of the completed disc drive. Kanban controls were employed, but instead of a separate kitting operation, the assembly operators were expected to kit parts for themselves. Thus there was no delivery of kits to station in the way used, for example, within ICL Ashton. A key advantage of the FMS cell was seen to be its ensured quality of disc drive covers, very important if the drives were to fit together properly at the assembly stage and, in itself, was an enabler of the JIT kanban philosophy.

The plant also contained a number of automated guided vehicles (AGVs), although their use was restricted to the transporting of parts between stores and the assembly buffer area, and return to stores of completed drives. The loading and unloading of AGVs was a manual process. The use of robotics, automated cranes and AGVs illustrated the fact that the plant was moving towards the integration of its manufacturing activities through the extensive use of automated handling devices. However, the flexibility of the overall system was restricted by the degree of facility dedication: reconfiguration of the overall system to produce different designs was not viewed as a viable, cost effective option for future systems development.

The design of new facilities within Company A utilised multi-disciplinary teams comprising representatives from the various affected functions within the factory. The structure of the project team tended to be tailored the which particular product and associated process was to be introduced within the plant. The plant's managers boasted considerable in-house expertise in the design of systems, so the use of external parties and systems vendors in the development of systems was very rarely instigated.

The "design for manufacture" concept was advocated in product design work and, wherever possible, the use of existing facilities and resources for the production of new products was encouraged, although given the product specific nature of many of the facilities the scope for this seemed somewhat restricted. Once installed and the manufacture of the product established, the production system would be left to stabilise itself. This was effected by the removal of design engineers from the production area and their transfer to concentrate upon new product introduction projects. The existing systems were, therefore, left to fine tuning by production and operating personnel through continual, non-radical improvement activities.

Control of the assembly line was very much by kanban, with each operation on the line linked to stores via replenishment containers. Thus the control was of a simple, manual type and computerised parts tracking through barcodes or data collection terminals was not used: the stock data only being updated as completed products came off the line. Visual management was seen to be an important part of manufacturing control, the usual kanban rule of a shortage resulting in line stoppage being an obvious example of this management by sight. The most obvious area of computerised control technology was within the disc drive cell where all machines ran under direct computer control and were linked together within a discrete integrated system.

The plant raised a number of important contemporary issues regarding work organization as a result of its mass manufacturing techniques. The FMS cell feeding the assembly line required no skilled machinists and was run by highly qualified computer technologists from a keyboard: an example of where robotic automation has almost completely dispensed with the traditional skills offered by the machine tool operator. Conversely, final assembly operations were almost entirely manual. However the conveyorised flowline techniques adopted subjected operators to repetitive, short cycle work. Managers interviewed suggested that this problem was offset by the advances made through the company's quality improvement programme, which had encouraged the workforce to expand their responsibilities by becoming involved in continual improvement of the process. The single status nature of employment contracts within the company was also supposed to illustrate the importance of every employee to the corporate effort, although the extent to which this can be used in defence of the monotonous work practices imposed upon shopfloor personnel must, I feel, be questioned.

Incremental developments in the manufacturing processes within Company A are rare, other than minor modifications made by operating personnel as noted before. Process changes tend to be more radical in nature: replacement rather than evolution being the order of the day. The implementation and installation of new processes coincides with new product launches. Process technology, in the main, is advanced and highly automated along mass manufacturing lines and there exists little user interaction in design and development of new systems. Managers unashamedly admit that implementation is executive driven and imposed upon the operating personnel. In such circumstances a phased approach to implementation is not deemed applicable. Managers argue, however, that once systems designs are implemented there exists ample scope, and no shortage of zeal on the part of production employees, to become involved in incremental continuous improvement of the facilities.

In summary, Company A managers and engineers alike advocated the need for product focused systems within their organization. Evaluation of performance of the operating system reflected this with a balanced collection of measures comprising quality, service, delivery and cost. Product, process and work design were seen to be intertwined and were tackled with a radical redesign on a regular three yearly cycle, in fit with the planned product life cycle. However, the scope to change discrete systems once implemented was severely curtailed, but done so by design in order to enable systems to stabilise over a long period of time. Despite the restrictions on change in existing systems, the managers interviewed took pains to stress that they always embarked on a process of post-audit for all process investments in order to evaluate the level of success of newly implemented systems and to identify any problems or lessons which may be of use in future systems design activity: the notion of the "learning organization".

Company B

Company B, like Company A, is a large multinational manufacturing company with a presence in the UK. In fact, the UK plant is part of a division of the company which also comprises two sister plants, one in the US and the other elsewhere in Europe. The main product produced with the UK plant is an electronic document handling system, configured to meet individual customers' requirements. Customers come from wide and varying sources and company payroll processing tends to be a very common area were the document handlers tend to be used. However, by far the largest customers of the plant are financial institutions, most notably banks, who use the product to process statements prior to sending on to their customers.

The company as a whole has a widely published "technology strategy" which embraces and encourages the development of "open systems" (conformance to industry standards) for its products which need to interact with computers, etc. The strategy also states the need for "productivity" (the speeding up of processing power) and "enterprise networking" (the integration of all IT equipment within a business). This strategy has obvious implications and offers guidelines for the development of new products in all parts of the company.

In fact this strategy merely represents the response to the overwhelming technological push within the industry and to the requirements of its customers in satisfying their often distinctive IT needs. The division, within which the UK factory forms a part, has responded to these environmental factors through what it calls the "intelligent use of the Design function". This manifests itself in a number of ways. Firstly, all products within the plant's portfolio must be designed in a "modular" form so that a wide range of optional features can more easily be added to the basic unit to satisfy individual needs. Secondly, the product design function has been fully integrated into the assembly plant so that new products are designed, prototyped, developed and manufactured on the same site. This is seen as improving the design to manufacturing link, and that this more effective communication results in a speeding up of the new product design process. Finally, any customer request for a product with features that cannot be satisfied by the existing range of optional modules can quickly and effectively be designed and manufactured under one roof, drastically reducing the order to receipt leadtime for customised products.

Organizing design to manufacturing integration on one site has lead to the Plant Director having responsibility for both functions. Interaction between design and manufacturing personnel is on a day to day basis and the development of a common design engineering information database for use by all personnel in the factory has added to this improved communication and the company's managers now claim that the manufacturing leadtimes for customised products within the existing range of modules has been cut from three to four weeks down to as little as one week. A particular feature of this plant were the open plan office accommodation in the administrative and managerial areas and the degree to which employees were expected, and given the opportunity to, bridge the gaps between traditional functional areas, open plan accommodation being one of the means the this end.

The evolutionary process of product development, in stark contrast to the radical approach taken by Company A, means that there is a less direct relationship between product and process design. In the past, new production systems have been developed to manufacture existing product ranges. New systems must be justified in their own right, therefore, and must not merely rely upon the fact that they are required because of a new product introduction. The process of justification is started with an outline specification for new projects, which is then incorporated within a capital paper. This paper presents a summary of the range of alternative systems designs considered and the reasons for choosing the selected solution. The writing of this part of the capital paper is very much at the discretion of the system designer. However, it is not until a more detailed design is produced taking the form of a general engineering specification that financial approval was sought. Once capital funding had been granted, plant managers virtually had a free hand on how the money should be spent. Functional and engineering specifications would then be passed to prospective systems vendors who would suggest their preferred technical solutions. It was then the responsibility of systems designers within the plant to integrate these elements into the overall system design and to evaluate the vendors' solutions against the company's measures of effectiveness and with respect to the original specification criteria.

Manufacturing facilities within Company B's plant was divided into discrete operational areas, namely printed circuit board (PCB) manufacture, cable harness assembly, subassembly and final assembly. Product variety and customisation were high, whilst volumes were relatively low per product type. Some degree of automation in the form of automatic crane and racking facilities existed within the PCB assembly and the materials storage areas, but automation beyond this and into other production areas was not seen as appropriate because of its inert inflexibility in the context of high variety manufacture. The cables, subassembly and final assembly areas as a result consisted of simple manually operated systems. The short product life(in the order of twelve to eighteen months on average) had led systems designers to appreciate the virtues of designing process flexibility into their manufacturing operations. Flexibility, in terms of the abilities to cope with new product introductions, product redesigns and mix, was considered a paramount requisite. Engineers looked for low investment, flexible designs in the subassembly and final build areas which enabled any reconfiguration of systems to be accomplished with the minimal of time, effort, cost and justification.

Subassembly operations comprised a wide variety of tasks and very low cycle times from start to completion. Therefore single stage assembly was used in this area with flowlines difficult to justify and put into practice in any effective form. Single stage building was also attempted at one time for final assembly, but it was found that this method could not cope with the volumes demanded and so the company reverted back to multi-stage line operations here. Units are moved along the final assembly line by means of castors attached to their base, therefore eliminating any problems that are normally associated with palletised materials handling or fixed mechanised conveyors.

Parts kitting was adopted in the PCB area where components were small and could fit into small containers. Elsewhere kitting was not used as the parts used in subassembly and final build were considered too large to transport effectively in kits and complexity in terms of product variety could make this a difficult exercise to implement logistically. The plant exhibited the lack of any integrative materials handling system between different areas on the shopfloor and there were no satellite buffer stores, all storage of bought-in parts and excess work-in-progress being held in the central Stores.

Despite the potential for JIT within the plant, a push mode of materials control based upon MRP was in practice at Company B. JIT techniques were being investigated, but problems were foreseen in applying the principle to the plant's operations due to its high variety, low volume nature. Introduction of kanban type controls and inter-area buffers of parts kits was also viewed with some trepidation, not least because of the limited availability of floorspace and because of a lack of commonality of parts across the products made. Instead, the company were more concerned with investigating the further development of MRP, possibly into MRPII (Manufacturing Resources Planning).

In terms of production organization, the division of the manufacturing areas gave rise to what can best be described as a functional layout. Assembly tasks within each area varied, but there appeared to be the general rule that in the component and subassembly areas, where work contents were lower and the variety of tasks more diverse, a complete build policy was adopted. However in final assembly, where work contents to complete an assembly were higher, flowline techniques and multi-stage build operations were adopted, although as stated before this did not involve conveyorised materials movement. The operators did not work from kits except, to a limited extent, in the PCB assembly area. Most parts were, therefore, issued to the areas and line in bulk.

In the process of designing and developing new production systems, manufacturing engineers within the plant tended to take key responsibility for coordination and project management, although the activities of the engineers was augmented by the temporary establishment of multi-disciplinary project teams to work on specific aspects of design and implementation. Vendors and consultants were frequently utilised in the design process and were seen as essential in generating alternative systems design options. Some facilities had been installed on a turnkey basis, although it was stressed that company personnel were expected to conduct design work in areas in which they had sufficient expertise.

Implementation of systems within Company B has been an incremental process with facilities being installed in a phased manner. Systems design and implementation within the plant were very much engineering driven and there existed restrictions on the extent to which operating personnel could participate and effect systems design. On the other hand, the excellent communication between functions and manufacturing and design engineers ensured that, at higher organizational levels, a truly multi-disciplinary approach was in evidence.

Company C

Company C is also part of a large multinational organization who have a manufacturing presence in the UK comprising two main plants, one producing computer peripherals and the other, used as the basis for this case study, manufacturing sophisticated industrial testing equipment. The parent company has faced reduced growth rates in its home market over the last ten years whilst, at the same time, has experienced growth in overseas markets, Europe in particular. The factory was in fact set up to supply the whole of the European market with the test equipment products. The market within which the product is sold is extremely competitive with a number of very large players all challenging one another for business. Customer choice from amongst these suppliers is normally based upon a mixture of cost, quality and service.

Company C's test equipment products are generally seen within the industry as being innovative and technologically advanced but are, as a result, expensive to manufacture. Effort is therefore put into maintaining cost to competitive levels whilst ensuring that product quality and service back-up provides an edge for the company over its competitors. Linking to this, the company emphasizes the selling of "complete solutions" to the customer rather than merely trying to sell a piece of equipment. This has led to increased product customisation and so there has recently been a significant increase in the number of product configurations assembled within the plant.

At a manufacturing level, the recent emphasis upon cost controls had an effect upon the strategies for operations. The approach is now to couple the technical and quality drive, assisted by the fact that as in Company B responsibilities for product design and development were at the level of the manufacturing plant, together with maintaining competitive costs of manufacture and offering the flexibility to provide customer specific product solutions. In fact it is surprising that costs were not considered as important drivers in the past, particularly when one considers that material costs can account for 70% to 80% of the total. A significant response, seen to embrace all these objectives, has been the adoption of JIT, both for in-house production control and in the supply chain. JIT is seen a paramount in reducing costs through reducing the level of inventory holdings and generally improving plant efficiency. Despite the severity of competition within the markets that Company C operates, the company's sales are expanding above the general growth rates for the industry as a whole which, management advocates, is evidence that their strategies and performance over recent years must be viewed as having been very effective.

A noteworthy feature of Company C is that it is a single status company and has been so for over forty years, with as few demarcations in its organization and personnel as possible. The stated management philosophy is one that "all decisions should be made in an environment of consensus". The company has for many years seen the need for a strong and identifiable corporate culture and has actively promoted this both internally and to the outside world. This manifests itself within the factory by the fact that there are no separate production offices in an administrative complex: instead managers sit with the operators on the shopfloor, partition screening replacing walls in most cases. Following the formation of a quality circle programme in the late 1970's, the organization has also been pursuing a "Total Quality Control" (TQC) philosophy over many years in order to sustain the open and participate culture that has been nurtured. It was stated that the employees were very committed to quality in its widest sense within the plant.

The production facilities within Company C's plant incorporate single stage build assembly operations. This was though necessary for two reasons. Firstly, although seeming to be a relatively standard basic product, the configuration to suit customer specifications meant that flowline operations would offer problems in terms of balancing work contents. Secondly, short cycle stage build assembly, with little perceived relationship to the end product for the operator, was not seen as conducive to developing the right attitudes towards total quality and improvement. Therefore the facilities were generally "low-tech" and "make complete" in nature, with no automation by way of storage or materials handling. Product life cycles for the standard test equipment products varied between three and nine years, although there were minor modifications and redesigns quite frequently within this. Generally, production personnel reckoned on a new product introduction every two to three years. However, the basic principles and techniques for production remained unchanged with the advent of new products.

Supporting the assembly area was a PCB subassembly module which did contain a degree of automation, but only in the form of an automated components storage carousel at each workstation. PCB assembly was performed manually and assisted by an overhead projector system for locating components on to the boards which, following its introduction, had vastly reduced cycle times for the high variety of units produced.

The factory's management had been considering "process standardisation" as a means to reduce manufacturing costs. In addition an extensive relayout of manufacturing facilities was currently being undertaken to bring them more in line with the emphasis upon JIT and continuous flow. The final assembly area had adopted the kanban kitting approach to such an extent that every component was carefully kitted to the exact quantities required for one assembly: no bulk delivery to line was allowed for any item, no matter how insignificant its stockholding costs. The objective for this was to take the JIT philosophy to its ultimate for all parts and to enforce the disciplines of working in a disciplines and tightly controlled environment. It also offered considerable flexibility in terms of handling customised orders in the manufacturing area as parts for each product assembly could be kitted individually. Component storage and the kitting operations were located close to the final assembly area and the kitting operator was additionally responsible for goods receiving administration and stock level monitoring. Both kits and products were conveyed around the operations on simple wheeled trolleys.

Considerable effort was afforded in the training of vendors as an attempt to educate them in the principles of JIT and to illustrate the benefits of functioning within the JIT environment. This resulted in more frequent supplier deliveries to the plant; some individual vendors delivered as frequently as every two days. The implementation of a self-certification programme by Company C ensured that vendors were given recognition of their excellence in JIT and would become totally responsible for the quality, quantity and delivery of items to the plant, eradicating the need for goods inward inspection.

An MRP system was still in operation to provide a reorder service for company and vendor alike. However the use of MRP was diminishing and the MRP system had recently been reconfigured to function around the JIT philosophy, rather than to dictate purchase orders.

Otherwise, there was very little computerised technology used in the direct planning, monitoring and control of production facilities, with computer systems mainly confined to the level of management information systems. The operating systems, as a result, were almost entirely dependent upon manual methods for production tasks, materials movement and operations control.

The plant adopted a very participative approach to new systems design and development and employees at all levels in the organization could become involved in facilities and layout decisions, in addition to continual improvement activities. The main constraint at the time within the plant was that all systems should be designed to fit in with the JIT philosophy. However, systems design projects were not a frequent occurrence with the company keen to utilise the existing simple manual facilities, with their inherent flexibility, to produce any new product designs that should emerge.

The performance measures used by the company were becoming increasingly customer orientated. Thus emphasis was increasing on measuring quality, service and delivery with a lower profile to in-plant productivity measures. The main focus of all evaluations conducted within the plant was the extent to which customer requirements were being satisfied as a means of gauging how well the company was doing in terms of cost (hence price), quality, responsiveness to orders and flexibility to deal with individual requirements. However, it was acknowledged that very little by way of post audit was conducted in respect to capital expenditure projects, but this in turn was defended by the fact that the adoption of predominantly manual systems kept investment to a minimum in any case.

Company D

Company D designs and manufactures sound mixing equipment as used by the broadcasting industry and recording studies, etc. The market for these products is dominated by two manufacturers, the largest producer having a sixty percent share of the world market and Company D, number two in terms of output, holding around twenty five percent. Both the leading companies are UK-based, despite the fact that the two largest geographic markets are the USA and Japan.

In relation to other electronics markets, for example consumer goods and the IT industry, sound mixing is a relatively small worldwide business. Company D, then, despite its position in the industry, is the smallest organization used in the electronics industry case studies, employing a total of 1000 employees on two sites. The company grew from a one man business in the 1950's to its current size, but growth over the last five years has been somewhat stinted. For the last three years the company had been fully owned by a large European electronics group, although the reason for their interest in the company is difficult to ascertain given their portfolio of interests elsewhere. The degree of influence exerted by the parent company had not been great to date, but there existed a measure of apprehension as to what the future may bring in terms of a plant rationalisation to one site and employee redundancies. Currently one plant, the headquarters of the company, was involved with research and development and specialised production, whereas the other was the main production unit, concentrating on the more standardised products and generating eighty percent of the company's output by volume.

The two areas in which executives saw Company D having competitive edge were in product build quality and reliability of performance, both product related domains. The opportunity to improve manufacturing performance was seen as a key concern in the future, as the current systems were very low investment in nature and had been developed in an ad hoc manner over a period of years.

The specialised nature of customer demands meant that this company was frequently faced with the need to adapt its manufacturing activities in response to product redesigns, developments and high value special orders. Indeed its factories, particularly the one concerned with R&D, had the appearance of being design labs, prototype areas and manufacturing facilities all rolled into one. A strategy for future product development was now emerging which entailed taking a rather more structured response to the requirements of the market. The design of a "modularised" product, some parts of which would be standard and others left with the potential for variation, was seen as the way forward.

Although the plants had always been flexible in terms of the ability to produce a wide variety of products, design and process engineers were now starting to address the need to standardise the product as far as possible, thus reducing the range of operations required, cutting response leadtimes, whilst remaining "intelligently flexible" and still providing customers with the "right" product for their needs. An integrated approach of this type, it was felt, would give the company the edge over its main competitor in terms not just of quality and reliability, but also technology, manufacturing performance and customer response.

The organization was of a very traditional, but complex nature. It was developed on the basis of functional specialisms and geographic location, with a distinct feeling of hierarchy and imposition in its management style. The factory managers had responsibility for production volumes and quality, although quality assurance within the plant was seen very much as the domain of the Quality Control and Test departments. Management saw little advantage in the adoption on such approaches as quality circles, for example. Responsibility for product design, purchasing, personnel strategies and so on were entirely within the hands of the headquarters plant which was located some 500 kilometres from the main production factory. The interaction between these plants was usually limited to infrequent senior management visits and meetings and the two van trips per week between the two plants. Some fairly senior managers at both plants admitted that they had not visited the other plant, despite having worked for the organization for some years.

In summary, managers within Company D had identified the need to radically change the way it manufactured its products. However the highly paternal and hierarchical nature of its management style and organization structure has presenting itself as a severe barrier to change. Although there were areas of engineering expertise, particularly in product engineering, within the Company, managers had not yet been able to fully integrate its various strategies nor were its systems adaptable enough to cope with change in the near term.

Systems Design in the Electronics Assembly Industry

The electronics industry is characterised by its extremely dynamic market and environment: product life-cycles for most products is short in comparison with other industries and new process technologies such as surface-mount for printed circuit board production are still appearing. Couple these factors with the fierce competition coming, as it does, from some of the world's largest multinational companies, innovative Japanese companies and low-cost Far Eastern manufacturers and one can understand why managers from these companies stress the need for flexibility and responsiveness from their manufacturing operations.

The above factors have an obvious impact on the nature of production systems design in the industry. Very often time is a key concern and so, although it would be beneficial in some ways to fully appraisal and justify new systems expenditure, the reality is that time taken at this stage means late implementation of production systems and, because so often in the industry the installation of new systems goes hand-in-hand with new product introductions, late entry to the market and lost sales. Also, because the life-cycle of production systems is likewise relatively short, there is often little time to fully evaluate the system following implementation: often systems designers and managers are involved with the introduction of the next generation of products and processes almost as soon as a system is installed and so see little value in retrospective analyses.

One distinguishing factor between the systems designs in the industry relates to whether the product volumes are high and standardised or low and high variety. In the case of Company A volumes are high and so the focus is on developing systems of mass manufacture with little flexibility, albeit that these have a relatively short life. For the other companies volumes were low and product range diversified, so the attention here, like the case of ICL, was on developing systems with range flexibility. Often the low volumes made it difficult to justify high levels of process technology and so attention was paid to increasing the flexibility and mobility of labour within the systems. Finally Company D, the smallest of those studied, demonstrated that not all electronics assembly companies operate systems that are effective and responsive to the needs of the market. It will be interesting to map the long term development of this company.

5.3 Electrical Engineering Industry

Industry Overview

The electrical engineering industry is defined as a sector manufacturing products primarily comprising electrical circuitry, but also some mechanical components. In many ways the industry is very similar to that of electronics and, at the boundaries, some operations may be difficult to categorise into electronics or electrical engineering. Indeed some companies' operations span both sections (for example Lucas Industries). It was exactly because of the similarities and closeness, however, that this sector was identified and chosen as a first step in considering the applicability of the DRAMA model beyond electronics assembly in order to evaluate the extent of the model's generic properties.

Whilst the manufacturing activities and product types would seem to bear resemblance to those of the electronics industry, there are a number of succinct differences in the nature of these industries and in the markets and environments within which they operate. Electrical engineering manufacturers tend to be more traditional in their outlook and approach to those in electronics, particularly the computer manufacturers. The markets for products is longer established and product technology, whilst advancing all the time, is not doing so with the speed and uncertainty of electronics. The net result of this is that customers are not so much motivated by product advancement and latest technology, but more by quality, cost and delivery. The rate of new product design and design modifications is less rapid, meaning that product life cycles tend to be longer and more easily forecasted and determined, thus reducing uncertainty. In addition the companies operating in the sector tend to know their competitors rather better than in the electronics industry, there already having been a considerable shake-up in the industry in its formative years reducing the industry to a typical oligopoly of a few large players and many smaller companies picking up the pieces.

This has consequences upon the systems design activities. As seen within electronics uncertainty regarding product lives, competitors' designs and changing customer requirements means that systems are developed either with an extremely high degree of flexibility in terms of product range, or are dedicated but low investment with little expensive automation. This high variety, low volume criteria does not necessarily confront companies operating in the electrical engineering industry however. Longer product lives with fewer modifications and changes and less need for customisation means that firms can adopt manufacturing activities based upon economies of scale and high volume manufacture, with fewer requirements for process flexibility, operator multi-skilling and mobility, etc.

Having said this, the electrical engineering industry is now coming under increasing threats, both from international competitors and, perhaps even more significantly, from outside the industry, most notably from electronics. As electronic technologies advance, we are now witnessing the replacement of more and more mechanical and moving parts with electronic components: enter the era of "black-box" technology. Electrical engineering manufacturers appear to be adding less and less value to the end products and are increasingly being asked merely to produce the links between these black-boxes and to assemble these together. One only has to consider the motor industry, a major customer of electrical engineering manufacturers in the UK, and the addition of electronic ignition, fuel management systems and other electronic devises to standard ranges of cars to understand the threat this poses to its traditional suppliers. This would seem to indicate a shift towards downstream assembly manufacturing activities for these companies and the critical need either to develop their own in-house electronics expertise or, more commonly, to search for collaborative deals with electronic companies. The effects of the above must surely call for a change in the way systems designers approach the development of new facilities.

Company E

This company produces electrical components chiefly for the motor industry, but also for other final assemblers who require such components in their product build. The company employs around 4500 people across four major sites, although the main site is far larger than the other three comprising around 3000 of these employees. Two of the manufacturing plants, including the main site, have been established for over forty years and so there exists a degree of tradition and a certain amount of inertia. The other two plants however have been set up for less than three years. In the newer factories, with a workforce new to the business, Company E has been able to introduce conditions of employment, new technologies and working practices appropriate to the needs of the industry with the minimum of negotiation and bargaining.

In worldwide terms the company is relatively small, but seen as medium sized in the European context. The consensus amongst senior managers is that to survive the company must grow. As E's major customers strive for economies of scale in the manufacture of vehicles it is seen inevitable that they will focus their business with larger suppliers who can offer substantial support in terms of engineering, product and process development, and extensive logistics management. Large contracts and single sourcing will become the order of the day and it is unlikely that small or even medium sized suppliers will be able to win orders.

The greatest pressure upon the business of those listed above is the demand for advances in product technology. Clearly the business needs not only to be large enough to handle large scale R&D projects, but also needs to develop its production and engineering technologies in response. Current methods of production are very labour intensive and resource consuming in terms of logistical and engineering support. As the design of components advances, however, there appear to be substantial opportunities for automation, despite the fact that the range and variety of product configurations demanded by the customer is increasing. These changes in production technology require significant capital investments which, under the current market conditions of recession, are becoming increasingly difficult to justify using conventional accounting techniques, let alone fund.

Company E has considered acquisitions as a means of growth, but the recent financial performance of the company once again limits the justification for this. The strategic response adopted to the market and environment is, therefore, one of improving financial performance over the next five years, targeting a specific niche-group of customers who comprise the growth segment in the UK market (ie: Japanese transplants) and increasing collaboration with an already established joint-venture partner, a worldwide Japanese manufacturer. The aim is to position the company, in partnership with its collaborator, as the leading supplier of components to the Japanese segment of the market in Europe.

The other key aspects of corporate strategy for Company E is the reduction of manufacturing and overhead costs at the rate of eight percent per annum, organization of the business into five product centred business units each with "profit ownership", measures to improve perceived current weaknesses in delivery performance and new product introduction, and a capital investment to effect this through the implementation of new computer based production and engineering systems. All the above are specified in detail, with quantified targets attached, in the company's strategic plan statement which is produced in a structured manner an annual basis. The strategic plan also contains a SWOT analysis and statements on the perceived state of the competitive environment.

In terms of manufacturing strategy, the objectives include the improvement of delivery performance from 98% on time delivery to 100% in the next twelve months, the improvement of labour productivity by 25% over the next two years, improvement in the stock to sales ratio of 20% per annum, costs of quality reduction at 20% per year whilst maintaining 100% defect-free customer deliveries and a reduction of indirect labour and white collar production staff by five percent per annum. These are in addition to statements concerning the need to develop advanced systems for manufacturing to remain competitive within the industry.

The pressures upon the company, as reflected by corporate, market and manufacturing strategies, have necessitated a radical organizational change. However, in common with a number of the other companies surveyed, there still appears to be a time-lag between the recognition of new organizational forms and attitudes and their implementation. Despite attempts to foster a more innovative and change oriented "culture" within the company, the evidence suggest that it is the newer plants that closer exhibit the types of organization necessary for flexible production whilst the older plants lag behind with a legacy of functional specialisation, hierarchical management styles and a resistance to change. Matrix management has been tried and is seen as being relatively successful for project team organization. However, the Personnel Director still considered some managers "misused" matrix management and still had difficulties in coming to terms with dual responsibilities and multiple reporting structures.

The difference between the "old" and "new" factories is most evident at the level of physical systems. More traditional methods of work remain at the more established plants where the product is made complete at a single workstation by one or two operators. This method does offer benefits in terms of flexibility and is currently the only feasible way to produce the more highly customised products for specialist customers. However the costs of production tend to be higher particularly in terms of direct labour and inventory holding. By setting up at two sites which were "greenfield" for Company E (although the buildings were previously used by other companies for different operations) management saw the opportunity to introduce new production methods as practised by its Japanese joint venture partner. This new work organizations represented a move away from single stage to multi-stage build using principles of flowline working. This way of working is particularly conducive to kanban production control as practised by Toyota and the delivery of incoming goods to the line. This way of working served to drastically reduce inventory (batches of one in kits as opposed to bulk supply to workstations, typically in quantities of twenty-five. However these new methods were only suitable for higher volume product variants, and there was some discussion ongoing as to the desirability and long term effects of shorter cycle operations (ten minutes cycle versus the typical make-complete cycle of around two hours).

The Japanese multi-stage build technique incorporated a layout with a circular assembly line instead of the long linear tracks frequently found, for example, in car assembly plants. This configuration lends itself to the implementation of cellular manufacturing and the company has as part of its "organization strategy" the objectives to invoke structures based upon product focus and profit centre accountability. This modular work organization is also seen as offering advantages in terms of flexibility, with additional production cells being added and others being dissolved as and when the business dictates with little interference on the system as a whole. Cellular manufacturing is also seen as a vehicle for increasing teamwork and cooperation amongst employees and to this end a number of what were previously central services (eg: manufacturing engineering, maintenance, etc) now have one or more of their personnel assigned to each cell with a dual reporting role to the function and also to the production manager in charge of the cell.

Implementation of multi-stage build operations and cellular organizations is widespread in the two new factories and the majority of employees who work within these only know this way of working within the company. Progress is less advanced and implementation more difficult, however, in the older established plants where a considerable degree of organizational inertia, cultural resistance and traditional industrial relations still persist. The company are trying to make incremental progress by gradually introducing cellular working. The capture of a large supply contract from a major Japanese car manufacturer and the locating of the business within the main factory is seen as an opportunity in the coming months to introduce a catalyst from which existing product centres at main site are expected to follow. The results of this are awaited with anticipation.

Company E is currently committed to the development of computerised systems under the banner of Computer Integrated Manufacturing (CIM). A key success factor is seen to be the reduction of product design and order to receipt leadtimes. The result is that over two million pounds has been invested in Computer-Aided Design (CAD) technology since 1984 and, since 1988, the company has been committed to the implementation of Manufacturing Resources Planning (MRPII) for more effective production planning and control systems. The CIM project has evolved from the recognition that the CAD based engineering systems need to incorporate Computer-Aided Process Planning (CAPP) and require integration with the production management systems and recent advances in process technologies in order to avoid the risk of "islands of automation" with no links to one another. However the majority of investment for CIM is still seen by senior managers in terms of an "act of faith", that the business needs effective and integration production management and control systems to remain competitive in the industry.

Company E are confident that the measures they are taking to implement and establish more effective and flexible production systems are steps in the right direction. The financial results over the last twelve months, however, have been poor as the company finds itself subject to the recession that has beset the UK car industry since early 1990. Until the market recovers in the UK, it will be difficult to evaluate the true level of success of production systems developments over the last three to four years.

Company F

Company F is the UK subsidiary of a large multinational corporation which, for many years, has been the world market leader and largest player in its chosen market, but is now coming under increasing pressure from a increasing number of highly innovative later entrants to the market. In particular there is now intense competition from Far Eastern and particularly Japanese companies. The main competitive factor appears to be the ability to supply advanced products at low prices. Throughout the 1980s and into the 1990s competition has intensified to the point where product life cycles, and that of its production systems, are of the order of eighteen to twenty-four months. In addition, industry-wide improvements in productivity have dramatically reduced assembly times in terms of build hours per machine.

Manufacturing within Company F's main manufacturing plant is therefore geared towards achieving flexibility and responsiveness to market requirements by achieving short product introduction times. There is, as a consequence, a strong emphasis placed upon the development of product-focused organizational structures, most notably a close link between the Product Design and Manufacturing functions. Much attention has been paid to the interfunctional relations of personnel within the organization in an attempt to improve teamwork and communications within the organization. To facilitate this, a complementary programme of quality improvement has been in operation for a number of years where importance has been placed upon developing market and customer awareness amongst all employees.

The organization structure of the company, in common with the wider parent organization and its other subsidiaries, has progressively displayed an increased market focus and has reduced its number of management levels. Also the number of managers who directly report to the Plant Director has been reduced from as many as eight to four, thus enabling senior managers to have inter-disciplinary responsibilities across a number of the more traditional organizational functions. The four areas of management responsibility comprise two product-specific Production departments, an Administrative function (including Personnel, Finance, etc) and Services (Quality, Engineering, etc.).

The development of closer links between the Design and Manufacturing functions presented potential difficulties because of the geographical locations of each function. The main Design activity was based some one hundred and fifty kilometres distant from the manufacturing plant. Improved links were developed in two ways. Firstly a direct electronic Computer-Aided Design (CAD) link was installed between Design and Manufacturing to improve information flow between the functions. Secondly the link was enhanced through the frequent periodical formation and deployment of product-focused multi-disciplinary teams which now concentrate on coordinating design and prototype activities in the simultaneous development of products and manufacturing processes. This initiative involves the secondment of manufacturing engineers, production managers and shopfloor operators from the manufacturing plant to pilot the operation of new production facilities and assess new product development work in relation to its manufacturability.

The results of these changes to organizational structures and inter-functional processes and relationships have enabled Company F to remain competitive in world markets with reduced times to markets for new products, a more thorough testing and proving of product designs and build strategies prior to production and the engendering of a right first time attitude within design engineers and manufacturing personnel. Moreover, aligned with the total quality management programmes now deployed within the company, senior managers now believe that the level of customer awareness amongst employees at all levels in the business enables them to maintain their position at the forefront of their market. However market share continues to reduce and, although not at the rate experienced in the early 1980s, this still presents somewhat of a challenge to the company's management team.

Company G

Company G opened their plant in the north-east of England in the mid 1960s. The factory was extended in 1970 and today is the company's largest plant worldwide, being a global manufacturing and design site. The factory produces high volume domestic electrical appliances and exports 70% of its output. A particular feature of Company G is its emphasis on developing effective manufacturing strategies and on the efficient implementation of new production systems, both of which its manufacturing director saw as critical to its manufacturing performance.

The company's managers identify two so-called *foundation stones* that support the overall policy: what is known within the company as the plant philosophy. The first foundation stone was to recognize that "people are the key asset". In so doing the organization seeks to develop a corporate culture based around four elements: respect for the individual; progressive single status employment conditions including no clocking in or out and the same canteen facilities and holiday entitlements for all employees; continual people development where a large budget allows for excellent training facilities and an apprentice scheme for young entrants; and management credibility. The manufacturing director explained that Company G likes to see itself as a people organization. Furthermore it was claimed that the plant has excellent employee relations with not one hour being lost due to dispute since its opening. The second foundation stone was that of *distinct competencies*. This entails the plant only manufacturing those products and performing operations at which it is proficient and has an edge over the competition. The operations at which the company has such distinct competencies have been identified as the production of high precision components, manufacture of electrical motors and final product assembly.

Building upon the above the plant philosophy was described as comprising three elements: "to continually improve the quality of everything we do and everything we make through Total Quality Management (TQM).", "treating everyone as a customer or a supplier" and, associated with the first two elements, "providing and demanding Total Customer Satisfaction (TCS)."

On the basis of this plant philosophy, a five year manufacturing strategy for Company G's manufacturing plant has been developed. This has four main drivers: quality, flexibility, cost and the environment. Improved quality has been effected by a new "build methodology" where the emphasis has been to increase the cycle time of assembly operations and increase individual operator responsibilities for quality. The aim is to improve flexibility in terms of fast changeovers of processes and lines from one product to another, improved responsiveness to customer demand, the introduction of assembly lines with multiple product capability, and the ability to vary production rates. Whilst quality and flexibility have become increasingly emphasized over recent years, cost is still recognized as a key competitive factor. Efforts towards cost minimisation are based around increased asset utilisation of floorspace and capital plant and equipment. Finally, with regard to the working environment, people are viewed as the key asset and so efforts are made to get the best out of operators, administrative staff and managers by providing a high quality workplace conducive to effective working. In summary, the overall objective is "*to achieve and sustain (Company G) and its products as the best in the world*". The efforts taken over recent years, particularly the focus upon people, customers and quality, are now placing the plant in a position where this is, in the opinion of the management team, becoming a reality and is now being borne out by company performance and financial results.

The second critical factor recognized by Company G is its competence at introducing efficient new production systems through attention to detail at the implementation stage. The Company see people as being the key asset and the various human resource policies and teamwork approaches adopted by Company G are seen as being important in smoothing the way for implementation. Early involvement of people in the design process is seen as critical so as to identify and solve any potential problems and to communicate to people within the plant the Company's intentions and plans at an early stage.

Two factors explaining Company G's success in implementation were identified by its manufacturing director when interviewed. Firstly the company's engineers at its manufacturing plant now have many years of experience in the introduction of automated systems, are aware of the many potential pitfalls, and realize the importance of user involvement when attempting to translate design into operational systems. For many, it was argued, the introduction of automated new production systems is seen as a "way of life". Secondly the design process was not biased towards one single view. A committee of development personnel was responsible for design and the proposed systems were reviewed by other user groups, including manufacturing personnel, prior to installation and "before any buttons are pushed on the line".

A key part of the company's strategy for implementation was the use of turnkey subcontractors for the installation of new systems in order to take advantage of specialist knowledge and to help the drain on internal resources at the installation stage. One turnkey supplier had just completed the installation of a new flexible assembly and test line for the production of a range of electrical products at the Spennymoor plant and was available for interview on site. Based upon their relationship with Company G during this project and also earlier projects at the plant, the turnkey project manager identified two reasons explaining the successful track record at Company G in the implementation of advanced manufacturing systems. Firstly product design was performed within the plant and this combination of product and process knowledge on the part of personnel within the company enables problems to be identified and avoided before reaching the implementation stage. The second observation was that people at the plant appeared to be used to (and not afraid of) change. New products and processes were seemingly accepted by all employees and, within such a climate, effective implementation was facilitated.

Company G offered an interesting insight into what has been an extremely successful manufacturing company. The emphasis on manufacturing strategies and implementation over and above other factors was of particular note and has provided the researcher with a different insight to factors contributing to the success of production systems design projects.

Systems Design in the Electrical Engineering Industry

The companies investigated within the electrical engineering industry provide an interesting comparison with those in the electronic assembly industry. The electrical engineering industry is more mature and, as one might expect, the product-life cycles tend to be longer and technology advances more easily forecasted than is the case for electronics. However the substitution of electronic components for wiring assemblies is creating new challenges for companies in the industry. As a result firms are being forced, with the prospect of increased competition, to develop strategies, processes and work organizations that are appropriate for the manufacture of new and increasingly electronic product designs.

The more stable nature of the products and their designs mean that mass manufacture, often employing flowline production methods was the order of the day in the companies studied. However production facilities were increasingly not being seen as inflexible processes where the sole objective was to achieve economies of scale. All three companies saw it necessary to develop multi-model lines which could be reconfigured in a short period of time allowing the production of different product types and a wide range of variants. Increasingly, therefore, installations were not seen as dedicated to the production of a single product. In addition Company F now had an objective when installing production systems that no part of the system should be bolted to the floor and that the system could be taken out and replaced by a new process over a weekend. So, although of a flow-line nature, their production systems were not considered to be rigid or permanent systems but capable of quick adaptation or replacement if necessary. In response, therefore, to the increasing dynamics of the market and competitive environment in which they are now operating, companies in this sector are now approaching the design of their production systems and the development of work organizations with a view to providing flexibility in terms of both product range and response to changes in volumes, mix or product designs.

5.4 Mechanical Engineering Industry

Industry Overview

The case study companies investigated within the mechanical engineering industry are largely concerned with metal fabrication, but also (and increasingly) with some subassembly activities connected with their metalworked parts. The industry is generally more capital- and less labour-intensive than the electronic assembly and electrical engineering sectors and operations tend to focus around large press equipment. The industry is also more mature and the three case companies have been involved in the business of producing fabricated and semi-assembled products for many years.

Manufacturing operations in the industry were subjected to automation at an earlier stage than most industries, but this tended to be of a fairly rigid, inflexible form. For many decades investment has been an important factor in this industry in order that companies could keep pace with advances in process technology and remain competitive. This has continued to be the case with the introduction of more flexible, reprogrammable technologies over the last twenty to thirty years where the use of computers for process control has become increasingly widespread. This commenced with early forms of numerical control (NC) using punched-cards and paper tape and has progressed through computerised numerical control (CNC), networked or direct numerical control (DNC) and on to such concepts as Flexible Manufacturing Systems (FMS) and Computer Integrated Manufacturing (CIM). Indeed, mention of factory automation, FMS and CIM to most casual observers brings with it notions of automated machine intensive factories and CNC machine cells of the type found within this industry. However production system design changes have not merely been determined by process innovation in the mechanical engineering industry. It is also important to recognise the organizational changes that have occurred in many factories at the shopfloor level, and the changing relationships these upstream operations have with their customers within the overall value chain. These will now be explored in more detail.

Firstly the availability and use of new processes and control mechanisms for manufacture has tended to create a technological fix in many mechanical engineering firms where new technologies are often seen as the solutions to competitive problems. Indeed, analysing the competitive position of many British engineering firms this argument would seem to have some poignancy: the lack of investment in the UK comparative to competing industrial nations has certainly been a causal factor in the demise of this sector of British industry in world markets. However technology by itself can only be seen as a partial solution and so many companies have turned to a parallel development of new organizational forms for manufacturing operations. Traditionally operations in these industries has been of a batch manufacturing type characterised by functional production layouts, process orientated work for skilled operators dedicated to one type of operation and all the inherent problems of batch production described in Chapter Four included long throughput times, excessive queuing and buffering of stock, high work-in-progress, etc. Given this the concept of Group Technology (GT) has had a generally high appeal in the mechanical engineering industry, and many companies have now adopted and implemented GT in their operations. Thus the traditionally process-orientated and technology-driven nature of companies in this sector has been tempered somewhat by the introduction of product- and, by extension, customer-focused cellular forms of organization. A recurrent point in the cases in this sector is the move towards GT cells and the implications of this upon the whole organization.

A second factor worthy of mention here is the changing relationship between suppliers and customers within the supply chain. Mechanical engineering is an *upstream* manufacturing activity in that it primarily produces items that are used as component parts by its customers rather than producing finished consumer goods. Increasingly the downstream customers have been keen to adopt just-in-time based inventory systems whereby a minimal amount of stock and work-in-progress is held at each stage of production. Many customers have naturally looked to extend JIT to the management of the supply chain: receiving more frequent, but smaller order quantities from a smaller number of highly trusted suppliers. In such circumstances the supplier company, in this case the mechanical engineering firm, has two main choices: to adopt the principles of JIT and produce in smaller batches upon demand, or to hold a stock of finished items from which the customer can draw their requirements. The latter arises where a firm finds it difficult to reduce its batch sizes to the order sizes demanded by the customer. Whereas in an assembly environment it is usually relatively easy to produce in a *one-by-one* method, in mechanical engineering setting, such as in a press shop, changing from one item to another often incurs considerable set-up times and costs. Again the adoption of GT may assist by standardising operations to produce discrete families of parts and thereby minimise set-up times. Whatever solution developed, however, the influence of changing customer demands and the pressure for reduced batch sizes has had a significant influence upon production systems in the mechanical engineering industry.

Company H

Company H is a producer of motor vehicle body panels whose major customers are in the UK and Sweden. Like other companies in the British motor industry Company H suffered a decline in business during the recessionary period of the early-mid 1980s. The situation in the late 1980s looked more positive, but the company was aware of the accumulated problems it had from a lack of investment through the 1980s. Although new process investments had recently been made, the press shop operations still had the appearance of being disorganized with seemingly no logical flow of material around the factory and poor materials handling, and toolrooms and die-stores which were remote from the main processes - all typical and negative features of the traditional press shop. Company H's managers were now, as a consequence, in the process of developing a better organized plant whereby cleanliness and order were features of the system. The aim was to develop a factory whereby layout and positioning of the main processes, the die stores and the toolroom would mean that the movement of materials and dies would be minimised thereby reducing inventory levels and set-up times and so increasing the responsiveness of the operation.

The plans for process investment were centred around replacement of presses in an incremental manner for advanced computer-controlled equipment. As new presses were being installed the opportunity was taken to reorganize the area around the installation. Of note is that some new presses were being installed in what was previously the assembly area where the company assembled minor parts on to some of the body panels it produced as requested by the customers, the car manufacturers. This meant that space was freed up in the press shop to move some assembly operations close to the presses in there. The production area was then being laid out on the basis of operations sequence and the operators were grouped into work teams with work organization becoming more product orientated. In effect the company was adopting the principles of group technology to replace the traditional batch operations it had traditionally employed. However, given the level of investment required for new processes and in changing the layout of operations, the process of production reorganization was protracted and, at the time of the research visits, only about 25% of the factory had been reorganized in this way. It was liable to be another five years until the factory relayout would be complete and, even then, some old press facilities would still be in operation.

The company saw the need to make changes in the production planning and control system to reflect the physical system and work design changes so as to ensure that the strategic manufacturing goals of low inventory, short leadtime, fast set-up times and low cost production could be met. The company had, for a number of years, used what was now a rather unwieldy MRP system to plan production. Based upon both firm and expected customer orders into the future, it would plan the production of body panels and assemblies using rules of minimal batch sizing. However both of Company H's major customers were now demanding a form of just-in-time delivery of materials to their factory and, as a consequence, Company H's operations were seen by its managers as not being responsive enough to react to customer demands. The UK customer now expected to make a daily call on materials and the volume demanded per day varied considerably as dictated by production rates of particular product models at the car assembly plant. They introduced a rule that their suppliers, Company H included, should hold three days stock of final products in despatch ready for them to draw off; in effect the suppliers were now holding what was previously the car manufacturer's goods-inward stock.

In response to the demands of its UK company in particular, Company H introduced a hybrid MRP-JIT system to control their own operations. MRP was now run twice a week and was primarily concerned with the replenishment of the three day outward stock, although plans were also projected in the longer term for forecasted production levels and materials requirements for the own suppliers. In effect the press shop and assembly operations would only produce what was required to replace outward stock that had been drawn by the customer. For the newly laid out GT operations inventory levels could be reduced significantly in relation to the more traditional production facilities because of the faster set-up times and, in particular, the very short manufacturing leadtimes (a matter of hours instead of days and weeks). In turn the production areas would now draw their requirements from main stores in discrete lots, thus initiating a pull system throughout the operations. Company H also instigated what it termed a "milkround" of local suppliers whereby the company's own vehicle would do a circuit of local suppliers every day drawing off immediate requirements rather than stocking them at their own factory.

The new layouts, work organizations and control and integration systems appeared to be working well; indeed they were a substantial improvement on what previously happened. However there were doubts as to whether Company H could make the necessary changes to improve its manufacturing performance at a fast enough rate. Some competitors were now setting up new greenfield sites using joint venture capital from the vehicle producers and so were quickly able to establish modern manufacturing technologies and techniques. The question was, therefore, whether Company H could continue to compete, be profitable and so be able to raise the investment funds necessary to develop its operations into the future.

Company I

Company I is a large international company which manufactures a wide range of specialised heavy duty agricultural vehicles. The case is that of the UK operations and part of this factory in particular: the transmission production area which manufactures gearboxes which go into the final products it produces in a facility alongside. The company has continued to be successful over the last twenty years, but all this has taken place against a background of plant rationalizations and job losses as the process has become increasingly automated and with the reduction of indirect workers and administrative staff. Thus publicity has been rather negative, although the company continues to be profitable.

The company has always produced a wide range of vehicles and, within that range, there has been a multitude of configurations of gearboxes. Also, unlike transmission production for volume motor cars, the gearboxes have been complex in nature with as many as twelve forward and four reverse gears. So, given the circumstances outlined above, gearbox transmission systems at Company I were traditionally made in what was akin to a workshop environment with highly skilled operators taking the bought-in materials and assembling the whole of the product. In fact the process had all the trappings of job production with many of its associated drawbacks including duplication, high skills and training requirements, generally low resource utilisation and high work-in-progress inventories. The late 1980s show the introduction of new vehicles with even more varieties of customer configurations. Not only this, but the company was becoming ever more conscious of the need to reduce costs, increase responsiveness to customer needs and so reduce inventories and manufacturing leadtimes in its operations. Its systems designers were therefore called to develop the transmission manufacturing facility to match these requirements. The outcome was the design and introduction of, what was at the time, a quite novel and innovative manufacturing system.

The new system was one where the existing benches were removed and, in its place, a system of automatically guided vehicles (AGVs) introduced. Alongside the AGVs' looped route a series of workstations were set up and so a system of stage build was established (akin to line assembly) in place of the previous job-type operations. The AGVs would not only be used, therefore, for movement of the main materials into and through the transmission production area, but would also in effect be the benches upon which the gearbox assembly would be worked by operators. Operators would refer to a job card on the AGV so as to know which configuration of transmission to produce, so in effect a mixed model line was established, albeit with a low number of production stages of relatively long cycles (around 20 minutes) and with a higher variety of products then one normally expects to find on a mixed model line.

The company claimed the system to be a great success in that it had reduced inventories significantly, lowered the manufacturing throughput times and was very flexible in that it allowed for changes in schedule right up until the last minute. There were questions as to whether the AGVs represented technological overkill: many people in the organization considered the system could have run equally as well using a conventional conveyor or manual trolleys. However this was dismissed by the system designers on two counts. Firstly, from a control and scheduling point of view, the use of AGVs inserted discipline into the production area in terms of the sequence of operations and the pace and timing of production. From this discipline came flexibility in terms of the ability to make changes. Using a conveyor it was felt that there would be too much rigidity and inflexibility in the system whereas the use of manually controlled trolleys, in addition to increasing the demand for indirect service operatives, would likely reduce the inherent disciplines and integrity of the system. The second argument was that, from a work design perspective, working around and assembling on AGVs would be preferable to working on a mechanized line or in a possible environment of chaos caused by the use of manual trolleys. They would also save space within the factory.

The system was relatively quickly installed over a six week period and now satisfies the demand for the full range of transmissions required by the final assembly line. It has been found that new product designs and gearbox configurations can be easily integrated within production and, in addition, that the system is flexible in terms of volumes produced: if demand changes it is merely a matter of either removing or adding AGVs to flex production output. The system's designers reported that they had learned much from the design process and recognized the need for operator and supervisor involvement in design particularly when it involved such a change in work design and operating procedures as was the case with this system.

Company J

Company J is a small company of around 200 employees which fabricates and supplies tubular steel products and pipe assemblies to UK motor vehicle and gas appliance producers. The products are relatively small, being used as they are for car vehicle exhaust and coolant systems and domestic gas appliances, so the physical scale of production is smaller than for the previous two cases. Although one of the major manufacturers of these products in the UK, the company still faces considerable potential threats from the environment by virtue of the fact that the costs of entry in terms of investment and skills is relatively low. Thus there is no place for complacency. This was recognized by the company's management who had recently instigated a new manufacturing strategy which aimed to improve performance in a number of areas including costs, quality, delivery performance, manufacturing leadtimes and responsiveness of manufacturing to new product design. The strategy hinged around two factors: the need to reconfigure the existing facilities and the development of teamwork in its employees. The strategy therefore comprised two elements: the conversion of traditional batch manufacture using a process orientated layout and functional work organizations to group technology (GT) cellular operations; and the introduction of a total quality management (TQM) programme for employee development. Each of these is now considered in turn.

The company saw the opportunity to introduce GT to replace the functionally orientated form of production it previously used because of the portability of its processes. Unlike the manufacturers of large fabricated parts, the company employed small hand-presses and machining equipment which could easily be moved from one part of the factory to another. The reorganization followed the conventional steps of a conversion to GT described in Chapter 4. Firstly families of products and parts were identified on the basis of similarities in process routing and settings on machines. Where a family was particularly large, it would then be further subdivided on a customer basis to enable the formation of an appropriately sized cell. Secondly the machines were relocated and set into U-shaped cells within the factory in the sequence of operations required. In parallel people were allocated to cells and then encouraged develop the skills necessary to perform all the tasks required within their cell. Cell team members names and photographs were posted above each cell so as to improve communication and help develop team spirit and a sense of ownership. Production planning and control systems were also accordingly changed from make-for-stock to a make-to-order philosophy which was now possible given the reduced leadtimes and increased responsiveness within the factory.

The second major element in the manufacturing strategy was the instigation of a TQM programme. This was intended to develop employees, increase their customer focus and provide them with the tools and techniques necessary to address any problems they might incur as individuals or as a group. It was hoped that TQM would foster a more coherent culture committed to quality within the factory and so would facilitate improved teamwork. Employees were provided with TQM training and encouraged to embark upon their own quality improvement activities. However, it is here that problems occurred in that the programme was seen by operators to have been management initiated and so this some resistance within the factory. It is to these problems of planning and implementation within Company J that we shall finally turn.

The major problem with the strategy at Company J was that it was largely imposed by managers and allowed for little consultation during the design and implementation of the new systems and quality improvement programme. With more participation on the part of employees, the implementation and long term effectiveness of the changes would have been enhanced. The result was that even though the proposals for GT and TQM were sound solutions for the company, the reasons for the changes were not explained or understood by the workforce. One middle manager interviewed as part of the fieldwork was almost distraught with the process saying that the proposals were excellent in principle, but poorly implemented and so the new systems were never likely to achieve their full potential. Nonetheless the changes have still benefitted the company enormously and are a great improvement over the situation that prevailed before. On the whole managers have achieved their goals as set out in the manufacturing strategy and the company is now in a far better position to react to any competitive threat that may occur into the future.

Systems Design in the Mechanical Engineering Industry

The mechanical engineering industry provides a good contrast to the largely assembly based and downstream operations in the electronics assembly and electrical engineering industries. The industry is, to all intents and purposes, mature in nature and its process equipment and production systems designs tend to have much longer lives than is the case in the previous industries studied. Most companies have tended to work in a batch manufacturing environment as a result of the time and costs involved in resetting plant and equipment between jobs. Where product variety has been demanded, companies in the industry have tended to fall back to job systems, relying on the skills and adaptability of high calibre technically knowledge labour to satisfy requirements of variety and quality.

More recently, however, the advent of the concept of cellular manufacturing in the form of GT has had an considerable effect within the industry. Many companies now appreciate the benefits of changed their functionally organized batch manufacturing facilities into cellular configuration. The problem seems to arise though from an inability to effectively manage and implement the changes. This can be put down to the fact that in the past process engineers in the mechanical engineering industry have tended to see their job as being about the selection of discrete pieces of advanced manufacturing technology intended to increase economies of scale of production. The new forms of organization and production systems design require a different approach whereby the technology has to be balanced against the requirements of the customer for variety and fast response and the work organization issues of multi-skilling, teamwork and responsibility for quality on the part of the workforce. Whereas Company I above seemed to have been successful in managing its programme of systems redesign, systems designers at H and J appear to have been less successful. Although the idea to move towards GT would seem to make sense in both cases, Company H seemed to be moved at too slow a pace due to a lack of investment for the changes, whereas Company J had imposed the changes and so, by not addressing the issue of reducing resistance and informing the workforce of the changes, would probably not achieve the full benefits and potential that might otherwise have accrued from the new system.

The DRAMA model was found to have provided a useful and robust framework of enquiry for the empirical work within these companies, both for structuring the data collection and also for the analyses presented above. On the evidence from the cases in the mechanical engineering industry, therefore, the model would seem to be applicable both as a research tool and also, it is suggested, for systems designers in the industry to consider when developing new processes.

5.5 The Carpet Manufacturing Industry

Industry Overview

The UK carpet manufacturing industry provides a contrast to the other industries selected for this research project. It is the most traditional and mature industry of the four and is concentrated in particular locations within the UK, so continues to be largely parochial both in terms of its workforce, but also in the paternal nature of management. In the main it remains a largely traditional manufacturing industry, but one where British producers remain as world leaders in the high quality and customised niches of the market (the so called "contract" carpet business of special designs and patterns). However companies are coming under increasing pressure from foreign imports and new product and process technologies which, together, have caused somewhat of an erosion of the domestic carpet sales for UK manufacturers. To understand the nature of these competitive threats it is necessary to firstly consider the technologies of carpet production.

Traditional carpet production is of two types: hand woven and machine woven. Hand woven carpets are low volume specialist products typically produced in the Middle East, China and other parts of Asia and demand a high price. The majority of sales for traditional carpets is obviously for machine woven cloth and it is here that British manufacturers have developed their reputation and expertise both in the design and construction of power loom technology and also in the manufacture of cloth on these looms. Loom produced carpets are of two types: "axminster" where the pile is basically hooked into the jute or manmade backing as a series of "U"-tufts; and "wilton" where the desired tuft colour at any one point in the cloth is cut or looped as pile and the other colours of yarn in the carpet are woven into the backing with the warp and weft. Given this, wilton carpets, as they use more yarn and are more complex in construction, tend to be more highly priced than axminsters.

However the last thirty years has seen the emergence of "tufting" technology. A tufted carpet is where tufts of yarn are shot through a pre-existing backing material or else glued into place; they are therefore of "non-woven" construction and tend to be cheaper than woven products. At first tufted carpets were of very poor quality and so had little impact on the woven part of the market. However tufting technology has now advanced to the stage where quality has improved and taken market from the traditional manufacturers. Almost without exception the traditional manufacturers have needed to move progressively up-market to find niches and have dropped their lower range products under competition from the tufted (mainly overseas) manufacturers. Add to this the advances in manmade fibres, softer forms of nylon in particular now being more acceptable to consumers, and one can see additional pressure on UK manufacturers who have tended to produced wool-blended carpets.

The response of UK manufacturers has been of two types. Some companies have sought to move gradually up-market and concentrate on the higher value and world-wide contract business in order to lessen dependence on the domestic market which has been under threat from cheap tufted imports. Other manufacturers, normally those at the lower end of the woven market, have moved into tufting technology themselves in an attempt to maintain market share in the UK and abroad. Generally speaking the companies adopting the first strategy have been more successful than those adopting the second, although the extent to which one can keep retreating up-market and maintain volumes into the future is open to debate. Many UK carpet producers however, probably as a result of organizational inertia, made neither of these responses: these form the majority of companies that, over the last twenty years, have been lost in a huge shake-out of industry players in Britain. We will now turn to the case studies to consider what effect the changes in the market and industry have affected the process of production systems design.

Company K

Company K is a privately owned UK manufacturer of axminster and wilton carpets employing approximately 2500 employees and comprising three main manufacturing sites. The company has a long and successful history and has continued to be profitable throughout the 1980's at a time when most of its competitors were making losses or going out of business. The company has been established for over 200 years and has a high degree of vertical integration in its operations, from woolwashing and spinning through to dyeing operations and on to carpet production. It is also distinctive in that it engineers and builds its own axminster looms which are the most technology advanced of any in the industry. Additionally K does not sell its process technology to any other manufacturers, so it has a considerable edge over any of its UK or foreign competitors.

The company has developed a market strategy, in line with many in the industry, of moving up-market and concentrating on the lower volume, high value added contract business as opposed to volume production for the home domestic market. This has, however, had implications for manufacturing. Most notably it results in a much higher incidence of machine set-ups or "loom alterations" as they are known in the industry. It also means that a wider variety and mix of yarn colours must be handled (in effect the main component of the industry) and so this adds complexity to the production planning and control activities of the firm.

Manufacturing strategy within Company K now stresses to need for "effective" rather than merely "efficient" production. This involves a lowering of dependence on such measures as machine efficiency and labour productivity towards evaluation of operations in terms of adherence to schedules, customer satisfaction and quality. Additionally, the key areas for winning orders in the contract business are seen to be the response to customer enquiries and the lowering of leadtimes, design to manufacturing and order to receipt. These requirements have placed intense pressure on existing design and manufacturing planning and control systems and resulted in demands for the development of new systems.

In terms of product design, the company first invested in CAD equipment in 1980, although this was introduced on an entirely stand alone basis. Prior to CAD, and continuing in parallel until 1989, designers used to use paint and squared paper to generate design and these were used as the means of communication to the contract customers and production personnel. Clearly this was extremely labour intensive and tended to tie the designer up for some considerable time. This resulted in long leadtimes and a slow response to customer enquiries. It also meant that design modifications were a particular headache should designs need to be changed or if the contract customer require alterations. The CAD system gave a number of advantages. It enabled a more rapid design of carpets as the designer was now able to use replication commands and to draw upon base designs in the system rather than repainting squares on pieces of paper. Secondly modifications and design errors were easy to correct and design editing was cut down from days and weeks to minutes. Thirdly, and very importantly in terms of manufacturing planning, the CAD system is able to accurately calculate colour usages of different patterns and their variations across the loom, both in percentage terms and, when multiplied by the order or run size, the weight of each colour of yarn required, thus cutting much of the guess work from yarn and dyehouse ordering. The information from CAD was used in two ways by engineering and production. Firstly, as indicated above, the CAD information could be used for yarn ordering and specifying requirements by colour from the dyehouse. It could then be used at loom for placing colours on to "frames" in their appropriate place in terms of their usage ("planting the frame"). Secondly, CAD design information is used for generating instructions to the loom for colour selection. This continues to be done by a string of punched cards ("jacquards") presented to a bank of needles at loom, one card for each row on the carpet. This system had been in existence since the invention of the power loom and caused a number of problems, not least of which being the stamping of jacquards, a manual and time consuming process, each time a new design was required. This was, and continues to be, a significant bottleneck in the design and manufacturing processes and raised many questions as to why NC or computerised technology was not being employed for colour selection at loom. This technology has been employed for many years by the tufting manufacturers.

There were clearly areas of development in terms of design, engineering and production control systems. There was no automatic interface between CAD and any CAPM or engineering systems. Manual interfacing was the order of the day. As a result a number of initiatives were started in 1989 to improve performance and responsiveness to customer orders. This involved the introduction of a new production planning and control system, the development of innovative new computer controlled process technology including the exploration of so called "electronic jacquards" for colour selection at loom, and the integration of systems requiring the further development of CAD.

By early 1991, an MRP package had been installed and production plans where now automatically generated. Management reports have been developed, but the investment in networked systems and the subsequent on-line enquiry facilities have suffered from constraints on expenditure as a consequence of recession in the building and house markets which directly effects carpet sales and, therefore, profitability. So a planning system exists, but management control of production has not been fully realized. The final stage of development was the integration of the MRP system with the rest of the company's systems and towards MRPII/CIM. This proved more difficult to tackle and poses a great many issues within the company. The main difficulty is one of the different platforms upon which the various systems around the company were developed. Integration with sales order processing was relatively straight forward as both the sales order processing and MRP systems were, to all intents and purposes, driven by the Data Processing Department within which the Management Services Manager resides. However the design, engineering and process control systems were developed by other groups at a time when there were no guidelines in the form of an information technology strategy within which to steer developments. The linking of these islands is proving to be a major stumbling block and is, it now regarded with the company, as indicative of previous approaches where developments were not user or management led.

Developments in terms of CAE have been, since 1989, largely based upon the integration of CAD with process technologies. The company has a high esteem for its engineering expertise and, contrary to the activities of other UK carpet manufacturers, has a policy of designing and building its own machinery instead of buying from specialist equipment manufacturers. There are two activities of note in this area. Firstly the company have invented a new way of presenting yarn to looms to replace the traditional method of yarn wound on to bobbin-type packages. This involves blowing yarn into tubes and ensuring that exactly the right amount is in each tube to match the yarn requirements of each end at loom, as determined by the design pattern. This was initially developed in a standalone experimental machine, but is now interfacing directly with the CAD system. The result is that yarn usages are not only calculated in aggregate, but also that the right amount is provided at each point across the cross-section of the loom. This is a great advantage in the weaving department where yarn packages do not need to be juggled with across the back of the loom to ensure yarn is in the right place at any given point in time. The second area of investigation is that of replacing the jacquard. The woven carpet industry generally has been slow in exploring the use of CNC for colour and pattern selection at loom and has tended to remain with the old technology of cardboard punched-cards. Research and development is currently under way in collaboration with an electronics systems supplier to develop such a device whereby CAD design details are downloaded automatically to loom. This would eliminate the bottleneck activity of card stamping and substantially reduce manufacturing leadtimes and so increase responsiveness to the customer. Developments on the "electronic jacquard" are still at an exploratory stage although, given that colour selection on tufting machines has been in use for over ten years, the technology is seen as being entirely feasible.

So developments within Company K have evolved to the stage where integration is now seen as the key to developing truly effective systems. However there is still substantial work to be done in the interface of the established CAD/CAE and CAPM systems to effect the CIM environment. Control and integration continues, therefore, to lag behind the company's expertise in process engineering and physical systems design.

Company L

Company L is a small producer of very high quality axminster and, most notably, wilton carpets for which it has a high reputation for product quality within the industry. Employing 250 people at its one manufacturing site it continues to pursue a market-niche strategy whereby it concentrates on the production of up-market and luxurious products for both the domestic and contract markets. In terms of production technology, however, its facilities are very dated. It uses looms bought from the standard loom manufacturers in the north of England, some of which are sixty years old and most of which are over thirty years in age. It also has not heavily invested in design or production planning and control systems and so produces carpets in much the same way as it has done for many decades.

The above position leaves the company rather vulnerable to the potential competition. As other UK manufacturers progress up-market in their product range it is quite liable that they will begin to squeeze Company L in its chosen markets. This danger was recognized by the newly installed manufacturing director who was, at the time of the fieldwork investigations, he was endeavouring to address these issues. However he was experiencing resistance from other members of the paternalistic management team who saw his desire for change as an unnecessary over-reaction. In the light of this the manufacturing director confided that he saw the only solution as being to remove certain members of the management team and to replace them with new managers who would see the need and be responsive to change.

This case was interesting because it studied a successful and profitable company where there had been very little attention to developing production systems over a number of decades. The company, both managers and workers, had not as a consequence any experiences of recognizing the need for change and managing and organizing such transitions. A professional manager from outside the industry had been brought in who had experiences of developing new strategies and managing production systems design projects. He seemed well versed on how to organize for change, what issues to address and how to manage change projects. However he was finding many blocks in his way in an environment where inertia and lack of investment was the continuing order of the day.

Company M

Company M was the carpet division of a large diversified multi-national company which was a major world player in the home decoration market. The carpet division was in fact an amalgam of a number of traditional British carpet companies which, over a period of ten to fifteen years, had been subject to numerous takeovers and mergers. This was apparent with one sight of the company offices alongside the factory on the roof of which the brandnames of all these companies were displayed, these still being used for marketing purposes. The various companies had traditionally been woven carpet manufacturers but had, over a period of years, invested in and installed new tufting machines. Company M therefore now competed predominantly in the low- to medium price range, except for its contract business which was largely based upon axminster production.

The takeover of this group of companies took place in 1983 and was seen as a saviour by many in the business. The new owners gave the management team considerable scope to develop their product range and manufacturing operations, although did not inject as much investment into these activities as the managers had at first envisaged they would. Nonetheless production facilities were reorganized and rationalised within one manufacturing plant and design to manufacturing links developed to such an extent that leadtimes for new designs, from their completing the design to the despatch area was cut from 26 weeks to 10 weeks. The company also began to produce new designs from their parent company which were intended to match with home decorations such as wallpapers, furniture and ceramics produced by other companies within the corporate body.

In the light of the lack of financial investment from the parent company, a new manufacturing strategy was formulated by Company M whereby the intention was to further reduce costs and improve quality and delivery performance by further improving the layout of facilities, the flow of materials and the planning systems employed, all items that could be tackled for relatively little expenditure. The result of these efforts was a significant reduction in inventory holding costs and an increase in the responsiveness of the production system to customer needs. There still remained the concern over a lack of investment in new production processes by the parent firm, but the company's managers remained quite content that the measures they were taking would ensure the medium term survival of the company at the least.

The bombshell to managers and workers alike came in early 1990. The parent company, due to financial difficulties and stretching itself with takeover investments, announced the closure of all its UK manufacturing subsidiary plants, not just in carpets but across the full range of products. So, despite the efforts of managers and the improvement of their production systems and organization over a period of ten years, high level corporate considerations had dictated the end of the line for the factory. This case presents to sobering reminder that developing a more efficient manufacturing system will not, necessarily, ensure the long term success or survival of the business.

Systems Design in the Carpet Manufacturing Industry

The three case studies above provide an intriguing insight to the process of production systems design in the carpet manufacturing industry. Of particular note in such a mature industry is the built up inertia over many years that can block change and, hence, both the radical and incremental development of production systems. Company K illustrates the case of an organization which, one way or another, has always seen the importance of continually developing its production processes in order to maintain a competitive edge. Although in the past this has meant concentrating almost entirely upon developing advanced loom equipment, it has over recent years sought to develop its control and integration of design and production operations to support its advancements in machine technology.

Company L is, perhaps, the most traditional of the companies studied. It has survived more as a legacy of its past strategies of luxury carpet production than on devising strategies of change. Many similar companies have lost their existence in the carpet industry probably by simple virtue of producing slightly lower quality products. Whether Company L can remain unaffected by competition in its markets is now highly questionable, particularly as companies like K are now increasingly being perceived as luxury manufacturers. Finally Company M would seem to be an example of a company who attempted to change and probably did most things right, but unfortunately fell foul due to corporate difficulties within its parent company, an overseas organization.

The DRAMA model was once more found to provide a robust framework of analysis for conducting the research in the carpet manufacturing companies. The carpet industry, like the electronics industry, demonstrates the links between markets, strategies and production operations in a fairly direct manner and thus the value of a business orientated model such as DRAMA is immeasurable. DRAMA also allowed the researcher to tease out many of the shortcomings of systems design within the carpet industry, particularly with regard to a lack of attention commonly towards work organization issues and a lack of competence by managers and systems designers alike in the management of system design projects.

5.6 Summary

Each of the industries studied within this chapter had certain distinctive features in their process of production systems design. For the electronics industry it is a continual concern: product designs change and new process technologies evolve so dynamically in what it still, in many ways, a new industry. As a consequence systems need to be developed for manufacturing that are flexible and adaptable to cope with change in the short term, and capable of replacement without loss of financial payback in the medium to long term.

The electrical engineering companies are moving in a similar direction, although the pace of change remains slower and typically, the product ranges more standardised. Here there is much attraction in developing multi-model production lines whereby economies of scale can be achieved whilst still maintaining some flexibility in relation to product range and product introduction. The mechanical engineering industry has traditionally adopted a batch manufacturing form of production, but the benefits of reorganizing into GT cells are so apparent now that many companies in the industry are now adopting this more market-focused form of organization. However, in so doing, firms must recognize that attention must also be paid to developing an appropriate control and integration system and work design for employees if the full potential of the new system is to be achieved. Finally the more successful systems design projects in the carpet manufacturing industry in recent years have been where attention has been paid to the design to manufacturing link, and production planning and control systems have been developed to support the physical systems of manufacturer. These would appear to be the major design considerations for each of the four industries into the future.

In summary, this chapter has presented an commentary on each of the case studies conducted as major part of this research project. Obviously only a brief overview of the cases can be provided within the constraints of dissertation length and far more material on the case companies and their design processes has been collected than can be presented here, but the wider findings have been used in the analyses presented in Chapters 7 and 8 and also in developing the DRAMA II generic model of production systems design in Chapter 9. The basic DRAMA model was used as the framework both for conducting the fieldwork enquiry and collecting data, and in analysing the design processes in each of the thirteen cases presented. It is argued, therefore, at this stage that the case study investigations in themselves go a considerable way towards validating DRAMA as a model of production system design within the four selected industries.

Chapter Six
RESULTS OF THE PRODUCTION SYSTEMS DESIGN SURVEY

6.1 Introduction

This chapter presents the results from the postal survey on production systems design. The survey was conducted in late 1991 after the empirical case study research was conducted and serves two purposes; firstly, to increase the number of organizations from which data was conducted for the project; and, secondly, to act as a follow up to those case study organizations described in Chapter 5. Thus the survey was intended to validate and increase the confidence of the conclusions drawn on the basis of the case study research and to provide some quantitative data to support the qualitative results generated thus far. The questionnaire sent to respondents is given in Appendix D.

The chapter begins by giving information on the number and range of survey responses, before providing the results in a summarised format. The results from the case study companies are then explored in order to determine whether these companies provide a representative cross-section of manufacturing firms in the selected industrial sectors. A summarised analysis of the survey results as a whole is then presented, before conclusions are reached on the findings emanating from the empirical and survey results. By the end of the chapter we will be able to proceed to the detailed evaluation of the strategic, organizational and operational factors in production systems design as contained in Chapters 7 and 8.

6.2 Survey Responses

Of 55 organizations approached, 37 responded by completing the survey questionnaire representing a return rate of 67% (see Table 6.1). Given the complex nature of the questionnaire and the time and thought required to compete it, the author was pleased with the response rate, although a high number of organizations needed to be reminded and prompted into returning the completed questionnaire. A sample size of 37 overall, and the lower numbers in each industrial category, could not be deemed as being statistically significant given the population size of organizations in the sectors studied. However, coupled with the case study material in Chapter 5, the survey results give an interesting insight into both the general and more detailed aspects of production systems design and the decision making process underpinning process choices.

Table 6.1: Responses to the Survey

Industrial Sector	Responses	Requests	Response Rate (%)
Electronics Assembly	9	15	60%
Electrical Engineering	6	12	50%
Mechanical Engineering	12	16	75%
Carpet Manufacturing	10	12	83%
TOTAL	37	55	67%

6.3 Survey Results

This section presents the results of the production system design survey. The questions asked of respondents are considered one at a time and the data is summarised in separate tables. Fuller information is given in Appendix E which gives a detailed, company-by-company disaggregation of the survey results.

The first question asked respondents to identify the main stimuli for the development of new products. Table 6.2 shows that "customer/market demand" was identified in all industrial sectors as the main determinant, exerting 63.5% of influence, followed by "competitive threat" (18.7), "product technology" (11.6) and "process technology" (6.2). It is interesting to note that, other than a notably higher influence of product technology in the electronics assembly industry, the responses given in each sector were extremely similar in nature.

Table 6.2: **Main Stimuli for the Development of New Products** *(Figures in average weighting out of 100)*

Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Customer/Market Demand	55.5	70.0	65.8	64.0	63.5
Product Technology	17.8	10.0	9.5	9.5	11.62
Process Technology	3.9	-	8.3	9.5	6.22
Competitive Threat	22.8	20.0	16.3	17.0	18.7

The second question asked respondents to identify and weight the main influences upon the process of marketing strategy formulation (see Table 6.3). The results show that "customer needs" exerted a 38.0% influence, followed in order of importance by "corporate objectives" at 18.4 and "competitors" (17.1). To this question the responses were more varied across the industrial sectors. In particular the electronics companies saw external factors such as customers and competitors having more bearing upon marketing strategy than the internally generated corporate objectives.

Table 6.3: **Influences upon the Process of Marketing Strategy Formulation** *(Figures in average weighting out of 100)*

Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Corporate Objectives	8.8	16.7	20.1	26.0	18.4
Customer Needs	43.8	43.3	35.9	32.0	38.0
Competitors	17.5	15.0	15.4	20.0	17.1
Product Diversity/ Range	11.3	1.7	4.3	11.0	7.4
Market Geography	3.8	3.3	2.1	1.5	2.6
Product Technology	13.1	16.7	10.7	5	10.7
Production Process Technology	0.6	-	5.6	1.0	2.2
Own Manufacturing Competencies	1.3	3.3	6.0	3.5	3.7

In order to analyse the different competitive factors and the basis for competition for the surveyed companies, respondents were asked to indicate on what basis customers evaluate and choose between the products of competing manufacturers in their industry. The results (Table 6.4) show price and, especially, quality to be the two major factors as perceived by manufacturers of their customers. However, customers of the electronics industry firms would appear to place less emphasis on price and more on other factors such as after sales service compared with the mechanical engineering customers for whom price was the major concern, having nearly twice the importance in weighting terms than for electronics customers. A number of other factors, not listed on the questionnaire, were indicated by respondents including "product performance", "first to market", "company/brand loyalty", "performance characteristics" and "aesthetic designs". However the weighting attached to these tended to be relatively low, and so was not deemed to render the questionnaire question as invalid or unrepresentative.

Table 6.4: **Basis upon which Customers Exercise Choice amongst Competing Manufacturers** *(Figures in average weighting out of 100)*

Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Price	21.1	33.1	38.7	32.0	31.7
Quality	35.6	38.1	30.3	33.5	33.7
Ability to Supply Specials/Customs	11.7	8.5	11.3	9.5	10.5
Delivery Performance	14.4	17.0	11.8	17.0	14.7
After Sales Service	10.6	3.4	5.0	2.0	5.3
Others *(see Note)*	6.7	-	2.9	6.0	4.2

Note: *Others included "product performance", "first to market", "company/brand loyalty", "performance characteristics" and "designs".*

The fourth question required respondents to identify and attach a weighting of importance to the most significant changes in their market environment that have affected them, as manufacturers, in the last ten years. Increased competition was given the highest overall importance, most notably in the carpet manufacturing industry. However the average figure tends to hide substantial variations in the responses given. For example the weighting given assigned to "increased competition" by respondents in the electronics industry varied from zero to 100 and likewise, but not so marked, in the other three industrial sectors. Other than this it is interesting to note that reduced product life cycles were identified by electronics and electrical engineering companies as having greater affects upon manufacturing than increased competition. This was seem to be due to the fact that the rate of product innovation and technology change in these industries are greater than for mechanical engineering and carpet production. Also "increased quality requirements" were seen as an important change factor in the electrical engineering, mechanical engineering and carpet industries, with higher weightings than the electronics industry. On first consideration this appears confusing. However, the evidence from the case studies suggest that electronic producers, particularly those in computers and telecommunications, have seen quality and near-100% product reliability as a given in their markets for many years, whereas the quality revolution has come later to companies in the other industries.

Table 6.5: **Significant Changes in the Market Environment Affecting Manufacturing over the last Ten Years** *(Figures in average weighting out of 100)*

Change Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Increased Competition	30.0	25.0	38.3	42.0	35.1
Reduced Volume per Variant	4.4	8.3	4.6	3.0	4.7
Reduced Product Life Cycles	34.4	31.7	12.5	11.0	20.5
Increased Product Variety	10.0	11.7	14.2	11.0	11.9
Number of Optional Extras Demanded	6.7	3.3	3.8	-	3.4
Increased Quality Requirements	13.3	20.0	20.8	28.0	20.8
Others *(see Note)*	1.1	-	5.8	5.0	3.5

Note: *Others included "flexibility/volume changes", "technology/product performance" and "environmental legislation".*

When asked, in Question 5, whether their companies have a documented manufacturing strategy, the responses were quite varied across the four industries. In fact, a surprisingly small proportion across all sectors possessed such a strategy, ranging from 67% on electronics to only 30% in carpet manufacturing (Table 6.6). Of those companies who possessed such a statement, there was roughly a half and half split between those who presented a target-orientated, quantified manufacturing strategy, and those who reported a qualitative, less specific, mission statement- type of manufacturing strategy. The responses to this question indicated practitioners lagging behind the widely publicised prescriptions for manufacturing strategy such as the "order-winner" type strategies suggested by Hill

(1993) and also indicated a failure to follow any coherent methodology for manufacturing strategy formulation such as that provided by the Cambridge Group (DTI, 1988).

Table 6.6: Companies Possessing a Documented Manufacturing Strategy

	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Percentage with Documented Manufacturing Strategy	67%	50%	50%	30%	49%

Whereas many works in the literature have considered the factors to be considered in manufacturing strategy formulation, rather less has been said of exactly who is, or should be, involved in this process. Question 6 addresses this issue by considering which functional managers become involved in the process of manufacturing strategy formulation, and at what level in the organization are they drawn from. Table 6.7 shows that the Manufacturing Director (or equivalent) has the greatest involvement, and this was fairly consistent across all industries and individual firms. Three other interesting, and less predictable, observations can also be made. Firstly, there was a high degree of involvement of the Finance Director in both the electronic assembly and electrical engineering companies, and certainly more so than in the other two sectors. No apparent reason can be found for this from the case study evidence. Secondly the Chief Executive had a larger part to play in electronic engineering and carpet manufacturing firms. Again, no cause for this has been identified. Finally, there was a higher degree of involvement of non-director level managers in manufacturing strategy formulation in the electronics and mechanical engineering industries than in the other two sectors. The reason for this appears to be different in both cases. The case study investigations in the electronics industry identified a greater involvement of lower-level employees generally in decision making than in the other three industries. The fact that middle-ranking managers from a range of functions take a more active part in strategy formulation is, therefore, not surprising against this backcloth. The reason for a higher involvement of production and engineering managers in the mechanical engineering sector has been tied down to quite another phenomenon. In these more traditional engineering firms production operations were generally perceived as more technological and technical in nature than in the other three industries. Under such circumstances, it is more likely that decisions on production strategy rely heavily on the input of middle-ranking production/engineering specialists.

Table 6.7: **Involvement in the Formulation of Manufacturing Strategy** *(Figures in average weighting out of 100)*

Director/Manager	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Chief Executive	5.6	24.1	7.9	20.0	13.2
Manufacturing Director	27.2	34.5	36.3	45.0	36.1
Finance Director	17.2	20.7	5.8	7.0	11.3
Marketing Director	-	6.9	2.9	7.0	4.0
Engineering Director	-	3.5	9.2	8.5	5.8
Other Director	4.4	-	-	-	1.1
Production Manager	18.3	3.5	19.6	8.0	13.5
Engineering Manager	18.9	5.2	17.5	4.5	12.3
Other Managers	8.3	1.7	0.8	-	0.8

When asked where the greatest priorities lie in manufacturing there was a high degree of uniformity across the four industries (Table 6.8). Once more costs and quality achieved the highest weighting, with electronics assembly and electrical engineering emphasising quality more, whilst mechanical engineering and carpet firms placed more emphasis on costs.

As a supplement to question 7, question 8 asked respondents whether their specified objectives for manufacturing were mainly quantitative or qualitative in nature. Table 6.9 shows that there was virtually a 50/50 split in responses: 49% of firms said their manufacturing objectives were quantitative in nature, 51% said qualitative. The mechanical engineering firms tended more towards quantitative objectives (67% of respondents) whereas electronics producers were the converse, 67% indicating mainly qualitative objectives. The other two industries were somewhere between these, with a more equal division between quantitative and qualitative objectives.

Table 6.8: **Priorities within Manufacturing** *(Figures in average weighting out of 100)*

Factors	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Costs	24.4	27.5	34.2	34.5	30.8
Machine Productivity	3.3	2.5	10.8	9.0	7.2
Labour Productivity	9.4	6.7	8.3	4.5	7.3
Product Quality	30.0	32.5	19.6	28.5	26.6
Service and Response	16.7	29.2	10.8	12.5	15.7
Inventory/Stock Levels	7.8	1.7	8.8	5.5	6.5
Production Yields	6.1	-	6.3	5.0	4.9
Personnel Development	2.2	-	1.3	0.5	1.1

Table 6.9: **The Nature of Manufacturing Objectives** *(Figures in percent)*

Nature of Objectives	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Mainly Quantitative	33%	50%	67%	40%	49%
Mainly Qualitative	67%	50%	33%	60%	51%

The survey questionnaire thus far concerned the market, environment and strategic aspects of manufacturing and the ways in which companies seek to evaluate their performance in response to these demands. Questions 9 to 12 then asked respondents to provide information concerned organization for production and the nature of their operations and structure. Question 9 asked respondents to indicate the proportion of their operations that fell into the standard categories of production types. The responses varied, as might be expected, from the different industrial sectors (Table 6.10). Electronic assemblers tended to categorise themselves as small batch producers, whereas electrical engineering firms tended to rely on flowline manufacturing. The responses for mechanical engineering and carpet manufacturing were somewhat similar: a tendency towards large batch production and an element of process manufacture, particularly in the case of upstream operations. Overall the results concerning the distinctive nature of production operations shows a good spread of different facility types: desirable when testing the generic applicability of any process design model.

Table 6.10: Nature of Production Operations *(Figures in average weighting out of 100)*

Type	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
"Make-to-Order" Jobbing	17.8	5.0	11.7	8.5	11.2
Small Batch	51.1	16.7	26.7	13.0	27.3
Large Batch	4.4	25.0	34.2	52.0	30.3
Mass Manufacture	6.7	-	7.9	-	4.2
Continuous Flow	16.7	53.3	8.8	10.5	18.4
Process Manufacture	3.3	-	10.8	16.0	8.7

Table 6.11: Degree of Vertical Integration *(Figures in percent)*

Degree of Vertical Integration	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Low	53%	82%	-	20%	31%
Medium	44%	12%	29%	30%	30%
High	3%	7%	71%	50%	39%

When asked about the degree of vertical integration there were, once more, noteworthy differences between the selected industries (Table 6.11). The electronics and electrical engineering firms (particularly the latter) tended towards a low degree of vertical integration, whereas carpet producers and, especially, mechanical engineering firms in the survey could be characterised by a relatively high degree of vertical integration. Again the overall average figures show a proportional spread of production operations ranging from those with low to those with a high level of vertical integration within their company. Taken together questions 9 and 10 illustrate the wide variety of production types characteristic of different sectors of industry. In such circumstances very detailed generic models to cover the vast array of physical system types and choices are difficult to envisage, hence supporting the view that any model of production systems design needs to concern itself more with the processes of design and decision making rather than reference to specific physical system design choices.

Previously questions 1, 2 and 5 (Tables 6.2, 6.3 and 6.5) respectively explored the main determinants upon the development of new products, the formulation of marketing strategy and the running of manufacturing in recent years. Question 11 then asked respondents to indicate the major factors stimulating the need to design new production systems or to redesign existing facilities. The results in Table 6.12 enable us, therefore, to explore the perceived determinants on the process of production system design.

Table 6.12: **Factors stimulating the need to Design New Production Systems/Redesign Existing Facilities** *(Figures in average weighting out of 100)*

Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Changes in Product Market	14.4	10.0	2.5	9.5	8.5
Changes in Customer Needs	18.9	20.0	13.8	16.5	16.8
Competitive Threat	22.2	5.0	17.1	28.0	19.3
New Products	24.4	10.0	20.8	6.0	16.0
Advances in Product Technology	15.6	17.5	14.6	3.0	12.2
Advances in Manuf'g Technology	4.4	20.8	31.3	37.0	24.6
Others *(see Note)*	-	16.7	-	-	2.7

Note: *__Others__ included "quest for improved quality" and "quest for reduced cost".*

The picture revealed by these results is one of multiple determinants upon the process of system design, where no single factor is seen as predominating over others. Most interesting is the variations between sectors. For example, product related factors such as "new products" and "advances in product technology" is the major determinant in the electronics firms accounting for 40% of influence, whereas the carpet companies surveyed show these factors as the least important factors, even when taken together, accounting for only 9% of influence. Conversely, the carpet manufacturers (and the mechanical engineering firms) show "advances in manufacturing technology" as being the major stimulant, whilst electronic assembly firms considered this to have only 4% influence. In conclusion one can say that whilst all sectors consider there to be multiple factors stimulating the need for new production facilities, the design of production systems in the electronics industry tends to be product-orientated whereas the carpet manufacturing and mechanical engineering industries are more process orientated.

Table 6.13: Organization Structure for Manufacturing *(Figures in percent)*

Characteristics	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
5-6 Levels	22%	33%	42%	20%	30%
3-4 Levels	67%	67%	50%	70%	62%
< 3 Levels	11%	-	8%	10%	8%
Separate Systems Design and Production Function	33%	33%	17%	60%	35%
Separate Product Design and Production Function	56%	83%	67%	50%	62%
Product-Focused	67%	67%	33%	20%	43%
Process-Focused	22%	33%	58%	80%	51%
Matrix	33%	33%	25%	20%	27%
Divisional	11%	33%	58%	30%	35%
Single Site	44%	50%	33%	50%	43%
Multiple Site	44%	50%	42%	50%	46%

This product-process orientation argument is supported by the results shown in Table 6.13 which summarises the responses by sectors when companies where asked to describe their organization structure. Two-thirds of electronic assemblers and electrical engineering companies described their organization structure for manufacturing as being product focused, whereas a third or less of respondents in the mechanical engineering and carpet firms answered this way. Conversely only a small proportion of electronics/electrical firms saw their structures as process-focused versus a figure 80% and 58% for carpet manufacturing and mechanical engineering companies. Otherwise the responses to the question on organization structure in the survey are rather uniform although mechanical engineering companies tended to have more management levels, tended more readily to integrate their systems design and production functions, and were more likely to be organized along divisional lines when compared with the other three sectors. Also noteworthy was the fact that electronic engineering companies appeared more likely to dislocate their product design and production functions than companies in other sectors.

Question 13 of the survey considered the use of temporary and/or multi-disciplinary teams for the design of production systems. The results in Table 6.14 once more show a spread of responses, but what one can say is that the majority (ie: 70%) of the firms surveyed do, at some time, use a multi-disciplinary team based approach to production systems design, although the mechanical engineering sector seemed less liable to do so than companies in the other three sectors.

Table 6.14: **Use of Temporary Design Teams/Interdisciplinary Task Groups for New Production Systems Design** *(Figures in percent)*

Use of Teams	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Frequently	33%	50%	-	30%	24%
Sometimes	33%	33%	58%	50%	46%
Never	33%	17%	42%	20%	30%

Questions 14 and 15 addressed the issue of justifying investment in new production systems. Question 14 asked respondents to indicate which benefits are most frequently quoted when justifying new production facilities. "Cost savings" was given the highest weighting by respondents in all four sectors and, overall, was seen as being over twice as important as for any other category of benefits. The conclusion, therefore, is that financial considerations taken priority over other factors in practice when justifying investment in new systems. The overall figures however do mask some differences between individual firms. For example two companies, one a Japanese company and the other having a Japanese parent, gave "cost savings" a zero-weight. Although this is difficult to believe in actual practice (do survey responses always give a true representation of reality?), it does show a considerable difference in emphasis between firms with varying management styles, from what Hassard (1988) has termed a "financial control" management style on the one hand to one based upon "strategic response" on the other.

Table 6.15: **Quoted Benefits when Justifying New Production Facilities** *(Figures in average weighting out of 100)*

Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Cost Savings	38.9	46.7	35.8	39.0	39.2
Market/Customer Requirements	16.7	9.2	19.2	22.0	17.7
Quality Improvements	20.6	19.2	13.3	14.5	16.4
Inventory Reductions	11.7	13.3	11.3	6.5	10.4
Improved Efficiency	8.9	10.8	19.2	16.5	14.6
Improved Working Conditions	3.3	0.8	1.3	1.5	1.8

Finally, and most illuminating, improved working conditions received a very low priority: only 1.8 weighting out of 100 overall, and no more than a 10 out of 100 weighting in any individual company. Given the widely accepted argument of the Human Relations School and, in particular, the socio-technical paradigm, that improved working conditions are a positive determinant upon manufacturing efficiency, the results of the survey are notable. They show that financial considerations absolutely predominate over and above human and work organization factors, even in a survey where respondents might feel tempted to present a more "humanistic" image of their company.

In anticipation that financial matters would predominate when quoting benefits for new systems, the survey then asked what measures were used by companies for appraising proposed investments in new production facilities. The results show that the simplest measure, that of pay-back period (PBP), was uniformally used as the main measure across all four sectors (Table 6.16). This said, the responses from individual companies show that 8 out of the 37 companies surveyed relied 100% upon the more comprehensive discounted cash flow methods of internal rate of return (IRR) or net present value (NPV). One company cited Return on Investment (ROI) as an important measure: it was an oversight when the questionnaire was developed that ROI was not included and it may well have more important than is indicated in these results. Despite the attractions of PBP in terms of its simplicity and risk aversion, it was somewhat surprising and, it might be said, disappointing, that other measures which consider returns on investment over the life cycle of the facility seem, in most companies, to hardly ever be used. This seems indicative of the widely publicised short-termism rife amongst UK companies and financial institutions when considering manufacturing investment.

Table 6.16: **Measures used for Investment Appraisal for New Production Systems** *(Figures in average weighting out of 100)*

Appraisal Measure	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Pay-Back Period	68.3	66.7	62.5	80.0	69.3
Internal Rate of Return	31.7	25.0	29.2	16.0	25.5
Net Present Value	-	-	8.3	4.0	3.8
Return on Investment (ROI)	-	8.3	-	-	1.3

Question 16 moved on to consider exactly which people within the organization actually *participate* in production system design projects. The results (Table 6.17) show that engineers and technical staff are the prime players in all four sectors, thus demonstrating that production system design activities are seen, primarily, as technical projects.

Somewhat surprising is the low recorded participation of production managers in design: only 28% in total. Again the figures mask some wide differences between individual firms. It seems that some rely almost entirely upon the technical staff in their organization for new facilities design with very little input from other members within the organization. However a notable few companies had a wider participation from different functional areas. It would seem that most companies see system design as a technical activity, whereas some see it more as a combined technical and organizational change process requiring involvement from a number of interested parties. Finally it is interesting to note the high participation of board level directors in system design in the carpet manufacturing industry, indicative, no doubt, of the very hands-on management style detected in the case studies in Chapter 5.

Table 6.17: **Participation in Production System Design Projects** *(Figures in average weighting out of 100)*

Employee Group	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Board Level Directors	1%	2%	4%	25%	8%
Finance Personnel	1%	2%	5%	4%	3%
Engineers/Technical Staff	61%	66%	59%	40%	55%
Senior Production Managers	16%	21%	22%	24%	21%
Junior Production Managers	9%	7%	6%	5%	7%
Production Supervisors	9%	2%	3%	3%	4%
Shopfloor Personnel	3%	2%	-	1%	1%
Others *(see Note)*	-	-	1%	1%	0%

Note: *Others included "Quality Manager" and "Marketing Staff".*

Question 16 above considered the participation of different managers in the system design process. Question 17 then went on to enquire who, from the list above, had primary *responsibility* for: (a) day-to-day management of systems design projects; (b) decisions concerning expenditure; and (c) decisions concerning physical systems. Table 6.18 shows that 78% of companies overall stated that engineers and technical staff had a leading role in the day-to-day management of projects: other personnel had very little responsibility in this area. However, in relation to responsibility for making expenditure decisions, engineers/technical staff had little responsibility (Table 6.19). 68% of firms surveyed indicated that board level directors had primary responsibility following by 46% stating finance personnel and 41% senior production managers. Primary responsibility for making decisions on system designs, however, fell once more to the engineering and technical staff (89% of firms) followed by senior production managers (49% - see Table 6.20).

Table 6.18: Primary Responsibility for Day-to-Day Management of Systems Design Projects *(Figures in percent)*

Employee Group	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Board Level Directors	-	-	8%	30%	11%
Finance Personnel	-	-	8%	-	3%
Engineers/Technical Staff	100%	83%	58%	80%	78%
Senior Production Managers	11%	17%	42%	40%	21%
Junior Production Managers	22%	17%	8%	-	11%
Production Supervisors	-	-	-	-	-
Shopfloor Personnel	-	-	-	-	-

Table 6.19: Primary Responsibility for Expenditure Decisions *(Figures in percent)*

Employee Group	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Board Level Directors	67%	50%	50%	100%	68%
Finance Personnel	56%	67%	42%	30%	46%
Engineers/Technical Staff	22%	-	25%	-	14%
Senior Production Managers	33%	50%	50%	30%	41%
Junior Production Managers	11%	-	-	-	3%
Production Supervisors	-	-	-	-	-
Shopfloor Personnel	-	-	-	-	-

Table 6.20: Primary Responsibility for Physical System Decisions *(Figures in percent)*

Employee Group	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Board Level Directors	-	-	25%	40%	19%
Finance Personnel	-	-	-	-	-
Engineers/Technical Staff	78%	100%	92%	90%	89%
Senior Production Managers	44%	67%	50%	40%	49%
Junior Production Managers	22%	-	-	-	5%
Production Supervisors	-	-	8%	-	3%
Shopfloor Personnel	-	-	-	-	-

Tables 6.18 to 6.20 show that areas of responsibility for different elements of the systems design process are markedly similar across the four industrial sectors with one notable

exception. Once more the role of board level directors in production system design activities was far greater in the carpet manufacturing industry than others to the extent that 40% of carpet producers indicated that directors had a leading responsibility for making decisions on physical system (Table 6.20). This again demonstrates the norm in this industry of directors being involved with operational decision making.

When considering the design, operation and evaluation of production systems it is important to understand the cost structure of manufacturing operations. Respondents were therefore asked to state the cost breakdown for their operations in terms of labour, materials and overheads. The results in Table 6.21 show that materials on average accounted for 57% of total manufacturing cost for those companies surveyed. Their are, however, differences between industrial sectors. Electronic assembly and mechanical engineering firms have a very high materials cost content in relation to labour costs, whereas electrical engineering and carpet manufacturing companies have a relatively larger labour content: in fact labour costs in the carpet manufacturing sector were higher than material costs as a proportion of total costs. Given these differing cost structures, it might be expected that quite different performance measures might be used to assess performance. This will be returned to later under question 22 (see Table 6.26).

Table 6.21 **Cost Breakdown for Manufacturing** *(Figures in percent)*

Cost	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Labour	12%	28%	15%	40%	23%
Materials	74%	54%	62%	36%	57%
Overheads	14%	18%	23%	24%	20%

The literature review in Chapter 4 covered, in considerable detail, many of the contemporary philosophies, concepts and technologies now widely adopted and used within manufacturing operations. Question 19 provided respondents with a list of a number of these (see Table 6.22) and asked whether they were employed within the respondents own company. The results of this question are self-explanatory, the figures in Table 6.22 showing the percentage of firms reporting that the concepts and technologies were used in their organization.

Table 6.22: Philosophies, Concepts and Technologies used in Manufacturing *(Figures in percent)*

Concept/Technology	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Total Quality Management	67%	67%	50%	50%	57%
Flex. Manufacturing Systems (FMS)	22%	17%	42%	-	22%
Cellular Manufacture	89%	67%	42%	10%	49%
Computer-Aided Design (CAD)	89%	100%	75%	60%	78%
Computer-Aided Manufacture (CAM)	56%	17%	58%	50%	49%
Computer Integrated Manufacture (CIM)	33%	17%	33%	30%	30%
Robotics	44%	17%	50%	-	30%
Material Requirem'ts Planning (MRP)	89%	83%	75%	60%	76%
Manufact'g Resources Planning (MRPII)	56%	33%	33%	20%	35%
Just-in-Time (JIT)	78%	100%	58%	40%	65%
Kanban	56%	67%	25%	-	32%

The results for the electronic assembly and electrical engineering sectors are rather similar, although the electrical engineering companies did appear to lag in the adoption of computer-based technologies (as one might expect, given that a number of the electronic companies were computer manufacturers). The mechanical engineering companies were not too dissimilar either, expect that their use of flexible manufacturing systems and robotics was higher (not surprising as FMS and robotic technologies lend themselves to the machine tool orientated mechanical engineering companies), and the adoption of JIT and kanban lower (again, not unpredictable given that these firms were operating in a non-assembly orientated environment). However the profile for the carpet manufacturing sector is quite different, a combination it is felt of certain concepts and technologies being deemed, either rightly or wrongly, as not appropriate (eg: FMS, cellular systems, robotics and JIT) or else that this industry is a laggard in its adoption of new technologies (eg: CAD, MRP, MRPII, etc).

The literature review also made special mention of the concept of *flexibility* and its importance in the many forms it takes to the management of manufacturing in contemporary companies. In order to determine the most important aspects of flexibility, question 20 considered the various dimensions of flexibility as identified in the literature and asked respondents to rank them in order of importance for their own manufacturing operations. The results showed the flexibility demands upon manufacturing to be quite different in the four industries surveyed (Table 6.23). The most important demands for flexibility for each of the sectors is as follows:

Electronics Assembly	1st	Speed of new product introduction
	2nd	Delivery reliability
	3rd	Ability to offer wide product range
Electrical Engineering	1st	Speed of new product introduction
	2nd	Delivery speed
	3rd=	Delivery reliability/Ability to alter volumes
Mechanical Engineering	1st	Speed of new product introduction
	2nd	Delivery reliability
	3rd	Delivery speed
Carpet Manufacturing	1st	Delivery reliability
	2nd	Delivery speed
	3rd	Ability to offer wide product range

Table 6.23: **Flexibility Demands upon Manufacturing** *(Figures are average rank positions: 1=high)*

Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Speed of New Product Introduction	1.7	2.8	3.8	5.3	3.5
Ability to Offer Wide Product Range	4.7	7.9	5.3	4.7	5.4
Ability to Offer Product Variants	4.9	5.3	5.5	7.3	5.8
Flex. of Materials Handling/Routing	7.3	5.6	6.1	6.9	6.5
Labour Flexibility: Multi-Skilling	6.2	7.4	7.3	6.9	7.0
Labour Flexibility: Mobility	6.8	5.9	4.8	5.3	5.6
Delivery Speed	5.5	3.3	4.2	2.7	4.0
Delivery Reliability	4.4	4.0	4.1	2.5	3.7
Ability to Alter Volumes	5.2	4.0	6.4	5.6	5.5
Expansion/Contract'n of Facilities	8.3	8.8	8.4	8.0	8.3

Overall speed of new product introduction achieved the highest rank, averaging 3.5 for all sectors, but ranging from 1.7 in the case of electronics assembly to 5.3 for the carpet manufacturing firms. Delivery reliability and delivery speed were also seen as important factors, but it is interesting to note how low a ranking was given to labour flexibility of any sort by respondents. Given the literature in the field of labour flexibility, and the numerous examples of unrest between management and trades unions on this matter, it is surprising what a low ranking this receives in all sectors.

Question 21 asked what formal or informal schemes are offered to employees to allow participation and awareness for employees in the companies' operations. The results in Table 6.24 show widespread adoption of the schemes listed across all sectors. However the electronic assembly and electrical engineering firms appeared to use a wider range of schemes to involve their employees than the, seemingly, rather more traditional mechanical engineering and carpet manufacturing companies.

Table 6.24: Participation and Awareness Schemes for Employees *(Figures in percent)*

Scheme	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Quality Circles	33%	33%	33%	40%	35%
Other Quality Improvement Schemes	89%	33%	83%	40%	65%
Task Forces	22%	17%	58%	10%	30%
Suggestion Schemes	100%	100%	58%	80%	81%
Regular Team Briefing Sessions	78%	100%	67%	70%	76%
Working Parties	22%	17%	58%	40%	38%
Company Newsletters	78%	100%	75%	50%	73%
Others *(see Note)*	22%	-	-	-	5%

Note: Others included "General Quality Culture/Involvement" and "Coffee Talks (all staff per week)".

The final two questions concerned the evaluation of production systems design and operation. Question 22 asked whether companies formally evaluate the success or otherwise of new production systems once installed and operating. The responses showed some evidence of such evaluations being conducted either for all or some system design projects (95% of companies - see Table 6.25). This finding is interesting as it conflicts quite markedly with the empirical evidence from the case studies, where interviewees were quite candid in saying such evaluations rarely or never take place. The validity of the responses to this question are, therefore, subject to considerable doubt as to their reliability.

Table 6.25: **Formal Evaluation of Implemented Production Systems** *(Figures in percent)*

Evaluation Conducted?	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Always	44%	17%	50%	60%	46%
Sometimes	56%	67%	42%	40%	49%
Never	-	17%	8%	-	5%

Table 6.26: **Measures used to Assess Production Performance** *(Figures in average weighting out of 100)*

Type of Measure	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Machine Efficiencies	3.3	3.3	21.7	35.0	17.8
Labour Productivity	14.4	13.3	13.6	6.0	11.7
Labour Costs	9.4	10.0	21.1	16.0	15.1
Quality/Defective Levels	30.2	27.5	20.7	14.5	22.4
Delivery Performance	28.5	34.2	9.6	17.0	20.2
Material Yields	1.9	1.7	4.6	8.0	4.4
Inventory Levels	8.5	10.0	8.8	3.5	7.5
Others *(see Note)*	3.7	-	-	-	0.9

Note: *Others included "Unit Costs" and "Daily Build versus Target".*

Finally the survey asked what measures are used to assess production performance for manufacturing. Quality and delivery were given as the primary measures of performance, followed by machine efficiencies and labour costs. Once more the validity of these responses are in some doubt as they conflict with the evidence from the case study organizations were labour productivity remained a predominant measure of performance even when, as in the electronic assembly and electrical engineering industries, labour costs form only a negligible proportion of total manufacturing costs. However, linking back the fact that the mechanical engineering and carpet manufacturing are characterised by proportionately high labour costs relative to total costs, it is interesting to note that more importance is placed on measures of labour productivity in these industries in comparison to the high material cost industries of electronics and electrical engineering production.

In summary the survey provided useful quantifiable data concerning the nature of production systems design in a total of 37 companies in the UK. So far as the author is aware this survey is unique in kind: although surveys have been conducted which address individual issues contained within this particular survey, none have been so comprehensive in terms of looking at the total design process for new production systems. The survey used the DRAMA framework as its main structure, so the questions in the questionnaire address issues contained within the ten DRAMA components of market and environment, manufacturing strategy, organization, justification, project management, physical system design, control and integration, work design, implementation and evaluation. The results above provide the raw metrics from the survey. It is the intention now to analyse these results in relation, firstly, to the empirical case study findings and then, in Chapters 7 and 8, to combine the survey findings with the case material and debates in the literature to provide a detailed analysis of production systems design and its associated decision processes in UK manufacturing companies.

6.4 Results from Case Study Companies

Responses to the survey were received from all 13 companies that comprise the case studies in Chapter 5. The results from the case study companies have been separately analysed and statistics developed in the same way as for the survey population as a whole. The question that concerned the researcher was whether production system design activities in the case companies were representative of the general situation in their industries. If so, the empirical evidence from the cases could have validity beyond the individual firms in the case studies, and so could be extrapolated to present a picture of the practice of production systems design in contemporary UK manufacturing companies.

Appendix F presents the survey statistics from the case study companies in each sector and compares the results with those for the population of 37 companies that responded to the survey. The statistics illustrate a very close relationship between the responses from the case companies and the results as a whole. It is thus claimed that the empirical evidence collected from the fieldwork within the 13 companies collaborating in the research, including the large amount of qualitative data, has some applicability beyond the specific companies concerned. Much of the remainder of this thesis therefore assumes the generic nature of both the case evidence and survey statistics across the four selected industrial sectors.

Although there was a very high association between the responses from the case companies and the overall results, there were, however, a number of notable exceptions to this rule. These, and some explanation to their cause, are listed below:

- From their responses, the case companies across all sectors would appear to be more "product-focused" (62% versus 43% overall) and less "process-focused" (23% versus 51%) in their organization structures than for the population as a whole (Table F.11). They are also probably larger in size given the high proportion of case study firms that described themselves as having "multiple-site" operations. As access to the case companies was gained on the basis of the researcher being interested in companies increasing the market-focus of their operations, and the fact that larger organizations are often easier for the researcher to access (more people equals more access points) the above observations are not surprising.

- There was a higher preponderance of case study companies using temporary and interdisciplinary design teams for new production systems design (Table F.13). Could the case selection be biased in favour of current "best practice" firms?

- Finance personnel in the case companies were seen as having less responsibility during the decision making process for new capital expenditure than for the industries as a whole (Table F.14). Could this link back to the use of an more interdisciplinary approach as mentioned above?

- The case study companies generally were more liable to possess computer-based technologies such as CAD, robotics, MRP and MRPII, although this could be a function of their size. They also appeared keener on the implementation of cellular work organizations in their production areas (Table F.21).

- The case companies in all sectors were marginally more likely to be concerned with conducting formal evaluations of production systems designs following their implementation. Again, this finding is not surprising: the case companies must have had at least some interest in the process of systems design to have allowed access for the researcher to conduct the relevant fieldwork.

The above are all general differences across the four industrial sectors. However some industry-specific differences between case companies and industry population were also observed:

- The issue of "competitive threat" both in terms of changes in the market environment in recent years (Table F.4) and as a determinant of production systems design (Table F.11) appeared to be greater in the case companies in the electronics industry than for the electronics assembly sector as a whole.

- Case study companies in the electronics assembly sector placed more emphasis on "cost savings" when quoting the benefits for new production systems during the process of justification than in the industry as a whole (Table F.14).

- The extent of vertical integration in the mechanical engineering case companies was less than for the industry as a whole.

The differences highlighted above however should not detract from the fact that there was an extremely high degree of similarity between case company responses and those from the survey population as a whole. Much of the commentary on the results within Section 6.3 therefore holds for the case study companies.

6.5 Analysis: Combining Case Study and Survey Results

The analysis of production systems design practice in the UK contained within Chapters 7 and 8 relies upon both empirical case material (largely qualitative in nature) supported by the quantified results of the survey. Both the case study enquiries and the survey questionnaire were structured around the DRAMA framework comprising ten, largely sequential, components of production systems design. Questions in the survey are related to particular DRAMA components and Table 6.27 links the ten DRAMA components with specific questions in the survey questionnaire.

Table 6.27 Relationship between survey questions and DRAMA components

DRAMA Design Component	Relevant Survey Question/s
Market and Environment	1, 2, 3, 4.
Manufacturing Strategy	5, 6, 7, 8, 18, 20.
Organization	9, 10, 12, 19.
Justification	11, 14, 15, 17b.
Project Management	13, 16, 17a.
Physical System Design	9, 11, 17c,19, 20.
Control and Integration	11, 19, 20.
Work Design	11, 20, 21.
Implementation	16, 17a, 17c.
Evaluation	22, 23.

The analysis of production systems design that follows therefore adopts the same structure as the empirical investigations and survey. Components of design in the *strategic domain* of organizational decision making are analysed in detail in Chapter 7 which explores the

the context of strategic decisions in manufacturing organizations. Those activities of the design process within the *tactical* and *operational domains* are examined in Chapter 8 which focuses in on the actual process of systems design.

6.6 Summary

This chapter has presented the results of the survey into production systems design in the four identified industrial sectors. The results from the responses to each question have been described. Although there is some variation in the responses from different sectors, this is not as marked as was originally envisaged - very encouraging given the main objective of this thesis is to develop a generic model of production systems design. What differences there are between sectors occurs more in relation to detailed systems designs, technologies and performance measures, not surprising given the differences in physical systems, cost structure, manufacturing processes and degrees of vertical integration between these sectors. On a general level, some of the most striking conclusions one can draw are as follows:

- Customer and general market factors are, far and away, the major determinants in the development of new products and the formulation of marketing strategies. However, in relation to production systems design, a number of other factors such as competitive threat, product technology and process technology are seen as equally important, although there is some variation between sectors, most notably for the electronics assembly industry in which production systems design appeared to be far more market determined.

- In all sectors, price and quality were the main competitive factors followed some way behind by delivery performance. The priorities in manufacturing reflected this with costs, product quality and service/response receiving corresponding weightings of importance from respondents. However the measures used to assess manufacturing performance did not match up neatly to the order-winning criteria and manufacturing priorities identified above with a strong emphasis still apparent towards machine efficiencies and labour productivity as key measures.

- Whereas companies talk quite frequently of manufacturing strategy, it is interesting to note that only about half the respondents to this survey stated that they possessed a documented manufacturing strategy. It is difficult to see how companies can evaluate their performance in manufacturing without such a strategy document.

- In the justification of new systems, this is heavily weighted towards cost savings into the future. Furthermore, the rather simplistic technique of pay-back period is by far the most widely used method for investment appraisal.

- Engineering and technical staff have by far the most dominant role in the system design process whether one considers systems design in terms of the participation of individuals, the management of design projects or making decisions on physical system layouts, machines and configurations. Board level directors and finance personnel, however, hold the sway when it comes to sanctioning expenditure. When viewing the statistics, it is surprising to see what little part production managers play in production systems design activities.

- When considering flexibility, it was the *response* types of flexibility (product introduction and delivery) that were given greater importance than *range* flexibility types (product variety, labour flexibility, etc.).

- 95% of respondents claimed to either "always" or "sometimes" conduct formal evaluations of implemented production systems. This is very much at odds, though, to the findings from the case studies where, when pushed, interviewees admitted that evaluations of the design of implemented systems rarely or never took place as a matter of course.

A major methodological concern of the research was the validity of combining case study and survey data in the analysis of production systems design. Two questions arise in cases such as this. Firstly, do respondents give the same response in an interview situation as they do when completing a questionnaire? Although some variation between interview responses and survey responses, most notably regarding systems evaluation, were observed, the results of the survey appear to correspond quite well to the impressions gleaned from the empirical fieldwork. It is thought that the closed nature of the questionnaire coupled with the request for respondents to attach weights to their responses (rather than merely tick a line of boxes) assisted greatly in ensuring validity and comparability of the survey and case material. The second question is whether the case study companies provide a representative cross-section of the industries within which they operate. By developing separate statistics for the 13 case companies and comparing these to the figures for all respondents it was shown that, subject to a few minor exceptions, the cases are representative of production systems design in the four selected industries. The detailed combined analysis of the survey results contained in this chapter with the case studies from Chapter 5 now proceeds, therefore, with conviction that the data collated in this research project has integrity and a high degree of generalisation within the chosen sectors of UK manufacturing industry.

Chapter Seven
THE CONTEXT OF STRATEGIC DECISIONS IN MANUFACTURING ORGANIZATIONS

7.1 Introduction

This chapter forms the first part of the analysis of the research project by evaluating the context of strategic decision making in the process of production system design. It will be argued that, in most organizations, systems design is often still seen as an activity to be undertaken at the operational level of the business, usually by technical personnel. The counter prescription to this was proposed by Skinner (1978,1985), Hayes and Wheelwright (1985), Hill (1985; 1993), Slack (1991) and others. This view is that decisions on manufacturing (including process choice) are important and will normally have a direct bearing upon the corporate performance of a production company for long periods into the future.

A number of approaches, methodologies and frameworks have been devised to link the process of strategic analysis and decision making with day-to-day manufacturing operations (most notably those provided by Hill, 1993 and DTI, 1988). Indeed, the theory and approaches advocated in such literature are now widely accepted by academics who subscribe to the manufacturing strategy paradigm. In consequence academic and training courses on operations, particularly those for practising managers, frequently comprise a high manufacturing strategy content and, in the author's experience, are well received by course participants. However, throughout industry generally in the UK, there still remains a lack of widespread understanding of the process of translating strategic decisions into manufacturing (ie: "shopfloor) operation. This problem was particularly well illustrated in the case studies contained in Chapter Five where, despite apparent market demands for flexibility, quality and response, companies still persist in using cost and productivity related measures as the key performance indicators. The survey results in Chapter Six also indicated the lack of involvement of senior managers in the production system design process: senior managers usually devolved strategy formulation for production system hardware, control systems and work organization to technical personnel who, typically, have little background in management, organization and business generally.

This chapter explores the relationship between corporate strategy and manufacturing decisions using the DRAMA model and, more specifically, the components of the *strategic domain* of decision making, as the framework of analysis. The purpose of the chapter is two-fold: firstly, to explore the nature of senior management decision making in relation to production system design choices by reference to the literature, case studies and survey results; secondly, in using the DRAMA model as the framework of analysis, its application as an analytical tool for evaluating strategic production design decisions will be tested. Following a general discussion on the nature of strategic decision making the four components of the strategic domain, namely Market and Environment, Manufacturing Strategy, Organization and Evaluation, will be explored in detail. Finally the summary will conclude the major findings with reference to the nature of strategic decisions in process choice and the robustness of the DRAMA model as an analytical tool. Chapter Nine will use the outcome of this analysis to develop a refined DRAMA model.

7.2 The Nature of Strategic Decision Making

The term "strategy" is perhaps too widely and loosely used by academics and practitioners alike. Indeed, in an invited lecture at Keele University in 1993 Alan Brown, Treasurer of Alcan (a major international aluminium producing company), who has responsibility for capital investment appraisal said that the word "..... strategy can often act as an invaluable cop-out: when the investment for a capital project proposal cannot be fully justified on purely financial grounds, and when all else fails, those seeking capital expenditure will say the project is important because it is strategically important to the company's future well-being[1]." The message here is that what some people see as strategic, others would disagree, and in most cases managers are quick to justify their actions under a smoke-screen of strategic intent. Whereas all managers talk about strategy, are their actions really strategic? So what exactly is implied by the term "strategy" in practice?

Some writers have inevitably attempted to define strategy and so we have examples such as those given below.

> "..... strategic simply means important, in terms of the actions taken, the resources committed, or the precedents set."
>
> (Mintzberg *et al*, 1976)

> "A strategic decision is one in which those who are involved believe they will play a bigger rather than smaller part in shaping what happens for a long term afterwards."
>
> (Hickson *et al*, 1985)

So the key point about strategic decision making is that is in some way important to the organization, and long term in nature. As a consequence the process of strategic decision making is highly complex, variables for consideration are dynamic and subject to change, and the outcomes are often uncertain. Hill, seeing production system design as a long term strategic decision, commented on this complexity, indicating that:

> "Corporate decisions on process choice entail going through the initial conceptualisation, justification and, finally, implementation of the procedures. ..... There are no short cuts. Understanding the complexity of a business and determining the strategic direction so necessary for its success are by-products of hard work and basing decisions on informed insights."
>
> (Hill, 1993)

[1] Comments made by the Treasurer of British Alcan, Alan Brown, at a presentation given to MA students at Keele University, 22 November 1992.

In contrast to this many people take a rather simplistic view of the process of strategic decision making. For example Pollert (1988; 1991) in her criticisms of Atkinson's (1984) "flexible firm" model argued that there was no evidence to support the view that the model, which details the development of a core and periphery workforce, represented a strategy embarked upon by Personnel Managers in industry because there was no conscious decision evident to adopt in the cases she researched. This represents a rather static and simplistic view of strategy formulation: that strategy results only as a consequence of deliberate and directed action (see Procter *et al*, 1992; 1994). Mintzberg, on the other hand, sees the process of strategy formulation in a more complex way. He argues that, in most cases, it should be seen as a long term and evolutionary process possessing little real structure.

Strategy, in the dominant Western business paradigm that has developed since the Second World War, has tended to be seen as something Marketing, Sales and Accountancy people are involved in because they typically have more capability and opportunity for making radical change. Manufacturing managers, in contrast, frequently need to make a long series of incremental changes which can be seen as more appropriate in the organizational cultures and structures in which they operate. The Mintzberg and Hickson *et al* view is, however, that under an evolutionary strategy these series of small steps can, and frequently do, amount to strategic direction. The continual improvement process inherent in the kaizen approach of Japanese and an increasing number of contemporary Western manufacturing companies is endemic of such strategy (Imai, 1986).

The picture that emerges of strategic decision making is one of a continuum ranging from radical large-change decisions and actions at the one extreme to small step incremental change at the other, with combinations and degrees of the two in between. It is the radical change strategies, often crisis-led or as a result of a change of management personnel, that attracts the media attention. Hence the plethora of management texts on the shelves of book stores written by successful business people who describe how they did it, and how you might replicate their success. The tendency of media attention to be drawn to decisions to establish factories in new locations and, conversely, those to close existing plants is again indicative of the attention naturally drawn to radical decision making. However evolutionary change over the longer term will not grab the same attention. The decision sequence that prompts this change is no less strategic in nature when taken as a whole, but is not commonly recognized as so, even though it is more liable to amount to the ordered change strategies most often appropriate in the manufacturing context.

Incremental and evolutionary strategy is also liable to be less top-management determined. It allows for the bottom-up inputs and influence of manufacturing personnel to the wider corporate debate within the organization. Therefore, in order to develop an understanding of manufacturing in the strategic context, it is important that we should understand more about the top down translations of strategic intent into production system design decisions and the two-way interaction of ideas and decisions between the strategic domain of the organization and the operational activities. This project has found that existing theories of decision making do not address these issues of translation and interaction between strategy formulation and operations. Given that many manufacturing strategies result from a long term evolutionary process rather than deliberate and explicit formulation at a single point in time, this suggests a substantial gap in the literature on manufacturing strategy. The rest of this chapter will therefore explore the process of strategic decision making with particular reference to the design and development of production facilities, and so examine the inputs, influences and attitudes inherent in strategy formulation within those companies studied and surveyed.

7.3 The Environment

The first component of DRAMA is that of Market and Environment. For the purposes of this analysis market and environment have been divided. However this does not mean that the two are mutually exclusive: rather that the market is one, if not the most important, element in the environment for competitive companies. So the environment in a general sense is firstly covered followed by some more specific observations on market influences upon the design of production systems.

The environment constitutes a wide range of factors including the market (including customers), the competition, product and process technologies outside the organization, social, governmental and legal aspects, not to mention the increasing importance of environmental "green" issues. A company's environment is frequently seen as being for senior management consideration, but in practice the organization interfaces with the environment at all levels in the organization: consider, for example, the engineer conversing with prospective suppliers in the purchase of new equipment, the sales administrator dealing with customer enquiries and the production controller expediting orders in the factories. However the interpretation and response to the environment is at its most critical in the strategic domain of the business. It is here that decisions will shape the company's operations, performance and image for a long time into the future.

Many of the companies visited during the course of the project were able to demonstrate ways in which they had analysed the environment within which they operate. Two separate, but in many ways interrelated, methods used for environment analysis were "benchmarking" and "surveys". Benchmarking, in one form or another, was used to position the firm's operations versus its competitors across a number of key determined criteria chosen by the company in question. Thus it enabled firms to identify areas in which they were particularly strong (distinctive competencies), areas in which they performed comparatively poorly and, consequently, enabled them to develop strategies in order to match or better the competition. A major difficulty of the benchmarking approach, however, was the question of how to gather data on competitors and, even when this has been accessed, how to compare data and values which may have been collected under different definitions and assumptions. Environmental surveys where also widely used as an efficient way to gauge external factors impinging on the company. Going under various names, but most commonly called "customer" or "customer-needs" surveys, the approach adopted was to send a questionnaire to relevant external parties asking them to identify and prioritise their requirements from the company and/or to rate the company's performance across a range of variables. Most often the views of customers were canvassed and, given that many were also supplied by competitive firms, the company could ask respondents to rank their performance against competitors. The general survey of the environment could therefore be linked, and provide data for benchmarking purposes.

Methods such as benchmarking and performance/needs surveys have obvious benefits for a firm, and the results were communicated in some way within the organizations studied to increase external awareness. They also formed an important input to the strategy formulation process at the corporate level of many companies, most notably the market strategies. However, the extent to which they were useful for guiding production system design was not apparent. There once more seemed a difficulty in associating external competitive and customer factors to the design or reconfiguration of production systems. Although providing useful data for determining manufacturing strategies, particularly in the identification and distinction of "order-winners" and "qualifiers" (Hill, 1993), there was little evidence that such strategies easily translated into an effect upon the design process: indeed there was a definite and pronounced lag in many of the companies studied between new strategies and the redesign of existing, or introduction of new and more appropriate production systems. The timing of new design initiatives therefore appears to be a key factor in the success or otherwise of system design, and is something to which we will return later in this section.

The survey provided some interesting results concerning companies interaction with their environments. In particular it confirmed the view held that the most critical environmental interaction a company experiences is in the design and tendering of products in the market. The survey asked respondents to prioritise the major influences upon the process of new product design and development in the organization[2]. The responses were strikingly consistent not only across the four manufacturing sectors chosen, but also across companies in each sector. The results showed that the main stimuli was "customer and/or market demand" which, overall, accounted for two-thirds of direct influence (63.5% of total influence). The issue of competitive threat was the second largest influence (18.7%) followed by product technology (11.6%) and then, finally, process technology (6.2%). This finding suggests the desire of companies to be market-driven, rather than technology-led in their operations and, by extension, in the design of appropriate production systems.

2 See Table 6.2.

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dominant forms of strategies. The view was expressed, though, from those case companies who had asked a similar question as part of a "customer needs" survey that the response one gives in a questionnaire is often different from what one practices. Most significantly, even though quality is often quoted as the main factor, the reality is that many purchasing decisions in the UK continue to be based on price with the vendor often playing one supplier off against another.

The most significant changes in the market and environment affecting manufacturing over recent years were listed as increased competition (35.1% weight), increased quality requirements (20.8%) and reduced product life cycles (20.5%). However the responses to this question were significantly different for some of the industrial sectors identified. The electronics assembly and electrical engineering companies identified product life cycle reductions being most significant, at the expense of increased competition. This indicates an increased awareness of the time factor: the need to react and respond quickly to the rapid changes in product technology in these industries. This was borne out in the case study observations: far more attention to collapsing product introduction times and engineering change management was apparent in these companies.

Synthesising the above, it would appear that companies adopt established structured approaches to the analysis of the market and environment in order to formulate their market strategies. It also appears that companies, and the people within these firms, are now quite often familiar with the needs of the customer and, but to a lesser extent, how their company ranks in comparison with the competition. However there remains very little awareness concerning how to reflect strategies in the external market with the internal operations of the firm. The framework provided by Hill (1993), which pivots around the understanding of how one's products win orders in the market, would seem to offer useful guidance on how the interlink corporate, marketing and manufacturing strategies. However, the evidence from most of the cases presented was that market strategies and strategies for other functions in the business, including manufacturing, are more often that not formulated and implemented in isolation. As well as a general lack of coordination and mutual support, these separate functional strategies can often conflict and act against one another.

It is therefore to the issue of manufacturing strategy we now turn in order to determine how companies might be able to forge a proper link between markets and manufacturing.

7.5 Manufacturing Strategy

The literature on manufacturing strategy was reviewed in some detail in Chapter Four. However, contrary to the views of many others, the view is held here that the main problem is not in the lack of theoretical frameworks and practical approaches in the literature; rather that dissemination of these has been poor. The literature generally acknowledges that managers should understand the basis of competition and where value in the product is most appreciated by customers in order that they might develop strategies for manufacturing which relate, support and are appropriate given the corporate objectives and market strategies of the firm. This is nowhere better articulated than in the Hill framework with the concepts of order winners and order qualifiers. When asked to define their manufacturing strategy, respondents in the case study companies often found this very difficult. Likewise the responses given to the same question in the survey indicated a lack of consistency between the market factors and the aims of manufacturing. One concludes from this that either companies did not in fact possess a stated manufacturing strategy (indeed, 51% of companies in the survey admitted to not having a documented strategy) or, if they did, it was probably shut away and not often referred to rather than being imprinted in the mind of managers.

Another factor emerging from the literature is a general consensus that manufacturing strategies should, as far as is possible, be stated in such a way that subsequent performance can be objectively measured against the targets set. However, once more the evidence from companies visited and surveyed was disappointing. Where strategies were stated, they often lacked clarity and objectivity. Commonly they were poorly expressed in the form of a mission such as "To become a world class manufacturer in the production and supply of *(product)*", and therefore often totally incapable of measurement. To support this observation, the survey found that only 49% of companies stated manufacturing objectives in quantitative terms, whereas the other 51% used mainly qualitative criteria. In addition, these vague statements of strategy seemed incommensurable with the market and environment within which the company operated. In the above example, it was difficult to comprehend why the company wanted to be the best in the world when it was clearly a small player who supplied a rather localised market.

When asked where the main priorities lie within manufacturing operations the survey showed a weighting of 30.8 out of 100 for "costs" and a figure of 26.6 for "product quality". Given that quality and price were identified as the most important order winners in the survey as a whole, it appears paradoxically that companies are giving attention to the appropriate factors. However the use of the survey method as a reliable indicator of activity might once more be drawn into question here. On the evidence of the case studies, cost performance is far more likely to have explicit targets set and be objectively measured and monitored than any other factor. Managers appeared still to take their budgets, cost figures and performance versus standard more seriously than any other form of evaluation.

Table 7.1: Flexibility Demands upon Manufacturing

Rank Position	Factor (average rank)
1	Speed of new product introduction (3.5)
2	Delivery reliability (3.7)
3	Delivery speed (4.0)
4	Ability to offer a wide product range (5.4)
5	Ability to alter volumes (5.5)
6	Labour flexibility: mobility (5.6)
7	Ability to offer product variants (5.8)
8	Flexibility of materials handling/routing (6.5)
9	Labour flexibility: multi-skilling (7.0)
10	Expansion/contraction of facilities (8.3)

Another common theme in the manufacturing strategy literature is the need for companies increasingly to consider flexibility in production operations as a potential source of competitive advantage (see MacBeth, 1989 and, especially, Slack, 1991). However, whether taken to mean adaptability, responsiveness or anything else, the truth is that flexibility takes many different forms and dimensions. The survey therefore asked respondents to rank different flexibility demands upon manufacturing in order of importance. The overall results, shown in Table 7.1, show that production introduction times and delivery reliability and speed are markedly the most significant imperatives underlying calls for manufacturing facilities to be more flexible.

The findings in the survey on the question of flexibility reinforces the emerging importance of "time", both as a competitive factor and as an area for research. Collapsing of leadtimes, design-to-manufacture and order-to-receipt, is becoming a key concern of companies especially in highly competitive and dynamic markets such as electronics, as reflected in the survey where respondents from the electronics assembly sector where "speed of new product introduction" received an exceptionally low average ranking of 1.7. As a consequence the concept of "time-based competition" has, over recent years, received substantial research attention, although the majority of the literature treats the subject in a very subjective and prescriptive manner. It is here that the frameworks for manufacturing strategy can be subjected to some criticism in that time is not taken into consideration to any satisfactory extent. Many of the frameworks are structural in type: they provide a structure for the strategic analysis of manufacturing and therefore implicitly direct decision makers to what actions should be taken, but say little about timing and, more specifically, that it is normally better to take actions as soon as is feasibly possible rather than waiting. As one manager explained when discussing the adoption of cellular manufacturing and just-in-time management in his company's factory: "It's not that we do not know, or are not doing, the right things; it's just that we should have done them before. A special project team told us all about the benefits of improved work flow and inventory management over four years ago and it has been resisted right down the line since then and until now. The most successful companies in my opinion are those that get the timing right: they do the right things early on rather than later and therefore steal a lead on the others."

The preceding statement gives a clue as to how we might deal with this issue at a theoretical level. The concept of product life cycles is well accepted by managers in companies: they realize that position of a product on its life cycle curve (growth, maturity or decline) has implications for its profitability and attractiveness. Understanding product life cycles also assists in the timely introduction of subsequent models or new products by avoiding the incidence of "design gaps" (for a fuller explanation see Oakley, 1984; and Bennett *et al*, 1988).

Application of the life cycle principle to production system design (or, for that matter, organization design), however, is not well advanced. It is argued here that "process life cycles" are worthy of consideration and study in their own right (organization life cycles are considered below). One reason explaining why processes have not been identified for separate consideration is that their life is often seen as being determined by the product. This may be the case, but not necessarily. Product design changes in, say, the electronics and electrical engineering industry may demand matching changes in the design of processes (eg: surface mount printed circuit board, PCB, products required surface mount technology processes to replace the older insertion technologies). In the mechanical engineering and carpet manufacturing sectors, however, processes are in many cases able to manufacture a number of product generations without radical redesign. Lathes in a batch production environment in the mechanical engineering industry are adaptable enough to reset not just to meet the process demands across current product ranges, but also for succeeding models over time. The same is true for many carpet manufacturing processes: the same loom may operate for upwards of fifty years in some cases even though products and their technology have changed substantially.

The key is, therefore, for managers to understand not only where their products are on the life cycle, but to have an approximation as to where their facilities are on the process life curve. Critical to this is to understand the determinants of production system design changes, and the results from the survey are interesting in this respect. Overall, product and market-related factors were seen as exerting 53.5% of total influence stimulating the design of new- and redesign of existing processes, but only 16.0% was directly attributed to the influence of new products[3]. Other major determinants for change were identified as "advances in manufacturing technology" (24.6%) and "competitive threat" (19.3%). Other factors one might, in hindsight, identify include social factors, as argued by the socio-

[3] The other factors were "changes in customer needs" (16.8%), "advances in product technology" (12.2%) and "changes in product market" (8.5%). See Table 6.12 for full details.

technical school (eg: Trist *et al*, 1963; Gyllenhammer, 1977) and the development of new planning and control philosophies such as has witnessed from the early 1980s on with the dissemination of Japanese manufacturing practices such as just-in-time (Schonberger, 1982; Shingo, 1986; Harrison, 1992), total quality management (Schonberger, 1982; Imai, 1986) and "lean" production (Womack *et al*, 1990).

It is one thing, though, to suggest that companies should know where their processes are in their life cycle, quite another to provide a means by which they might do this. One solution is that the company should have in place a series of "sensors" to signal when their processes appear to be getting out of step with market requirements, customer demands, the technology available, etc. The importance of some form of manufacturing audit is important in this respect so that an accurate assessment of manufacturing performance against competitive criteria can be developed. Although not explicitly developed with the concept of process life cycle in mind, Stages One and Two of the Cambridge Group methodology of Gregory and Platts (DTI, 1988) provides a means to perform such an audit. Use of such an auditing tool will provide adequate warning of the imminent misfit between the production system and time. This should, in theory, prevent the situation being reached of the "anachronistic factory", so eloquently described by Skinner (1969; 1978; 1985), whereby the production system is simply out of touch with the requirements of the times.

With this in mind the manufacturing strategy component of the DRAMA model has been modified to highlight the importance of manufacturing audit in the management of the process life cycle. Identification of imminent decline in the effectiveness of the process has two main benefits. Firstly it can prompt the organization into the timely design of new production systems. Secondly, in the same way that facelifts to the product can extend the maturity stage in the product life cycle, adaptations and reconfigurations of the production system can extend the useful and, moreover, effective life of the process if warranted.

Finally, and in summary of this section, this project has found some major shortcomings in the manufacturing strategy process in many, if not the majority, of manufacturing companies studied. The problem, however, does not stem from a lack of guidance. It has been argued that there is no shortage of valid structures and frameworks in the literature to assist in the analysis and formulation of manufacturing strategy. These include Skinner's model (1969), Hayes and Wheelwright's "effectiveness framework" (1984), the Hill framework (1985; 1993) and the Cambridge methodology (DTI, 1988). The problem is, rather, a lack of take-up within organizations who continue to have difficulties in linking operations and their performance with the corporate and market strategies of the company. Research in the future should, therefore, be directed towards exploring ways in which theory and best practice in manufacturing strategy can be more widely disseminated throughout UK industry, rather than being directed towards the development of more models and methodologies into practice. Where some attention is needed in manufacturing strategy theory, however, is in increasing the profile of time as a factor of success. It has therefore been demonstrated how use of the process life cycle concept, coupled with the adoption of existing manufacturing audit procedures, can provide useful insights when existing production systems require redesign or replacement.

7.6 Organization Design

An important, but frequently under-estimated factor influencing the process of production system design is that of the structure and nature of the organization itself. Organization design, and its effect on performance and effectiveness, has been a subject of significant debate ever since Adam Smith argued the case for the division of labour (Smith, 1776). Chapter Four traced the history of organization design and behaviour through the influences of scientific management with functional specialisation (Taylor, 1911), Weber's bureaucracy thesis (Weber, 1947) and the influence of the Human Relations and Socio-technical Schools (Roethlisberger and Dickson, 1939; Trist *et al*, 1963; Gyllenhammer, 1977). It has been shown how alternatives to the functional and hierarchical structure have been developed and used by companies keen to promote improved communication and teamwork across the organization for the design of production systems, although more commonly for product design. These alternatives include reducing the number of management levels (flattening the structure), the integration of function to reduce the number of lines of reporting, the evolution of product-focused (as opposed process/functionally-orientated) structures, the increasingly widespread use of matrix organization, and the development of flexibility by distinguishing between the "core" and "periphery" (see Robbins, 1990; Huczynski and Buchanan, 1991; and Atkinson, 1984). It has also been identified that current practice in organization development is very much influenced by the prescriptive works of the quality management gurus including Deming (1982; 1986), Juran (Juran and Grinyer, 1980), Crosby (1979) and Schonberger (1982; 1986), the holistic term for which we may term total quality management (TQM). This section will now consider the organization design issues as they pertain and influence the subject of production system design.

A commonly recurring theme in the case studies was the desire for the organization as a whole to become more market orientated, quality conscious and adaptable to change. The adoption of flexible technology, both process and information systems, was typically seen as facilitating such development: not the rigid and hard technology of the past, but reprogrammable and communicative computer-based systems which could increase responsiveness and control. However, despite espousing the need for such changes, companies seemed still resistant to reform of the hierarchical, functional organizational structures they possessed. Inflexible and segmented forms of structures were seen to act against programmes of changes such as customer awareness training, total quality initiatives and product/process design projects, and so limit the potential benefits achievable[4].

There are two main conclusions reached in relation to organization design in the project. The first relates, once more, to the concept and issue of life-cycles; the second considers the nature of technological change and the perception of this by manufacturing organizations. As was argued above for production system design, the life-cycle concept as is usually applied to products is also applicable to organization designs. Companies often fail to adjust to new circumstances, both in the environment and also within the firm, with a change in organization structure. Most notably, they persist with functional structures despite the common need for more product-focused forms of organization. There is a time lack, often a critical delay, between identifying the need for change and taking action. Again it comes down to the matter of timing discussed above: that successful companies are not just those who launch new products are modifications of these in a timely

[4] This matches the findings in Kanter's (1984) book *The Change Masters*, where she compared the performance of companies with "segmented" structures versus those which were functionally "integrated" .

matter, but also those who not only introduce new systems for production, but also redesign their organization to better correlate with the environment and customer demands.

This issue of timeliness draws into question some of the literature that many companies now refer to in running their organization. For example Deming argued the need for quality to be managers' responsibility, described how ideas could run up through the organization whilst authority only ever should come from above, and spoke about the relationship between functions, setting up supplier-customer relationships (see Deming, 1982). However, at the time when Deming was developing his ideas immediately before and after the Second World War organizations were characterised, almost without exception, by many hierarchical management levels, functional divisions and specialisations, and by authoritarian and paternalistic management styles. The question is, therefore, whether prescriptions of the type put forward by Deming at one point in time are applicable *ad infinitum* into the future. If one considers recent trends towards a more participative style of management, reduced levels of management and the introduction of product- as opposed to functionally-orientated organization structures, one can argue that the prescriptions of Deming really belong to an earlier era in that they seek to overcome many of the organizational problems that prevailed at that time.

The second conclusion refers to the perception of technological change and its relation to organization design as perceived by many managers. There is no doubt that production system design is still viewed as a series of technical projects by the majority of managers. The survey showed that engineers and technical staff had a very high participation in production system design projects (55%) to the detriment of senior executives and other functional managers. Given the importance of many production system design projects in terms of the overall delivery of products and the capital expenditure, it is interesting to find that quality and marketing managers had only about 0.5% input to the process, whereas financial personnel were only around 3%. Respondents in the interviews in the case study companies were, in most instances, quick to acknowledge the range and importance of organizational and social issues in the design and implementation of production systems. However production system design tended to be seen as a technical project activity that often runs into organizational difficulties, rather than being viewed as organizational change in itself. Even in a company widely recognised for its successful record of organizational change, the engineering manager, talking about the very direct issue of operator training, said that new systems were costed and then "..... we just add on 10% for training whatever; we do not really evaluate the training needs".

The argument here is that if appropriate changes to the organization structures and procedures could be instigated earlier in most production system design projects, then implementation and operation of the new system would proceed more easily. This is in some way similar to the view put forward by Ettlie (1988) in proposing his principle of simultaneous design[5]. However Ettlie took rather a technologically deterministic view of organizational change: that technical change was inevitable and, more often than not, the main determinant for change, whilst the organization must respond to this. In this thesis it is argued that this may not necessarily be the case, and that technology does not usually shape organizations; rather that the organization, the market, the customer needs and/or the politics within a company will usually shape the technology chosen, including the production systems[6].

7.7 Strategic Evaluation

In Chapter 4 strategic evaluation was identified as the comparison of performance of the organization against set targets for goals, profitability, quality, service and the like. It can take two basic forms: a measurement of ongoing performance on the one hand, and the post-audit of newly implemented production systems on the other.

Evaluation of performance can be conducted performed on a general level using conventional cost and management accounting techniques but, picking up on the argument of Kaplan (1990), strategic evaluation should comprise more than this. It should be seen

[5] That is to say the simultaneous design of technology and organization.

[6] Refer to the technological determinist versus managerial choice versus radical organization theory debate where the theoretical analyses of Woodward (1965), Child (1972), Braverman (1974) and Burrell and Cooper (1988), amongst others, are contrasted.

not merely as a measurement exercise as it should provide the impetus for organizational development and change where performance is seen as unsatisfactory. The view was held that whilst organizations were keen to adopt new methods of working and philosophies of manufacture, they were slow to realign their performance measure systems and evaluation methods to appropriate them to the new circumstances. The evidence from the case studies supported this observation. Whereas managers were keen to talk about their organizations' adoption of TQM, JIT and the like, they were not so forthcoming in describing how their management control and evaluation systems had been changed. Indeed interviewees in some cases were very critical of the lack of change and some felt aggrieved that whereas strategies for manufacture stated the need for maintaining high quality levels and delivery reliability, they were still measured first and foremost by senior managers on factors such as labour costs, productivity and machine efficiencies. The development of appropriate control and performance measures is now seen as vital in the implementation of market-driven corporate strategies. There was in fact some evidence in some companies that evaluation procedures were being revised in order that they might adequately reflect the quality, delivery and flexibility, as well as the cost demands of the customer.

The second aspect of strategic evaluation is post-implementation assessment of investments in new production systems. The case evidence here appears to be somewhat at variance with the results from the survey. Whereas interview respondents said that formal evaluations of new production systems once implemented were seldom or never made, the survey results show that 95% of companies perform such evaluations at least some of the time, and 46% claimed always to perform a formal evaluation. The author has placed more credence in the case study evidence than in the survey statistics. Interviewees, when pushed, often saw post-implementation evaluations as inappropriate: "Why look back...", asked one manager "...when keeping up the pace with competitors and reacting to change in the future is the key to success?" His view was typical of those interviewed. The conclusion derived from the case fieldwork, that formal evaluations of resultant performance against the justification seldom occur, is supported by the findings of a larger study into post-audits of production investments conducted by Neale and Holmes (1988). It is concluded that managers find it tempting in a survey to give the impression that evaluations to take place, but in an interactive interview situation are not so likely to make these claims.

In summary, strategic evaluation is a more an art than a science. Although techniques are available for assessing performance and in the post-audit of process investments, there is still an element of "gut-feel" when assessing manufacturing performance versus strategic need. There are many variables to account for, and these market, environmental, competitive and internal factors are always liable to considerable change. In the literature the method of "benchmarking", where companies compare their performance to that of competitors and comparable firms, is now widely stated as a useful tool for strategic evaluation. However, the evidence from this study is that although of appeal to managers, it is not widely practised for evaluating the performance of production systems.

7.8 Summary

This chapter has considered production systems design within a strategic context and as presented a synthesis of the literature, case study evidence and survey findings for the DRAMA components of Market and Environment, Manufacturing Strategy, Organization and Evaluation. Perhaps the main finding from the above analysis is that many of the theories, frameworks and techniques for strategic management underplay the dynamics of change. By reinforcing the "time" dimension, models of strategic production management can better reflect the real-life concerns of practising managers who are always trying to balance efficiency levels that are widely accepted as coming from steady-state operations with the need to change operations to adapt to changing circumstances. Strategy is an iterative process: an analysis and assessment at one point in time may well be useless in a few months time. The post-audit of production investments may be seen as a waste of time and resources if the circumstances under which the original justification for expenditure was made no longer endure. In 1954 Drucker said that management is not really about "doing things right", but success comes from "doing the right things". In the dynamic environment in which manufacturing companies in the 1990s find themselves, these words of wisdom should now read "doing things right *at the right time*".

It has been demonstrated in this chapter that the DRAMA model does provide a valid and productive framework by which to study strategic production system design issues. It links the market, corporate and manufacturing strategy formulation processes to the tactical and operational concerns of operations managers and systems designers. The DRAMA methodology, presented by Bennett and Forrester (1993) in the *Market Focused Production Systems* book provides the manager which a structured, step-wise but iterative approach to assess the strategic factors of production and to formulate appropriate strategies in response. However the original model and methodology are considered too-stepwise and not iterative enough following the wider programme of research contained in this thesis. The adaptation of the model in Chapter 9 is intended therefore to place more emphasis on the "time" factor and the importance of "good timing" in the decision making process.

Chapter Eight
PRODUCTION SYSTEMS DESIGN AND OPERATION

8.1 Introduction

This chapter focuses on the nature of production systems design as characterised within the tactical and operational domains of the DRAMA model. A principal concern is to investigate the nature of the decision making process within each of the components of design, namely justification, project management, physical system design, control and integration, work design, implementation and evaluation. The intention is to explore the manner in which strategic decisions are translated into systems designs and operation at the operational level. The chapter, by adopting the DRAMA framework, is also intended to test the validity and appropriateness of using the model as a means of analysis. The findings are discussed in the conclusion to the chapter.

8.2 Organizational Decision Making and Systems Design

As argued in Chapter Four, there has been a general failure in the literature to effectively link strategic decisions within manufacturing companies concerning markets, corporate objectives and organization design with the systems design and operations of the firm. The corporate, market and manufacturing strategy literature is largely retained to a conceptual level of organizational decision making, whereas system design theory is often detached from the wider business concerns and retained at a methodological or technique level. The tendency has been for research to concentrate on only one level of decision making, and not address the key issue of how detailed design decisions reflect and, in turn, influence strategic decision making. The DRAMA model of production system design attempts to do this, and this chapter will consider in detail the extent to which the framework can be used to describe the pattern of organizational decision making.

Before proceeding it is worth considering some of the published work which does give some insight to how strategy and detailed design activity might be related within a theoretical framework. Firstly, Utterbeck and Abernathy's (1975) concept of innovation within their model of the "production unit" suggests that design should be considered in three interrelated areas: product, process and work organization[1]. Abernathy (1978) later demonstrated how this framework could be used within a broader context of corporate decision making for the analysis of design and development in production at Ford, US. Whipp and Clark (1986) later utilised the framework in their study of the Rover SDI design project, but also added a longitudinal dimension whereby decisions were tracked through the stages of conception, design, implementation and operation. The Utterbeck and Abernathy model, augmented with the Whipp and Clark chronology, provides an analytical means for strategic decisions to be linked to design decisions on production systems design, work organization and products. However the analyses are largely retained at a conceptual level. It would be possible to take an analysis using this framework to greater levels of detail to include specific design options and choices within production systems development, but the model provides no explicit detail on how this might be achieved.

The second relevant work here is that of Gregory and Platts in their methodology for the development of manufacturing strategies, commonly known as the Cambridge Group methodology (DTI, 1988)[2]. Whereas their framework lacks the potential for temporal analyses of production systems design contained in the Utterbeck and Abernathy model, it does provide an approach whereby broader strategic choices can be linked to specific detailed design options. Certainly managers who have used the Cambridge methodology to analyse their strategic position and develop new strategies for production systems development have been impressed by the level of detail the full evaluation entails (see, for example, the findings of Stevens, 1993). The strength of the Cambridge methodology, however, is in the guidance it provides for practitioners who wish to analyse their competitive position, and the framework is of considerably less relevant as a structure for research enquiry from an academic perspective.

1 The Utterbeck and Abernathy model is more fully described in Chapter Four.

2 Again contained in more detail in Chapter Four.

With the preceding shortcomings in mind, the analysis in the current work has explored the relationship between the various levels of decision making and the extent to which the structure of the DRAMA framework assists in conducting analysis of this. The cases, as was expected, showed some considerable disjoints between strategies and detailed design activity and operation. However use of the concept of an intermediate domain of decision making, where managers at the various levels interface with one another, was valuable in exploring the translation process from conceptual strategy to detailed design. The components of justification, project management and evaluation provided considerable insight and it was found that these could, as suggested by the original DRAMA model, be seen as the linking activities within most organizations, although the efficacy of most organizations in these areas was somewhat dubious. Each will be explored in more detail in this chapter, but first it is useful to consider some of the general findings from the survey and, particularly, the main stimuli for, and determinants acting upon, the production system design process.

The results of the survey, where companies were asked to attach weighting to the various factors stimulating the need to design new production system, were interesting in so much as they bore out some of the arguments put forward in Chapter Seven. There it was argued that managers frequently see manufacturing systems and their design as inextricably linked to products and their life cycle, whereas the evidence from the study suggests that the determinants of production system design are more varied. The overall results, derived from Table 6.12, are shown in Table 8.1. This shows that technological factors, particularly in relation to manufacturing processes, have equally as great as bearing on the design of production systems in practice as the product and market related factors. This goes some way to explaining the disjoint in the literature where manufacturing strategy theory can best be described as market-deterministic, whereas much of the traditional detailed production system design approaches are technologically deterministic. It is in relation to this that the rest of this chapter proceeds. The interface between the strategists and the technologists is explored, the ways in which a greater mutual understanding and relationship can be developed are considered and, to be summarised in Chapter Nine, the findings of this are fed into the development of the DRAMA model.

Table 8.1: Stimuli for the Design of New Production Systems

Factor	*%age Degree of Influence*[3]
Advances in manufacturing technology	24.6
Competitive threat	19.3
Changes in customer needs	16.8
New products	16.0
Advances in product technology	12.2
Changes in product market	8.5
Others (quality- and cost-related)	2.7

Each of the components of DRAMA that comprise the tactical and organizational domains of decision making are now considered in turn.

8.3 The Financial Justification of Production Systems

Justification is the process whereby the case for a new production system, or modifications of an existing one, are developed. New production systems normally involve substantial financial investment, and so has traditionally involved the use of investment appraisal techniques such as pay-back period or discounted cash flow methods (Arnold and Hope, 1990) in order to test whether the expense of developing and introducing new systems is financially viable and worthwhile[4]. However expressing a project's benefits solely in financial terms is increasingly seen as not wholly sufficient in assessing a proposed new production system's potential value to the organization. This helps to explain the "act of faith" justification of new systems observed within the case study companies, where a decision is taken to invest in new facilities when these are viewed as providing opportunities to the company, even though the outcomes are rather uncertain. Justification is, therefore, normally based upon a combination of financial arguments and more qualitative assessments

[3] The "degree of influence" in percent is taken as the respondents' overall average rating out of 100.

[4] Refer to Chapter Four for more discussion on the use of investment appraisal methods in the justification of production systems.

of business need[5], with inputs from a wide range of personnel within the organization, and not just financial people.

Whereas the justification case for new production systems is developed within the tactical domain, approval for new projects and capital expenditure of any significance will normally need to be sought from senior management. Justification is very much an essential link, therefore, between strategies and the translation of these into operation. In this context the justification process can be seen as a barrier through which only those cases for investment that show some promise and fit with overall corporate direction will pass. However it is surprising just how many system design projects proceed without the development of a capital paper to justify investment. This not only runs the risk of systems being developed, and the related energy and finances expended, which are out of step with the corporate objectives and strategies. It also poses potential problems further downstream in the design and implementation process when evaluating the performance of new systems versus the initial expectations. The capital paper used to justify the investment will establish a benchmark in terms of expected performance against which actual operations can be measured. If there are no terms of reference of this type, then measurement of achieved performance versus expectations is extremely difficult, if not impossible.

The survey provided the opportunity to test the assertions developed in the preceding two paragraphs through the collection of quantitative data concerning the stated benefits when justifying new systems, the types of investment appraisal methods used, and the type of personnel having responsibility for decisions on capital projects. When quoting benefits within capital investment papers, costs remain the prime consideration in all industrial sectors studied (around 39% of weighted importance in the justification of new facilities). It was also interesting to note that the pay-back period method was by far the most commonly used method for investment appraisal (69.3% weighted use) despite the

[5] Primrose and Leonard have conducted some pioneering work on financial justification of advanced manufacturing projects and how the intangibles might be built into a structured process of justification (see for example Primrose *et al*, 1985; Primrose and Leonard, 1986). See also Kaplan (1984; 1986; 1990).

shortcomings and overly simplistic nature of this approach[6]. The is probably indicative of the conservative view often taken of process investment in the UK, where companies tend to embark on low risk, short pay-back projects as opposed to larger, more ambitious and higher risk programmes. Finally, in relation to who makes the decisions concerning expenditure, it was apparent this was largely in the domain of board level directors, with finance personnel and senior production managers also having some significant responsibility. However it is interesting to note that engineers and technical personnel have a very small responsibility in decisions on expenditure, whereas they play a key role in managing the systems design projects and in making decisions on physical system choices. Table 8.2 summarises these results.

Table 8.2: **Involvement of Personnel in Different Stages of the System Design Process** *(adapted from Tables 6.19, 6.18 and 6.20 respectively)*

Figures refer to percent of companies responding

Type of Personnel	Responsibility for Investment Decisions	Responsibility for Project Management	Responsibility for System Design Decisions
Board level directors	68	11	19
Finance personnel	46	3	0
Senior production managers	41	21	49
Engineers/technical staff	14	78	89

Justification can therefore be seen as comprising two elements: capital justification, largely financially based and conceptual in nature, which is directed to senior managers in the organization; and detailed systems justification, technically based and directed towards engineers and systems designers. The capital justification centres around determining whether the basic concept is worthwhile, whereas systems justification, which has structural, process and technical aspects, involves the evaluation of whether a particular set of equipment should be purchased (Gerwin and Kolodny, 1992). The process of justification must, therefore, account for both of these needs. What is evident, however,

[6] See Chapter Four for a detailed assessment of the related advantages and disadvantages of the various investment appraisal techniques.

is that justification should be orientated towards the requirements of the business and tie in with corporate objectives and corporate strategy. Business orientated justification is an absolutely necessary prerequisite prior to the development of any new production system. The virtue of going through the process is:

i to clarify the worth of the new system to the business;

ii to provide information for senior decision makers upon which they can make a decision whether to accept or reject proposals for systems development and new investment; and

iii to provide "terms of reference" for the anticipated benefits against which to judge the eventual success of implemented systems.

A number of conventional investment appraisal techniques, frequently used in the justification process, have been reviewed including the "payback period", "return on investment", "net present value", "internal rate of return" and "life-cycle costing"[7]. However, in many cases, these established financial methods do not fully allow for the scale of benefits likely to accrue from large investments in advanced manufacturing technologies. Their main drawback is that they consider the value of investments merely in direct financial terms and ignore the intangible and indirect benefits likely to accrue from such effects as increased quality, customer satisfaction and reduced design and manufacturing leadtimes. It now appears that many companies, rather than merely accepting investment in advanced new systems on an "act of faith" basis, are seeking to develop justification or capital investment papers which outline both the quantitative and intangible benefits and so enable the senior decision maker to make a more balanced and informed judgment on whether to accept or reject proposals for new systems development.

The process of justification is carried out within the tactical domain of the organization and should involve interaction between strategic decision makers and systems designers,

[7] See Chapter 4.

coordinated and channelled by senior to middle level manufacturing and engineering managers amongst others. Close collaboration between managers, engineers and financial specialists should take place in the development of any capital proposal in order to establish the financial, technical and market consequences likely to arise from the design and operation of the new system. This cost/benefit information should then provide senior managers with an adequate foundation upon which they can make valid and informed decisions and judgements.

8.4 Project Management

Projects, and the need to manage projects, have always been a concern to mankind whether in civil engineering, social policy or, in the particular circumstances of this dissertation, in the design and implementation of new production systems. However organizations are now moving increasingly to a project-approach for activities which were previously subsumed within the normal span of activities and tasks for employees. This has much to do with the increasing complexity in the development of new manufacturing processes, particularly when one considers that theory and practice alike recognises the need for the simultaneous design of products, processes and work organizations (see, for example, Utterbeck and Abernathy, 1975; Whipp and Clark, 1986; and Ettlie, 1988). This complexity, and the consequence use of numerous disciplines, technologies and techniques in the development of new manufacturing processes, has resulted in the increased need for goal-oriented (hence project-type) management activities. As Stephanou and Spiegl (1992) have noted, this need has been further accentuated by the increasing market, organizational and economic pressures of completing design and implementation of new systems within a specified time frame, with specified resources and within budget.

A review of contemporary project management theory and practice has been covered earlier in this dissertation[8]. Managing projects is normally viewed in three stages: planning, scheduling and control and techniques appropriate to each stage including gantt charts,

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[8] See Chapter 4.

critical path analysis (CPM), network diagrams, program evaluation and review technique (PERT), etc., are well covered in publications on project management. This dissertation, however, has concerned itself more with the *process* of project management, from conception to completion, rather than the techniques. In this regard, and more so than choice of the appropriate technique, it was argued that the role and competence of the project manager and the management/coordination of the project team are the key success determinants in the outcome of a project. In relation to production systems design, the concept of simultaneous engineering of products and processes (Riedel and Pawar, 1991) was highlighted as a particularly pertinent consideration for the project manager and team: that the project will most likely require the services of individuals from a variety of disciplinary backgrounds and which a wide range of skills.

The observations from the case study companies bore out the perception of increased use of the project approach and increased complexity of production systems design projects as noted above. However, other than the identification of the importance of project management, the case-based research offered little in terms of quantified evidence of the nature of project management activities. it is, therefore, to the survey we must turn to derive an analysis of the current state of project management.

The process of project management through the duration of the project was the key theme in the survey questionnaire. Analysis of survey results from questions 13, 16 and 17a illustrate the following findings. Firstly there was a high frequency of companies who adopt the use of temporary design teams for production systems design projects: 24% of respondents said they "frequently" used such teams, 46% responded "sometimes" and 30% said "never". Thus 70% of the organizations surveyed relied, to a lesser or greater degree, on project-focused teamwork for the introduction of new processes rather than relying on a dedicated functional department responsible on a full-time basis for such work.

The second major finding was that production systems design projects, if one considers the involvement of personnel by functional background, remain largely as technical activities: the survey found that 55% of overall participation in design projects was accounted for by engineers and technical staff (this excludes production managers). When one considers the staff who have responsibility for managing production system design projects, the perception of these projects being technically focused is stronger still: 78% of project management over all companies surveyed was performed by engineers and technical staff. If one compares these figures with the situation for product design, where non-technical managers and marketing personnel, etc., have more participation and where it is more common to use interdisciplinary design teams and project managers from different functional backgrounds, one can question whether the design of new production systems is really as "market-focused" as many organizations claim it to be.

In synthesizing the literature and research findings, therefore, it is first important to acknowledge that effective project management and the adoption of adequate monitoring and feedback mechanisms are widely (and quite correctly) considered necessary in ensuring successful project development and implementation. Theory and practice provide a wide range of tried and tested tools and techniques for use in planning, scheduling and controlling projects and these have been reviewed within this chapter. Furthermore, the literature advocates the need for a high degree of user consultation during the design and implementation of new production systems. This is mainly because the degree of user involvement during the early stages of a project can influence the ensuing support for the project by developing a feeling of "ownership". However the reality is often some way detached from this ideal. Many companies practice a relatively autocratic style of project management, but argue this is necessary to ensure the terms of reference laid down in the capital justification paper are strictly adhered to in the design of new systems. User requirements, as a result, tend to be checked on an ongoing basis with the degree and scope of user participation in design somewhat restricted. This project teams are frequently structured around a number of functional specialists with expertise brought in as and when required from external vendors and consultants.

Given that the tools and techniques for project management are well developed and documented in the literature, the DRAMA methodology component for project management concentrated upon the process of managing a project and has provided practical guidelines for effective planning and control. A participative style of management is necessary in order for the design and implementation of market-focused production systems to be successful and readily accepted. The structure of any project should recognize the distinction between the tactical domain, where a steering committee may have responsibility for overall financial control and project reviews, and the operational domain, where individual design teams are responsible for the fine detail of systems design and implementation. Such a division of tasks results in more effective control and stimulates the alignment of project developments with corporate and business objectives.

Finally it is stressed that team cooperation, communication and effectiveness are achieved if certain favourable conditions are developed within the team structure. This calls for a balance between technical and organizational expertise, a power structure conducive to creativity, and the continued commitment of all to the development of successive systems. It is therefore essential that the effectiveness of project management practices and procedures are continually assessed and developed in order to improve the process and to ensure that future developments can be tackled with greater confidence and assurance in the mechanisms for development.

8.5 Physical Systems Design

The design of physical manufacturing systems is the component of DRAMA where least genericability exists, both between firms within an industry and, even more so, between different industry sectors. Physical systems design is truly at the operational level of decision making and can be extremely specific to an industry's or individual organization's needs. This is not to say, however, that it should be ignored by strategists or by marketing personnel: some physical facilities can involve huge investments (sometimes the largest investment within the organization) and the choice of manufacturing equipment can directly affect market performance in relation to the inherent flexibility of the production system and its responsiveness to change. Nonetheless the detailed and specific design work for physical systems remains a technical choice albeit overseen by interested parties. The survey results illustrated that engineers and other technical staff are held 89% responsible overall for physical system design decisions.

The two key themes that came through from both the case research and the survey work were that of integration and flexibility. Companies were keen to illustrate how they were integrating manufacturing hardware with design and other areas of the business through CIM. 49% of respondents to the survey said they were actively pursuing Computer-Aided Manufacture (CAM) within their organization which, in itself, is an integrating technology: if the production processes are under computer control it is not difficult, by extension, to see their future evolution to link up with CAD and create CADCAM, and to integrate with other computer-based systems within the organization. Indeed 30% of respondents quoted they were involved with the introduction of CIM. It was also widely recognized that, in order to respond effectively to the dynamic markets of contemporary industrial organizations and to produce the range of products in the varieties now often demanded, that flexibility was a key concern in the choice and introduction of new production hardware. It was acknowledged in most cases that manufacturing industry was now beyond the era of mass, economy of scale manufacture. Markets and customers now demand and expect cost effective and high quality production in small batches and with high variety and choice. The survey showed that speed of new product introduction, delivery reliability and delivery speed were the main factors creating the need for increased flexibility and responsiveness from the production system.

It is concluded, therefore, that the key concern in the development of modern manufacturing systems is achieving an appropriate balance between productivity of the system in terms of costs and efficiency and the flexibility offered to enable it to respond to changing markets, customer requirements and product designs. A valid way in managing the factory wide transition from being technology-led to market-focused is to analyse the design of the physical system at the three levels of factory, module and utility. This was demonstrated within the DRAMA design methodology by Bennett and Forrester (1993) who provided a series of generic design options for consideration by designers of physical systems.

The primary objective at the factory level is to ensure that output, productivity and service levels are maintained. Systems designers therefore need to establish appropriate designs and arrangements of modules that will promote manufacturing flexibility and responsiveness to market demand. The design of a module within the factory will obviously be greatly influenced by the product design and their associated processing requirements. Thus the variety of products catered for by the module will dictate its flexibility requirements through the combined configuration and design of storage, workstation and materials handling systems. At the utility level detailed and specific decisions are made concerning the hardware and processing kit for workstation design, storage and materials handling systems. The options at this level are multitudinous and vary considerably from industry to industry.

Some fundamental options and considerations were presented in the DRAMA methodology and some of the more common options were evaluated in the chapter on physical systems design within Bennett and Forrester (1993). From the evidence of the case studies in the four identified industries within this thesis, I still contend that this approach and the design options are appropriate across the full range of manufacturing activities. However it is impossible to be more detailed without losing the genericability of the DRAMA model.

8.6 Design of Manufacturing Control and Integration Systems

The development of appropriate manufacturing planning and control systems is a vital component in any manufacturing strategy and hence must be considered concurrently with the design and implementation of physical systems[9]. This section considers issues of operations control and the integration of the various subsystems or modules of the overall production system through computer software and physical control procedures. Effective planning and control systems results in the integration of the production management system and can improve the quality of products, shorten the manufacturing leadtime, reduce inventories, assist in increasing product variety, reduce investment requirements for plant and equipment and improve delivery performance. Although manual systems of planning and control, such as kanban systems, can be employed, the design and operation of

[9] In Hill's (1993) words, manufacturing strategy concerns not only "process choice", but also the selection of a suitable "infrastructure" for production operations.

planning and control systems is increasingly becoming technical in nature: approaches such as CIM can bring major benefits for the company, but require careful design and implementation. In such an environment, as evidenced in a number of the case studies in Chapter 5, there is a danger of systems designers going for the "technological fix"; a solution, probably off-the-shelf from systems vendors, that technologically may be sound and successful in some installations, but not particularly well suited to a specific application. In such circumstances it is important that the manufacturing planning and control system be seen as more than merely a software package, but as a wider organizational concept supporting, controlling and integrating different areas of the manufacturing process and the business as a whole.

There are various forms of inventory control systems and scheduling techniques including statistically based techniques, Material Requirements Planning, Just-in-Time and Optimised Production Technology.[10] More than merely controlling stock and sequencing job orders, the type of inventory and planning policy adopted has implications for the operation and effectiveness of the production system as a whole. This is now being more widely appreciated by managers and systems designers alike, and the concurrent development of control and integration infrastructures with physical production systems is increasing becoming the norm.

A fundamental decision must be made as to whether the manufacturing system should work predominantly in pull or push mode. In push mode this will now normally involve the use of an MRP system which plans the manufacturing and supplier orders for parts and materials. Alternatively, simpler reorder level or reorder cycle systems may be developed using statistical stock control techniques. Although beneficial in terms of scheduling and capacity management and providing a wealth of inventory information, MRP has the major problem of being poor at responding to short term fluctuations and changes in demand or unforeseen events such as machine breakdowns or cancelled orders. A pull system, based around JIT principles, will not schedule the throughput of materials in anticipation of future events. Instead parts and materials are pulled through the system of the basis of demand

[10] See Browne *et al* (1988) for a detailed description and comparative analysis of these various forms of manufacturing planning and control systems.

at the immediately succeeding operation. This should result in lower inventory levels than MRP and increases flexibility to respond to short term fluctuations. Although pull and push are different philosophies, it is now increasing common to use a hybrid push and pull system to achieve the benefits of both types of production planning and control philosophy. In a hybrid approach MRP is used for longer term ordering of material from suppliers and for forecasting likely implications of current and expected orders on the different areas of the factory, while JIT is used for short term control and pulling of materials into and within production areas.

Another important concept in control and integration is that of information. Computer technology has become an increasingly cost effective means of controlling manufacturing information and processes over the last twenty years or so (Warnecke, 1988). A key issue in the design of production systems today is how to integrate the various "islands" of computer based systems and processes. The CIM term has therefore emerged. CIM, however, should not be thought of as being merely confined to production processes. It also incorporates the full range of support activities which provide and require manufacturing information, including finance, marketing, production management, etc. This necessarily requires the development of a common database for use across the whole business which, in turn, demands data accuracy and integrity across the full range of organizational functions.

CIM encompasses a wide range of technological developments including Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), Computer-Aided Process Planning (CAPP), Computer-Aided Manufacturing (CAM) and numerical and computer numerical control systems (NC, CNC, DNC) together with the various Computer-Aided Production Management (CAPM) systems including MRP, OPT, etc. The establishment of an electronic link between design and manufacturing enables a reduction of design and manufacturing leadtimes. Herein lies the key strategic advantages of implementing a CIM infrastructure. The primary objective of CIM is to enable the business as a whole to react faster and more efficiently to the demands of markets and customers, thus facilitating the establishment of a flexible manufacturing infrastructure [Saul, 1985; Bititci, 1986]. Given the far reaching nature and consequences of its approach and objectives, there is also an argument to say that CIM should be treated as an organizational goal, in much the same way as in the case of the Total Quality or JIT philosophies.

In addition to satisfying particular needs within the organization, the application of computer technology must also enable the company to capitalise on future business opportunities. Identification of business and market needs allows systems designers to create and establish the appropriate computer architecture that effectively translates and communicates information across different parts of the organization.

In summary, the academic debates regarding the most effective means for planning and controlling production systems can also be found within manufacturing organizations where different people have conflicting views on how best to control and integrate manufacturing operations. This debate has been fundamental to the explanations given for the superior performance of Japanese manufacturing companies over their Western European and American competitors. However, there is no overriding and conclusive agreement as to what constitutes the "best" production control system. It is clearly apparent that many manufacturing companies are not so effective at controlling operations as some of their counterparts. In these companies the importance of revising and developing control systems and their integration cannot be understated; it is often the key factor in moving towards a market-orientated approach to manufacture. As the technology for CIM becomes increasingly available companies are finding it feasible to use a combination of push and pull systems and to create interfaces with other parts of the business. In this way the organization can capitalise on the benefits offered by a fully integrated system.

8.7 Work Design

If physical facilities require effective manufacturing planning, control and integration, then the need for appropriate work organization is perhaps even more critical. Without people, and their effective coordination, the best technical systems will not operate to their full potential. Hence, within the DRAMA model, work design is seen as the third component of the "operating system" in addition to "physical system design" and "control and integration". This fits well with the Hill (1993) notion of what comprises a manufacturing strategy: that in addition to process choice, their should be substrategies for the production infrastructure, both manufacturing planning and control plus people and their organization.

Evidence from this study plus many others points to the fact that unpredictable and unanticipated variances from plan are inevitable at the interface of people and the technology they are using. These can be due to the inflexibility of the process so that when markets demand product changes, redesigns and increased variety the operator and designer may know what is required, but is unable to adapt or reprogram the technology to respond. Other problems include poor organizational processes when failures or breakdowns occur, or else technology introduction which runs contrary to the culture within the organization. Many concepts and solutions have been forwarded to address these problems: industrial socio-technical theory after the Tavistock school and the experiences of companies such as Volvo of Sweden urges the systems designer and organizational development people to consider in tandem both the social and human issues together with the technical advancement of the business; Utterbeck and Abernathy (1975) were foremost in arguing that design work, in relation to a "productive unit", should not only consider the technologies of product and process, but also work organization designs; and Ettlie's concept of "simultaneous design" again comes down to the logic of simultaneous development of technology and organization.

On the evidence of the research in this study it is argued that systems designers should indeed, as prescribed in much of the literature, consider and evaluate work design of individuals and teams in the development of production systems. But how? The DRAMA model is intended to be analytical rather than prescriptive, but on the basis of this extension study three main influences have been identified which must be deliberated by those involved in systems design activities prior to the installation of new technology. The main influences upon the process of work design have been identified as:

1. The prevailing socio-technical factors in the industry within which the company operates and within the wider environment.

2. The decisions made relating to organization structure, interaction and communication at the strategic and tactical levels of the business.

3. The design of the other (technical) components of the operating system, namely physical system design, and control and integration.

A major decision facing an organization developing its physical and control technologies is the level of automation necessary within the operation. For highly automated systems it follows that the number of people working within the factory is far less. In these systems, therefore, decisions on work design have reduced scope although their impact may still be considerable. For other production systems, however, the human element will prevail, so the design of jobs requires significant attention if the system is to operate to its full potential. Other parameters influencing the design of work include Organization and the "socio-technical factors" within the wider industry and environment. Each of these three influences upon the process of work design is now considered in turn.

Industrial Socio-Technical Factors

Any factory will have interfaces with its environment at all levels of the organization and the shopfloor is no exception. Social interaction and working practices such as trade union activities, which span the boundaries of the organization, will result in employees developing some perception of the society and industry within which they work. In addition managers and systems designers will try to keep up to date with the latest developments in work organization and ergonomics within other companies in order to improve the inherent potential and effectiveness of production systems. Social, technical and industry factors, therefore, have a significant bearing on the development of work design at the factory level.

Organization

Decisions taken within the strategic and tactical domains relating to the structure and state of the manufacturing organization will have direct consequences upon the design of work for employees. The corporate policy on such issues as contracts of employment, responsibility for quality and output, payment schemes and codetermination will influence designers' scope for developing jobs and will determine the role of shopfloor workers in improving quality and increasing flexibility.

The Technologies of Physical System Design/Control and Integration

The two remaining DRAMA components at the level of the operating system will have direct consequences for work design. Key determinants are:

- the level of automation;
- the selected facilities and machines;
- the type of control systems adopted; and
- the skills, aptitude and flexibility required to perform the full range of machine operations, accomplish production tasks and operate computer-based and other control systems.

Work design considerations should, therefore, be incorporated into the technical work involved in developing hardware and software specifications and in implementing new production systems.

Other factors, other than the direct interface between people and technology also need to be accounted for and decisions made within the context of work design. There is the question of to what extent should different groups of employees actually be involved with the design projects for new production systems. Obviously engendering a feeling of employees having some say in their own destiny is attractive especially if, when successful, it facilitate the development of a change orientated workforce. However the survey showed a very low participation of shopfloor personnel in production system design project (1% of total participation overall[11]) and the figure for junior production managers and production supervisors were only 7% and 4% respectively[12]. As has been mentioned before within the analysis of project management, production systems design remains largely a technical activity in most companies.

[11] See Table 6.17 in Chapter 6.

[12] ibid.

Another non-direct operator-technology interface aspect of work design is the extent to which employees can and do became involved in various participation and awareness schemes in the normal course of business operations. The survey showed that suggestion schemes, regular team briefings, company newsletters and quality improvement team programmes were all extremely popular - other two-thirds of companies responding to the survey suggested that these were in operation. Rather less well used (and probably reflecting the low participation of employees generally in system design projects) was the use of working parties and task forces as a vehicle for participation[13].

The DRAMA methodology suggested a number of design options for work design (Bennett and Forrester, 1993) and, although not fully inclusive of all possible choices, it does provide an illustration of the decisions that must be made when developing effective work organizations. The first five options relate closely to decisions already made for the design of the physical system, the detailed implications of which have been discussed in Chapter 4. The other four design options can be viewed as organizationally-based decisions involving such factors as employee competencies and knowledge, responsibility for work carried out, and the explicit and the implicit expectations of operators and other workers.

Product, Process or Task Orientated Work?

The fundamental choice between product, process and task orientated work organization is dependent on, and should be taken in parallel with, the choice of physical system configurations. This choice is also invariably associated with the level and type of demand. It is widely acknowledged that product orientated work organization facilitates increased employee satisfaction because of the range of operations done, identity with the finished item being produced and an absence of monotonous and repetitive tasks. However, it is widely agreed that the cost of designing work in this way becomes more prohibitive as the demand for highly standardised products increases.

[13] See Table 6.24 in Chapter 6.

Group Technology

Work organization according to group technology principles is an attempt to introduce the efficiency benefits of task organization to the batch production of goods. Small group work and product focus also brings benefits in terms of job enrichment, the possibility for job rotation and increased responsibility for matters such as quality. However, the cost of installing and operating small production cells must be evaluated in detail since these can frequently increase over and above those for process orientated work organization. These must therefore be offset against the advantages listed above.

Autonomous Working

Autonomous working involves changing from flowlines to small group work, where a major objective is to gain some of the advantages of job production and product-orientated organization. Benefits frequently cited include increased employee satisfaction, improved range and response flexibility, more responsibility for quality and output and greater adaptability of operators in the long term. There are still questions, however, regarding the efficiency of this form of organization compared with the other forms outlined above. The overall cost of operating such a system is also the subject of some controversy.

Training and Development

Training and development is generally seen as a positive activity within the majority of manufacturing organizations. Not only can it equip company employees with skills, competencies and knowledge, but can also be a direct and indirect way in forming or changing employee opinions. This may increase the management and workers' understanding of the objectives, operations and issues within the business. Cost and time are the major constraints on the level of general training given, although such expenditure, if spent wisely, should be seen as a future investment in the business as a whole.

Quality Training and Awareness

In recent years many companies have made significant investments in quality training and awareness because the issues of quality and customer service are seen as areas of common interest within the organization. Company-wide quality programmes will involve all employees and frequently focus upon customer needs and quality requirements. The main benefit of such programmes is frequently reported as the creation of a factory environment concerned with continuous improvement of products, processes and customer response. Despite their attractions, however, such programmes can be expensive to implement both financially and in terms of employee time, so organization designers must be clear as to the objectives of the programme and its scope.

Quality Groups and Teams

Many organizations place considerable value on the use of quality, or more correctly, continuous improvement groups and teams within their operations. Such programmes range from quality circles, where membership is voluntary and groups select their own project areas, to kaizen teams which focus on continuous process improvement focus. The direct benefits of such activities include cost savings and improvements in efficiency, whilst identified indirect benefits are increased organizational, systems and people flexibility and improving customer satisfaction.

Single Status Employment

The elimination of separate status for employees within an organization can yield benefits such as improved satisfaction, increased responsibility for quality and enhanced flexibility on the shopfloor. However, there can often be objectives on the part of technical and salaried staff to their erosion of status and the costs of promoting all employees to the level of salaried staff must be evaluated in detail.

So, in summary, work design has been given considerable attention in the literature on manufacturing systems, particularly since the early 1960s, but its importance is frequently overlooked by system designers when introducing new production systems. Many engineers and managers think of production systems as comprising the hardware and software of "Physical System Design" and "Control and Integration" and ignore the vital role played by direct and indirect personnel. No system, however, even if highly automated, can run uninterrupted without some human intervention and organizations which acknowledge and account for this fact in the design of work will operate more smoothly and efficiently than those that do not.

A number of forms of work design have been developed over recent years as alternatives to conventional batch and flowline working. Most notably group technology and autonomous working have evolved for the purpose of improving flexibility, increasing market responsiveness and to improve the jobs and working conditions for people within the factory. In many companies, the fundamental ideas of line production and functional layouts have largely been retained. However, there is a general trend towards less rigid plant formats and facilities, where increased operator flexibility and increased participation for employees in the day-to-day decision making processes of the organization are becoming the norm.

The main conclusion is that Work Design must be given the same or, in some cases, greater importance than the design of the physical and control systems in order to develop the most effective infrastructure for manufacturing. This section has described the process of designing jobs in parallel with developing the design for other components of the operating system. An overall rationale for work design is established through the translation of organization design in the strategic and tactical domains down to the level of the operating system. By considering the prevailing labour market conditions and the hardware and software systems, either in operation or to be introduced, specific details of appropriate work organization can be determined and implemented. The development of work designs must be viewed as an ongoing and iterative process. It should be reviewed and evolved in response to changes in the organization structure, developments in the labour market and social environment or when new physical and control systems are introduced.

8.8 Systems Implementation

Implementation is a critical component in the introduction of new production systems. Effective implementation, where the installation matches closely the initial system specification and user acceptance of the new system has been gained, will give even a moderate facilities design a good chance of success. A flawed implementation, however, can turn an excellent production system design into a failure, or at least will result in the design not achieving its full potential. So realising the benefits to be derived from its expertise, the company should decide whether implementation can be managed in-house or whether some form of "turnkey" installation contract installation with an external party is required. Should a turnkey approach to implementation be chosen, the nature of the key determining parameters of project management, physical system design, control and integration and work design will all need to be communicated to the outside party by means of a system specification for installation. If an in-house programme of implementation is preferred the same Key Parameters should be considered, although the company must itself decide upon the implementation plan and its effective management.

In managing the unfolding implementation of the new production system, a good working relationship must exist between system designers and the end users and adequate training must be given to personnel who will be involved in the operation and management of the system. Where there is prior experience of implementing large scale integrated projects a set of implementation practices should already be in existence, either explicitly stated or, more probably, in the form of custom and practice. These should be evaluated and used as the basis for shaping the implementation plan and its conduct.

Once installed the new production system will come under a period of start-up and, eventually, will reach full operation. This stage of implementation must be managed carefully, ensuring that any initial start-up problems are quickly solved. Once the project has been implemented the organization should begin to analyse its implementation procedures in an attempt to learn lessons for future projects. Processes and procedures should be reviewed and evaluated in order to develop further internal skills and practices

In summary, therefore, it is necessary it acknowledge that implementation of new production systems is a very imperfect process of control, particularly when it involves a radical change in technology. As Gerwin and Kolodny (1992) indicate, there are questions of financial and technical uncertainty throughout due to questions concerning the reliability of the system itself, and the appropriateness of standards and performance measures in use within the organization and against which system performance will be judged.There is the worry that what Gerwin and Kolodny term "social uncertainty" might grow amongst users of the system which can, and often does, result in growing resistance to the new production system design. This obviously needs to be closely monitored and sensed, and appropriate actions taken (either increased awareness training of the new system, or the system design amended in order to address the fears of the protagonists) in order to reduce such uncertainty and resistance amongst employees.

8.9 Systems Evaluation

Evaluation of the new production system following implementation occurs at all levels in the organization, hence the reason why the DRAMA model contains it within all three domains of decision making and management activity. Strategic evaluation of new production systems was considered in Chapter 7 where two basic forms were identified: measurement of ongoing performance viz-a-viz the emergent corporate direction and strategies, and the post-audit of newly implemented production systems - what one might call post-implementation capital investment appraisal[14]. In the operational domain the key concerns in evaluation are the ongoing evaluation of performance in relation to its design, and the monitoring of manufacturing through the use of operational performance measures. In relation to the first item, the survey of production systems design showed that formal evaluation of implementation was "always" conducted by 46% of respondents, "sometimes" by 49% and "never" by 5%. Therefore less than half responded that evaluation was the norm within their organization, and the case study research shows this to be probably inflated judging from the responses to questions by those managers interviewed. In terms of manufacturing performances, measures of quality were given the highest overall weighting of 22.4%, followed by delivery (20.2%), machine efficiencies (17.8%), labour costs (15.1%), and labour productivity (11.7%). Again these results were somewhat at odds with case findings, where cost measurement was found, in practice, to assume a higher importance and ranking than suggested in the survey, but the survey did confirm the view held that a wide range of performance measures were now in use by managers when assessing their system's operations. We shall now consider system evaluation and operational performance measures in turn.

[14] See Section 7.7.

Evaluating implies observing performance in some way and then assessing the actual performance against anticipated or expected performance. Evaluations can be achieved in a number of ways including informal conversations, formal meetings, tests, production studies, measurements, experimentation and reports. Based on the outcome of the evaluation process the manager may take action to improve performance or to remedy any shortcomings in the system's operations. The key point that came out of the case study research is that managers recognize that evaluation should be timely so that appropriate actions are taken in time, and not too late. To evaluate and control effectively effort must be expounded to develop communication systems that provide accurate information and allows for adequate time for the manager to react to any problems.

The communications systems should allow for both verbal and written interaction and increasingly information technology in the form of advanced telecommunications systems and computer-based management information systems are being used to facilitate such communication. Verbal communication to allow evaluations to take place takes a number of forms varying from informal discussions to the more formal forms of regularly scheduled meetings and irregular summary presentations on progress. The written, or documented, forms of communication include scheduled reports including periodic reports of different time coverage and computer output, plus unscheduled documents including memos from personnel in response to a special situation or request. So, in developing evaluation processes to assess system performance, organizations must explore the ways in which they are to encourage communication and interaction within the business, but to focus the output into concise information forms.

Performance measures is the second area for consideration. Once production systems have been installed and in operation it is necessary to measure performance in some way. The traditional approach is to stress financial performance measurement over and above other forms, so companies concentrated overtly in cost measurement and measuring performance against budget using variance accounting methods. However this approach has been increasingly called into question[15] as it tends to ignore other important variables of

[15] See, especially Kaplan (1990) whose edited collection of papers provides a detailed analysis of measures for manufacturing operations.

performance including quality, delivery and efficiencies. As Gerwin and Kolodny (1992) identify, concentrating on financial measures can mean managers:

- concentrating on reducing direct labour costs even though they constitute only a fraction of overall manufacturing costs;
- using static budgets and historically determined standards which discourages the development of a continuous improvement ethos;
- develop a short term orientation in their decision making;
- take decisions too late as often financial information takes some time to produce; and
- too great an effort on "keeping operations up and running" to recover costs rather than concentrating on quality and delivery performance.

Current practice in manufacturing companies, as evidenced in the case study research in this project, reflects the new ideas suggested in the literature. Organizations are moving away from operating performance measures based solely upon cost and resource inputs towards a more balanced collection of assessment and evaluation criteria which give a high priority to customer satisfaction. A strong factor determining the rate of this shift within individual organizations seems to be the nature of the historical development of the company. Those companies still advocating the need for tight financial control tend to be slower to adopt the new measures while those that are adopting them are companies who see the value of a management style based upon strategic direction and market focus. Consequently some companies will remain inflexible and unresponsive, whereas others will be better placed to identify problems with their systems or changed requirements upon production and so able to adapt their production system design and organization to suit.

8.10 Summary

This chapter has concerned itself with the process of production systems design and analysis within the tactical and operational domains of the DRAMA model. Following a general exploration of organizational decision making in relation to the development of new production technologies, the DRAMA components of justification, project management, physical system design, control and integration, work design, implementation and evaluation have been explored within the context of the case study research and the results of the survey conducted as part of this project. The intention throughout has been to explore the linkages between the strategic decisions considered in Chapter 7 and their translation into systems designs and operation. By considering the components of the DRAMA framework in turn, the validity and appropriateness of using the model as a means of analysis has been demonstrated. The next chapter now builds upon these findings to refine the basic DRAMA model into a more analytical framework for studying production system design activities within manufacturing organizations.

Chapter Nine:
DEVELOPMENT OF THE ANALYTICAL MODEL

9.1 Introduction

This thesis has been developed in order to test whether the basic model underpinning the DRAMA manual offered a framework for the analysis of manufacturing operations beyond the scope suggested by the original ICL case research from which it was originally developed. This has led to the development of "DRAMA II", "Decision Rules for Analysing Manufacturing Activities". The emphasis in the expansion of DRAMA has been to move away from a detailed, prescriptive and process choice orientated methodology applicable to a limited range of operations to evolving the model into a state by which it can be used for the analysis of manufacturing design in general.

The basic DRAMA model was described in detail earlier[1]. In developing the modified DRAMA II model two major changes have been incorporated. These are:

1. The evolution of DRAMA into a *composite* model of production system design whereby, instead of a fragmented disaggregation of the model into components, DRAMA II is represented as an inclusive model. The DRAMA II composite model contains all the design components of DRAMA and shows the main determinants upon these components and the linkages and relationships between them.

2. The addition of a time dimension to produce a more overtly temporal model. This is difficult to represent schematically, but needs to be more fully recognized in the use of the model for research purposes.

[1] See Chapter 2.

DRAMA II is presented within this chapter as a framework for investigating process design and change within manufacturing organizations. As such it does not claim to present a detailed set of specific design options as can be found within the original DRAMA manual. This said, the model does provide the basis for developing industry specific design methodologies should these be required, and again this chapter will illustrate how this might be done. DRAMA II, in addition to its use as a analytical research tool, could therefore be used as the structure for developing DRAMA-type manuals for different manufacturing sectors.

9.2 DRAMA I to DRAMA II

The original DRAMA model was developed within the context of a research product which had the aim of generating a process design methodology for the electronics assembly industry. This project has sought to further develop and adapt, where necessary, the basic DRAMA model from the confines of electronics assembly to a more appropriate structure for the analysis of production systems design in general. The evolved model, "DRAMA II", with its change in emphasis and presentation, better satisfies the demands for a generic process model than the original model. This section firstly recaps the pertinent structure and features of the basic DRAMA model prior to presenting the extended model, DRAMA II. Then the components and domains of DRAMA II are separately considered.

The Basic Model

To reiterate, the basic DRAMA model (reproduced in Figure 9.1) comprised ten components of production system design which spanned three hierarchical domains of organizational decision making: strategic, tactical and operational. At the next level of disaggregation the model was broken down into a series of component-specific diagrams identifying the key parameters influencing and shaping design decisions. The model was then used to develop design option guides and generalised flowcharts for the electronics industry specific design methodology. The development of DRAMA II has recognized this distinction between the basic DRAMA model (ie: the component/domain diagram and identification of the key parameters) and the DRAMA methodology (design option guides and generalised methodology flowcharts for the electronics industry). The model, therefore, has been accordingly adapted on the basis of the case study and survey analysis and then the way in which the resultant DRAMA II model can be used to develop industry specific design methodologies for production systems is presented.

Figure 9.1: The DRAMA Conceptual Model of Production Systems Design[2]

The basic model has strengths in terms of its simplicity and comprehensiveness as a representation of production systems design and, for this reason, is retained as the "top level" diagram in DRAMA II. The basic model identifies a general process of progression through production system design by recognizing these dynamic and interacting components

[2] Reproduced from Chapter 2 (Figure 2.4) and, henceforth, to be referred to as the DRAMA II "Basic Model".

of design activity which, in tandem, drive the organization and its manufacturing activities through time. In explaining the decision processes involved, DRAMA assumes a generally phase-wise progression through these components during a production systems design project. However, it is recognized that the components of design are interdependent and that decisions within one component will probably have an effect on a number of preceding and subsequent events in other components. Thus, as a result of evaluations and reassessments throughout the design process, there is a myriad of feedback and feedforward loops between components, too numerous to represent on any diagram of the model. Herein lies one weakness of the basic model: whilst inherently recognizing the existence of determining factors and feedback/evaluative relationships within the model, these are not adequately represented in the diagram, nor are any weights attached to their importance.

The second dimension of the basic model is the recognition of hierarchical domains of decision making. These are termed domains as they represent a sphere of decision making; to call them "levels" would limit the perception of interaction and intersecting areas of decision making between different levels of managers and members within the organization. The basic model represents this notion of multiple levels of decision making well and, as a general concept, was found to hold true as a dimension of production systems design across all four industries studied in this dissertation. So, to reiterate, the strategic domain embraces the activities of senior management down to the level of individual plant units. Market and Environment, Manufacturing Strategy, Organization and Evaluation components are identified as being within the strategic domain and can be considered together when focusing upon the strategic issues of systems design. The tactical domain spans what might generally be termed the "middle management" levels where senior management decisions are translated down into plant level procedures. Components within this domain are Organization, Justification, Project Management and Evaluation. The operational domain relates to the lower organizational levels where detailed production decisions and systems operation take place. The operational domain includes Project Management, Physical System Design, Control and Integration, Work Design, Implementation and Evaluation. Some components are represented as providing the main interface between different domains of decision making. Thus Organization and Evaluation span the interface between the strategic and tactical domain, while Project Management and Evaluation span the tactical and operational domains.

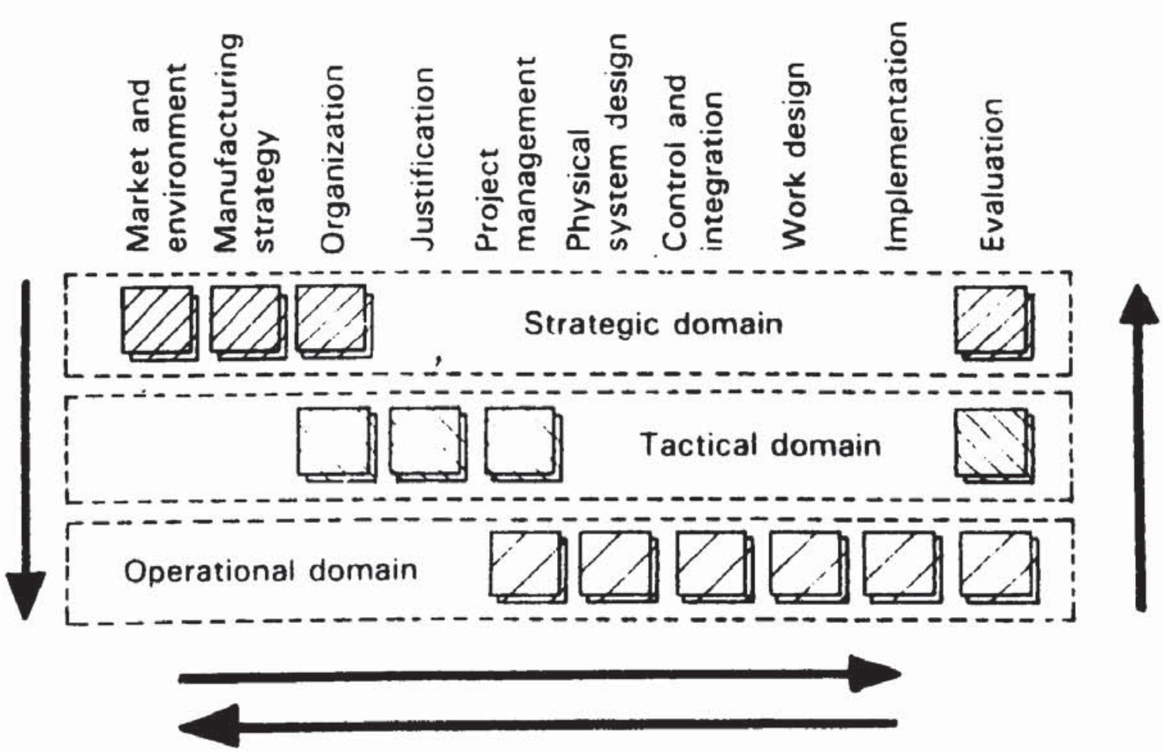
One major shortcoming of the basic model, as noted before, is the lack of representation of chronological time. Although a myriad of feedback and feedforward movements during the generally phase-wise progression through components was recognized, is not overtly represented in the diagram. It is to the extended and modified DRAMA model, DRAMA II, that we therefore now turn.

The Extended Model

The extended model builds upon the basic DRAMA model. However, as noted in the introduction to this chapter, it more clearly identifies the passage of time and, secondly, more fully represents the main factors or imperatives acting upon the design components and the relationships between these components.

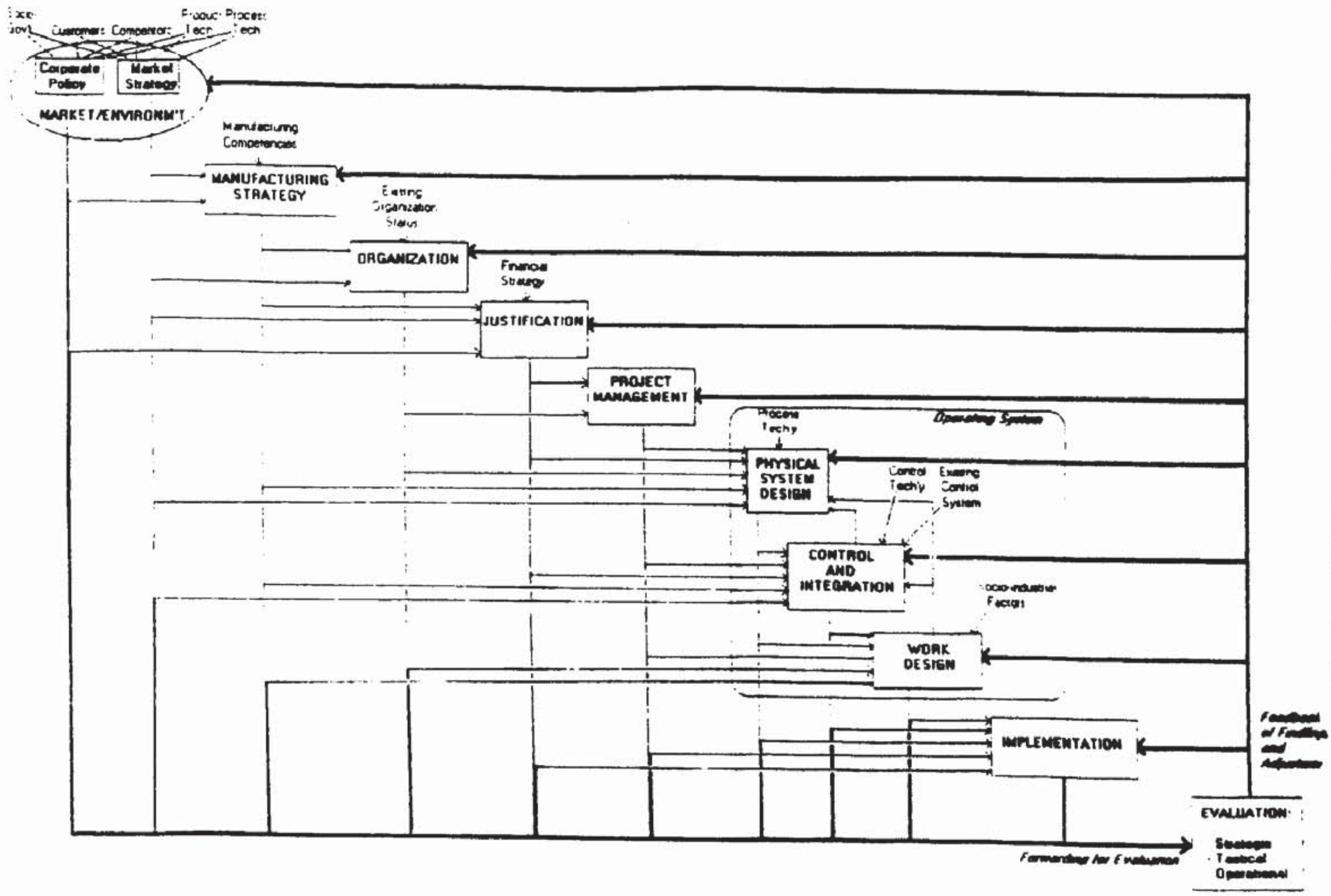
One problem with the basic model is the representation of time. In fact, in the diagram shown in Figure 9.1, time could be represented by arrows in all directions. The modified diagram in Figure 9.2 illustrates the passage of time and what movements up and down, left to right would represent. A movement from *left to right* is, during the process of new system design, the dominant direction as it shows the movement from high level strategies and plans through to detailed systems design, implementation and the system's evaluation following introduction. A counter move, from *right to left*, represents a feedback to or re-evaluation of previous components of design. Such feedback can occur as a result of many factors including changed terms of reference for the emergent system during the design process due to changed market circumstances and/or a redirection in corporate strategy. Alternatively it could be decided that a component was not designed and the process not conducted in line with the requirements for the new system and so needs to be returned to for adaptation and modification. A movement down, from *top to bottom* of the diagram represents the translation of strategies and strategic decisions into tactical concerns and, ultimately, to detailed systems design, whereas a movement up, from *bottom to top* is illustrative of information and performance assessments in the operational and tactical domains being communicated and assessed the upper domain/s of organizational decision making. So, given the myriad and complexity of forward and reverse flows of information in the design and associated decision making process, it is not possible to represent time simplistically in a phase-wise progression. However the diagram in Figure 9.2 does give some indication of the nature of such flows.

Figure 9.2: Temporal Representation of the Basic Model



This temporal representation of the DRAMA model has been extended into an holistic model of the production system design process. Henceforth called the extended or DRAMA II model, it is shown in Figure 9.3. The model builds upon the relationships and interactions that have become evident from the case study research and the results of the production system design survey. In so doing the influences of previously recognized "key parameters" have been assessed and then incorporated into a single model of production systems design.

Figure 9.3: The DRAMA II Model



The DRAMA II model comprises the ten components of design recognized in the basic DRAMA model, but uses a flowcharting technique in its construction not unlike IDEF modelling.[3] The main flow through the design process initially is a generally *top-left to bottom-right* movement reflecting the generally phase-wise progression through the design process from market and environmental analysis through to detailed systems design and implementation. Inputs to design components from preceding DRAMA II components are

[3] The positioning of the main components on the leading diagonal and the influences upon these components from the left and top is similar the IDEF representation of activities, but the DRAMA II model does not slavishly follow the IDEF conventions of showing constraints as up-arrows, etc. The reason why IDEF conventions were not fully followed was because they would inhibit the temporal features of DRAMA II and would not show the generally "anticlockwise" flow of information and decision making around the model: after all flowcharting should be an assisting tool, not a rule-bound constraint.

shown as arrows into the left of the box, whereas the major influences from outside the DRAMA II process are given as arrows into the top of the component boxes.[4]

The flow of information and the consequent temporal passage through the design process are neatly illustrated by DRAMA II. The left to right, top to bottom and opposite movements through the design components hold for DRAMA II in Figure 9.3 as they did for the temporal representation of the basic DRAMA model in Figure 9.2. This, in effect, sets up a generally and predominantly *anticlockwise* progression through the model. The outcome of analyses within the top left Market and Environment component, where the Corporate Policy and Market Strategy are determined by corporate strategists, sets up progression within the other components as and when this is determined to be necessary by the organization. As time progresses, however, through the design process the attention turns increasing to evaluating the position, the design process, the decisions made earlier and the functioning of the operating system. Hence the Evaluation component of design comes increasingly into play with its consequent feedback of findings and adjustments where necessary.

In addition to large *circling* motions within the DRAMA II model, evaluation of individual components and individual elements within components becomes a process of *ever-decreasing circles* as processes, systems design and operating performance are continually fine-tuned. This happens until, at some point, there is a major disjoint or step development. On the evidence of the research this would seem to normally emanate from the environment and, particularly, through competitive and product/customer related factors, although it can also be due to a change in strategic emphasis or manufacturing approach stimulated from within the organization. The image one has, therefore, is of a pulse and the pumping of information and design activities around the schematic system illustrated by the DRAMA II diagram. If the pulse (and hence the pace of change) slows at any one point in time, there is a trickling effect whereby more minor and detailed design activity, evaluation and adaptation can take place. This is akin to the continuous

[4] Obviously there are multiple influences upon the design and undertaking of each component, but DRAMA II highlights the major parameters as recognized within the cases studies and, more particularly, from the survey results.

improvement concept in organizations: the *kaizen* of gradual and incremental improvement or, as has been represented above, the ever-decreasing circles of evaluation, change and re-evaluation. However, if the pulse quickens due to dynamics outside or within the system, there will be increased pressure on the main *arteries* of the design process and so the major dominant direction of design through DRAMA II, from top-left to bottom-right through to evaluation and an anticlockwise flow (the large circles), is once more invoked. Thus the design process can be seen as a system of design and evaluation whereby the dynamics set up variable pulsing movements of design data, information and evaluative material around the process with the inherent speed-ups, slow-downs, blockages and delays that one might expect due to changes in the metabolism and health of the system and its inherent design process.

The extended DRAMA II model, therefore, has a similar representation to the basic DRAMA model, but shows more detail in its top level diagram without the need to resort to the disaggregation to key parameter diagrams required by the original DRAMA diagram. Although the diagram of DRAMA II in Figure 9.3 does not illustrate the domains of decision making, it would not be difficult to draw in their spheres of influence. This is not done here as it would add complication to the model, but could be added if desired. In any case, the basic DRAMA model will continue to be used as its strength is in its ability to show the disaggregation of the design process into the strategic, tactical and operational domains. DRAMA II presents an alternative framework for the analysis of production system design activities and is more able to capture the changes in specific parameters and their effect upon the operating system and the design activity within the organization. The metaphor of a system with a pulse is useful to bear in mind when referring to and using DRAMA II in that it gives some vitality and notion of a process always in motion and not unlike a living organism or manmade cybernetic system. We will now return to the ten components of DRAMA and discuss each in turn in relation to the development of the DRAMA II model, prior to considering the concepts of decision making domains in the light of the adapted model.

9.3 Production Systems Design Components

Market and Environment

Market and environmental analysis results in the definition of a corporate policy to reflect organizational objectives and then facilitates the formulation of an appropriate market strategy. Five more parameters influencing the process of design are recognized in addition to the evaluation feedback from within the organization. The case and survey results show the actions of competitors, requirements of customers and product technology (particularly in relation to reducing product life-cycles) to be the major determinants on this process in the four industries considered, although there is a considerable degree of variation between different industries. In some circumstances socio-governmental factors and process technology developments were also important. In the light of this it is important that, when using DRAMA II as a framework for enquiry, the researcher understands the major influencing parameters in any organization they select for study. This is particularly critical when the organization is undergoing a period of substantial production systems design as it is often changes in the market and environment emanating from these parameters that have the effect of "quickening the pulse"of design within the organization.

There are huge variations in the way, and to what depth, companies conduct their market and environmental analysis. The following, however, gives insight to a typical *good practice*, if somewhat idealised, progression through such an analysis as presented by a composite of companies in the research conducted. It is hoped that presenting this here will give researchers investigating production system design with some form of benchmark against which to assess the market and environment design component within an individual company:

1. *Consideration of customer needs and evaluation of competitors*

   Usually involves market research and direct interaction with customers for the former, and can include "competitive benchmarking" techniques for the latter.

2. *Internal audit of market competencies*

   This can involve a review of existing policy and market strategy, whether explicitly stated or conducted as custom and practice, and an evaluation of the extent to which the strategy and actual performance matches the needs of the market.

3. *Relating the findings of the internal audit with customer and competitor analysis*

   This normally facilitates the drafting a mission statement or similar to reflect the company's fundamental strategic response and approach to satisfying profit, growth and customer aspirations.

4. *Establishing markets*

   Identifying the precise products the company should sell and within which geographical markets it wishes to operate.

5. *Analyse the organization's position to evaluate the company's areas of strategic edge*

   A number of methods are typically adopted here. The information on the market, environment and internal company operations is sometimes be plotted on a BCG matrix or analysed within the Porter or Johnson and Scholes frameworks[5]. Alternatively the Hill framework could be used to establish the order winning criteria of products and the extent to which the company supplies these[6].

6. *Formulation of market strategy on the basis of the results from steps (1) to (5)*

   Functional strategies, including that for manufacturing and hence production systems design, will normally hinge around the market strategy. Indeed, it forms an important key parameter to the design of all DRAMA II components in the development of market-focused production systems. The precise product range may also be determined at this stage.

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[5] Refer to section 4.5.

[6] See section 4.6 for a review of the Hill framework.

7. Articulation of market strategy

More effective strategies are normally written in a form that facilitates a comparison between them and any subsequent performance.

8. Measure performance and comparison versus strategic targets

Performance is often not only measured using the company's own criteria and data, but also through customer feedback information and in relation to industrial competitors. The process leads naturally to a periodic re-evaluation of the company's market competencies, areas of strategic edge and the suitability of the existing strategy. In this way the market strategy can evolve iteratively and in line with developments in the market and environment.

Manufacturing Strategy

Manufacturing strategy is an interesting component within the design process. Although most organizations like to think they have a strategy, often these are not well thought through, hurriedly prepared and not conducive to later performance measurement. The key parameters to manufacturing strategy formulation are the corporate and market strategies from before, but also and critically an evaluation of manufacturing competencies in order that the current state of facilities and planning and control systems might be determined. Once more an idealised process developed from the studies of the better performing companies in the study is presented as an indication of some of the activities contained within the manufacturing strategy component.

1. Internal audit of manufacturing competencies

The results from this audit are sometimes compared to other organizations and competitors using benchmarking techniques, thereby allowing a performance gap between current performance and business needs to be identified.

2. *Deciding upon the level of integration*

In doing so, companies often consider the areas of strategic edge provided by the current operations and the requirements laid down by the corporate policy and market strategy. In doing this they might identify distinctive core competencies for certain operations and decide to subcontract outside those non-core activities.

3. *Formulating the manufacturing strategy*

The key decisions on the nature of process designs and production infrastructures to match corporate strategies and market needs may be taken at this stage. Also targets and objectives may be set for manufacturing performance in relation to costs, quality, delivery, etc.

4. *Consideration of the appropriate and relevant quality management system*

5. *Measuring performance versus objectives*

6. *Re-evaluation of manufacturing objectives and quality management systems*

This is done in the light of the performance recordings generated in (5).

7. *Periodical reappraisal of manufacturing systems*

Comprehensive reappraisals will be done in relation to the competition and in the light of corporate objectives and the performance figures from (5). This information is often then used to identify any perceived strengths and weaknesses of the manufacturing strategy, modifying it where necessary.

Organization

The design of the organization, both in terms of "structure" (ie: formal recognized composition and lines of communication as shown on the organization chart) and "state" (ie: the culture, employment climate, flexibility, etc.) has three major influencing parameters within DRAMA II: the existing organizational status, the manufacturing strategy and the market strategy. As was noted in Chapter 4, theories of organization design are numerous and somewhat conflicting. For the purposes of a DRAMA II analysis, it is appropriate to identify a typical process of organization design for manufacturing against which organization design within a company under study can be compared. The process of design can then be evaluated in the light of the theories and arguments developed in Chapter 4. The process of organizational design is, perhaps, subject to more inertia from within the organization than any other component of DRAMA II, but the following is the process by which some of the case study organizations determined to adapt their organization design have attempted to address this change.

1. Decision concerning the nature of organization "structure"

In contemporary manufacturing organizations there has been a tendency to move away from highly functional to product-focused organization structures. There is also the frequent question of what degree of centralization versus decentralization is appropriate so that there runs some central control, but that this does not hinder the need for effective functional links, particularly between Marketing, Design and Manufacturing. A further point often to be considered in organizational design choice is that of information communications which, ideally, should be allowed to run laterally and hierarchically to support the functional links. Finally a concern of many organizations is that corporate, divisional and unit sizes should be optimised to prevent the potential for bureaucracy and wasted resources. In evaluating the organization structure of an organization the researcher is directed to the discussion of different organizational forms discussed in Chapter 4.

2. Develop organization "state"

"State" in this thesis refers to the non-structural aspects of organization: that is to say culture, power, leadership, flexibility and politics. Flexibility, appropriate reward systems and the wider climate within the company is tending, more and more, to reflect the need for market focus. If deficiencies occur in any of these areas attempts can, and often are, made to adjust the state of the organization through the use of training and awareness for employees and, possibly, a review of incentive schemes, away from those geared upon productivity and output to ones which more directly reflect objectives for customer service and product quality.

3. *Integration of structural and state factors into corporate and manufacturing organization*

   Using the results of the evaluations in (1) and (2) the company will adopt what it perceives as an effective structure and attempt to nurture and develop an appropriate organizational state.

4. *Review and refine organization design*

   More adaptable companies will continually compare the existing organization structures and state with the objectives set out in (1), refining these over time if necessary, periodically evaluate the effectiveness of the prevailing design, and adjusting the design when mismatches are identified.

Thinking of organization design in the two areas of structure and state is a useful means of analysing and developing both strategic (ie: corporate) and tactical (manufacturing) organizations. It was widely argued by respondents in the research programme that organizational development should be ongoing activity if the company is to remain effective. In some dynamic cases such as in the electronics assembly industry where there is a fast rate of change in the market and environment, the organization must be able to adapt and change frequently and at short notice in response to these changes.

Justification

Justification centres around the activity of generating a case for a developing new or modifying existing production systems. Justification is normally based upon a combination of financial arguments and strategic need in terms of qualitative advantages. Approval for new projects and capital expenditure is usually sought from senior management on the basis of this justification. The key parameters shaping the process of justification within the DRAMA II model are corporate policy, financial strategy, market strategy and manufacturing strategy. The degree of influence of each of these should be determined by the researcher in order to assess whether the company, and hence its justification processes, are primarily driven from a financial, business, marketing or production perspective. This can often be an enlightening finding, not only in relation to the process of justification, but also in that it most often reflects the prevailing culture and identifies the power-bases within the organization.

Justification in the literature is often taken as a prerequisite for expenditure of new systems. However, the evidence from many of the cases in this research has shown that a detailed justification for new systems often does not take place, or else in a very scant form. Justification, and the production of a capital paper is important not just for the justification process, but also in evaluation of systems performance. The benefits and advantages of the new system as detailed within a capital paper will provide a benchmark or yardstick against which eventual system performance can be assessed. Observations of those companies in the research seen as generating comprehensive and useful capital papers show the process of justification to be a multiple step process. For the benefit of the researcher evaluating an organization's approach to justification using DRAMA II, a comprehensive approach to new system justification is now presented.

1. *Definition of the problem and of the requirements from new system*

   Organizations may firstly consider any existing manufacturing facilities and relate them to the statements made in the corporate policy, market strategy and manufacturing strategy. The gap between current system capabilities and performance and the business requirements of the system is then considered. If there is no existing system, the business requirements are compared with the expected or forecasted performance of the new operation.

2. *Alignment of capital proposal with strategic objectives*

   The basic proposal is developed in line with the business needs identified in (1).

3. *Estimation of time and costs*

   Time and cost forecasts are developed not only for the design and development of the new system, but also its operation once implemented. The way in which this is done and the information required, varies depending upon which investment appraisal technique has been adopted.

4. *Develop tangible benefits*

The associated financial costs and returns over the duration of the project and of the proposed system once in operation are then frequently estimated, thereby establishing the tangible benefits expected to derive from the investment.

5. *Develop intangible benefits*

The potential benefits which cannot be readily quantified are taken into consideration. These can then be analysed and developed to produce a schedule of advantages and disadvantages expected to result from the new system. These can be reviewed once more in an attempt to quantify the benefits if at all possible (cost being a common denominator or the "bottom line"[7]) and those previously intangible items which have now been financially quantified can then be moved into the statement developed in (4).

6. *Identification and recognition of supplementary strategic benefits*

Some organizations make a case and devise a category for so-called "strategic benefits" which are very difficult to quantify, but extremely important. Such items include the marketing benefits of having a "showcase factory", greater efficiency of new product introduction, etc.

7. *Submit capital paper for approval*

Using the data collected and stated in (4), (5) and (6) organizations can develop a comprehensive business case for investment in the new production process and submit to senior decision makers for approval. If accepted, the project will normally be allowed to proceed.

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[7] See the arguments of Kaplan, 1986.

8. *Review of the justification process*

In the light of experience when moving from (1) to (7) there are opining and views within the organization on the efficiency and appropriateness of the justification process within the company. The opportunity can be taken after a process of justification to evaluate the approach adopted and so improve the standard and efficiency of internal practices within the organization in the future.

Project Management

Following justification, and on condition that the capital has been granted, system design projects are then invoked. These need to be managed within the constraints of terms of reference, timescales and budgetary constraints imposed. the key determining parameters on the project management in DRAMA II are justification and organization. Other factors such as corporate policy, market strategy and manufacturing strategy also have a part to play, but the evidence from the cases and from analysing the survey results shows their influence to be more indirect, being reflected already in the terms of reference emanating from the justification process. The key factors influencing success or otherwise of project management were seen to be leadership quality of the project manager/s, team work amongst those players in the systems design project, and the involvement of systems users (mainly production managers, technical staff and shopfloor personnel) wherever possible. The generalised approach to project management adopted from a composite of those case study companies seen to be effective in the process is now given to enable comparative analysis by DRAMA II researchers.

1. *Identify constraints on the project*

The approved justification proposal will necessarily contain details relating to the time for development and the sanctioned cost of development. This provides the timescales for the overall project and the budget available for the scheme.

2. *Establishing the structure for tactical management of the project*

Here organizations might stipulate the function and set terms of reference for the operation of a high level project review group or "steering committee". This group will normally evaluate the time and financial constraints and ensure that the project continues to align with manufacturing strategy and corporate objectives.

3. *Creation of a design team*

Project team members are selected to provide a mix of skills and competencies that fit within the structures determined in (2). These individuals could be on a steering committee or work within more focused design groups. Some organizations, in an attempt to develop some degree of "ownership" by the users, try to recruit design team members who will be responsible for operating the new system or will be served by it. this is seen as easing management of the change and the acceptance of new technology downstream.

4. *Determining the degree of participants' involvement*

Despite the attractions of full-time design team members, the constraints on manpower will normally mean that most members in the project team will be part-time participants who continue to perform their usual functions and responsibilities during the design process. Where resources allow, users may be seconded on to the project on a full-time basis, but user participants more frequently tend to be part-time and work closely with specialists such as manufacturing engineers, information systems personnel and the like. Experienced project managers will normally attempt to agree the proportion of working time that individual participants will have dedicated to the project with other managers within the organizations so as to legitimise their calls on time and resources.

5. *Ensuring cooperation and coordination*

The engendering of favourable conditions for team cooperation and coordination a number of aspects. The competencies prevailing within the organization can be considered so that technical expertise and knowledge of the system can be best utilised and balanced. It is usually important to establish effective communication channels both between the steering committee and working groups and laterally between groups. Here it is important to understand the power structure within the formal organization and seek to ensure that this does not hinder progress in the design project. Finally a high degree of compatibility is often fostered between individual, group and corporate objectives.

6. Designing the system

The operating system is then designed. In DRAMA II this comprises the three components of physical system design, control and integration, and work design. Consider therefore, at this point, the typical approaches to systems design presented below for each of these components.

7. Controlling the design and implementation phases

Managing and controlling the design and introduction projects for new systems normally involves continually ensuring emergent systems adhere to the agreed timescales for development and are contained within the financial constraints. Whilst seeking to develop the best system possible, there should be a recognition of a trade-off between design optimisation and the time and budgetary constraints impinging upon the project.

8. Evaluating the process of project management

Upon completion of sub-projects and of the overall project, the effectiveness of project management can be reviewed together with the tools and techniques adopted.

Physical System Design

Physical system design concerns the choice of production system "hardware", plant layout and configuration of the equipment. Different industries and even different firms within the same industry demand different plant and equipment. In such circumstances, and on the evidence from the case studies, it is difficult to precisely identify a common or best generic practice. Therefore the researcher using DRAMA II is recommended to gain a basic understanding of process technology in the organization/industry they are evaluating without concerning themselves unnecessarily with the multitude of design options at the shopfloor level. To assist in the evaluation of physical system design a simple phase-wise framework of analysis has been developed within DRAMA II whereby design is divided into: factory-level, module level and utility level. The simplistic generic approach therefore identified is as follows:

1. *"Factory" level system design*

   Factory-level design relates to factory-wide principles and guidelines for layout, storage and transportation. Decisions here are taken in the context of perceived requirements for productivity, output, flow, quality and rationalization.

2. *"Module" level system design*

   Decisions made for individual modules, cells or areas within the overall manufacturing system. For each module decisions are commonly made concerning layout, storage facilities, transportation and materials movement, physical integration, tooling and work instructions.

3. *"Utility" level system design*

   Utility level design refers to choices on individual pieces of process equipment and work station design. These of course tend to be quite highly specific for individual industries, but certain choices such as the selection of storage and materials handling hardware are common in most.

4. *Evaluation of physical system design*

   The design principles and physical system operation at the factory, module and utility levels should be periodically assessed and amended where necessary to satisfy requirements of the system.

As has been stated before physical system design is just one of three components in the design of the operating system, so its design should be considered in an integrated way with the process of design for control and integration and work design.

Control and Integration

Control and integration concerns the design of the production system "software" including operations planning and control, the computer systems and the integration of the system as a whole. In addition to being influenced by a number of preceding and concurrent DRAMA II components, the case study research showed control and integration to be highly influenced by control (predominately computer-based) technology available in the environment plus the current state of its existing control systems. Very often technology was seen as the answer in developing increased control and integration to better align production operations with the business needs of the organization. Herein lies the trap that many of the case companies admitted to falling into: expecting the "technological fix" solution of buying expensive computer-based technology to alleviate their control problems, whilst really ending up with inappropriate systems for their needs or else automating their inefficiencies. However, in the light of these experiences, a more balanced approach by some organizations has been identified. It is reproduced now and provides a means by which the user of the DRAMA II model can compare design of control and integration systems in the organization they are studying with the approach adopted in part or whole by some of the more successful companies studying in this research project.

1. Establishing the overall mode of control

By taking into account the market and manufacturing strategies which influence design decisions, and also the available control technology, the companies can seek to establish a balanced combination of push and pull for system control. This could include MRP for long term scheduling and JIT for in-house and supplier operations control.

2. Establishing stockholding policies

After determining the mode of control, the organizations can then develop policies for stockholding within the business as a whole.

3. *Development of a material control policy*

Referring to the physical system design, material control policies can be established which take into account factors such as inter- and intra-module material flow, service levels required, extent of JIT/kanban control, location of storage points in the process, etc.

4. *Design and development of information systems*

The existing information systems can be evolved or extended to provide information for managing the inventory and order control systems and to supply management with information they might require to assist in decision making. Factors here include establishment of the control hierarchy, centralized versus decentralized control, the MRP/JIT interface, control of hardware, data capture and communication, and simulation.

5. *Establishing and maintaining control system interfaces*

Particular importance here is often paid to the interface between the control system and the human operator and the requisite demands for training, discipline to maintain data integrity, etc..

6. *Designing and integrating the material control and information system*

This involves integrating steps (3) to (5) in order to create the overall control system.

7. *Review the effectiveness of operational control*

In the light of changing market requirements and advances in the technological environment, the organization can re-evaluate material control policies, information systems and control interfaces in terms of their effectiveness and operation.

Work Design

Work design involves the choice of work organization within the production system and so the design of work and jobs for people is tied in with such concerns as flexibility, responsibility for quality and operator tasks, etc. In addition to influence from preceding DRAMA II components work design is widely recognized as needing to take place within the wider context of socio-industrial factors. Social interactions with people outside the company, working practices, trade union activities, legislation and the impact of the media all have an impact and influence acceptance of particular work designs on the shopfloor or for administrative, technical and managerial personnel. Work design can and, on the evidence of the case and survey results, often does take a back-seat to technical considerations of physical system design and control systems. This is no doubt that the continuing high participation accounted for by technical staff in design projects perpetuates the perception that projects are most often technical activities that run into organizational difficulties at a later stage. Some organizations, however, argue that systems design project should be seen as organizational change in themselves. If such a view is taken, one would concern oneself with work design issues up front in the design process rather than experiencing problems later on. Under such circumstances a more effective design process for work design would look something like this:

1. *Establish rationale for work design*

   The primary inputs for work design at the outset can be seen as the company's organization design and the general social factors within the wider environment. An analysis of these two factors would enable the company to establish the overall rationale for work design as it relates to different categories of employee within the organization. Consideration could then be given to flexibility requirements, responsibilities for quality and the micro organization design in each operational area.

2. *Development of work specifications for operators*

   The overall rationale developed in (1) can then be compared with the physical system design and control and integration designs elements as well as with the existing work design factors. The system designer can then develop detailed work specifications for all employee types. Considerations here include the exact tasks that need to be accomplished by individuals, the degree and nature of the interface between people and machines or computers, and the communication links and interaction between employees.

3. *Translating into individual work designs in practice*

   Individual work designs have been developed in (2), but these then need to be put into practice. This will entail considerable amounts of consultation and training.

4. *Review work design*

   The organization can conduct a periodic review of its work designs regardless of whether systems are themselves being redesigned. There is an argument to say that there should be continuous and careful monitoring as to whether the new work designs are operating in a manner which is in keeping with the overall rationale developed (step 1) and in the way described by the work specifications (step 2).

Implementation

Implementation pulls together the three components that comprise the design of the operating system through effective project management and in accordance with the original system justification. These, therefore, comprise the key parameters directly influencing the implementation process. Implementation, therefore, involves converting the design work conducted to date into the installation of efficient and effective new production facilities and ensuring their acceptance by people in the organization. Some of the companies more successful at implementing new systems from the case study organizations have adopted an approach not dissimilar to the following:

1. *Select either in-house or outside agent implementation*

   By conducting an internal audit of its expertise, the company can decide whether implementation can be managed in-house or whether some form of "turnkey" installation contract installation with an external party is required. Should a turnkey approach to implementation be chosen, the key parameters of justification, project management, physical system design, control and integration and work design will all need to be communicated to the outside party by means of a system specification for installation. If an in-house programme of implementation is preferred the same key parameters should be considered, although the company must itself decide upon the implementation plan and its effective management.

2. *Managing the implementation process*

A good working relationship between system designers and the end users is often seen as a necessary prerequisite and so adequate training must be given to personnel who will be involved in the operation and management of the system. Where there is prior experience of implementing large scale integrated projects a set of implementation practices should already be in existence, either explicitly stated or, more probably, in the form of custom and practice. These should be evaluated and used as the basis for shaping the implementation plan and its conduct.

3. *Commencing operation of the system*

Once installed the new production system will come under a period of start-up and, eventually, will reach full operation. This stage of implementation must be managed carefully, ensuring that any initial start-up problems are quickly solved.

4. *Reviewing the practice of implementation within the organization*

Once the project has been implemented the organization can begin to analyse its implementation procedures in an attempt to learn lessons for future projects. Processes and procedures could be reviewed and evaluated in order to develop further internal skills and practices for the future.

Evaluation

Evaluation is, in essence, the process which establishes the "control loop" for the systems design process and assists in future refining of the process within an organization. Evaluation is concerned with the maintenance and improvement of production systems and the process of decision making within the organization. Evaluation has already been covered in detail for each of the components of DRAMA II outlined above: it is the last step in the composite and idealised approach for design of each component. The evaluation process takes in the aggregated information from each of the previous nine components and then feeds back findings in order that adjustments and modifications can take place to improve or maintain the effectiveness of the design process and the operating system. In a generic sense the evaluation process can be seen as comprising the following five elements:

1. *Overall evaluation of performance for the new system*

   The starting point for Evaluation following the installation of a new system is for the organization to evaluate the performance gap versus expected performance and any other shortcomings in its operations for each of the components. This provides an overall view of the latest performance at the strategic, tactical and organizational levels of the business.

2. *Evaluating system performance from a strategic perspective*

   Strategic evaluation involves the assessment of corporate and market strategies, manufacturing strategy and organization design in relation to the latest circumstances of the company. Typically performance will be assessed within the strategic domain against the goals, profitability, quality and service targets laid down for the new system.

3. *Evaluating system performance at the tactical level*

   Generally tactical evaluation involves measuring and assessing performance against predetermined targets for productivity, cost, quality, output, inventory, human resources and service.

4. *Evaluating the operational performance of the system*

Operational evaluation involves consideration of the three elements of the operating system together with a review of the Implementation process adopted for new systems. The precise details of the form and content of this evaluation is provided within the generalised approach to design for these components contained above.

5. *Auditing the design process for DRAMA design components*

The results of the evaluations in (1-4) can be combined to give an overall assessment of the design process for new production systems within the organization together with the lessons fed back into the procedures for each DRAMA II component.

The components of DRAMA II detailed above form the nucleus of the analytical model for assessing the process of production system design. In an attempt to develop generic properties the fine detail contained within the DRAMA design methodology for the electronics assembly industry has been removed. Instead, and on the basis of the case and survey analyses in this research project, a composite model illustrating all ten components, their key parameters and interrelations has been produced (Figure 9.3). the user is then referred to the generic approaches identified for the more successful installations observed. The user of DRAMA II therefore analyses the decision routines in manufacturing system design in relation to the approaches outlined above, noting any differences in approach, the reasons for these and whether they are positive or negative on the process as a whole. It is to the use of DRAMA II as a framework for research analysis that we now turn for detailed consideration.

9.4 DRAMA II as a Framework for Research Analysis

The main aim of this research has been to evaluate and translate the DRAMA model for the design of electronic assembly facilities into a model with generic properties across a wider range of manufacturing situations (DRAMA II). The preceding part of this chapter has outlined the results of this research and described the structure and format of DRAMA II. DRAMA II is now considered to have generic properties to assist in examining the process of systems design across a wide range of industrial and organizational contexts having been tested and found to be a robust representation of systems design in a number of different industries and companies. The main purpose in developing and validating the generic model has been to provide a robust and proven model that can confidently be used as an analytical tool for company-based investigation by academic researchers. This section now describes how DRAMA II can be productively used by researchers in the field of production systems design.

The basic DRAMA model[8] (see Figure 9.1) provides a starting point for modelling the production systems design process. It is important that, before embarking upon fieldwork, the researcher should understand the essential features of the model in order that they might develop a sound framework and foundation for research enquiry. The researcher should be familiar not only with an understanding of what each component represents, but with the concept of multiple levels of decision making within the production systems design process as portrayed by the concept of decision making domains. The basic model provides a concise depiction of the process of design and its generally phase-wise progression through each of the components, so in itself provides the essential framework for structuring research enquiry. However DRAMA II provides a more detailed model which incorporates elements of theory and perceived best practice which enable the researcher to conduct more in-depth and informed investigations. It is to the use of DRAMA II that we now turn.

[8] See Figure 9.1.

The DRAMA II model[9] is a more detailed representation of the design process for new production systems and their development over time. It shows not only the main relationships and linkages between the ten components of design, but also the major influencing factors from elsewhere in the organization and, importantly, from the external environment. It also shows production systems design to be a highly iterative process through the incorporation of evaluative feedback loops: the iterative nature of the process is now so apparent from the basic DRAMA model. It is important for the researcher to familiarise themselves with these relationships and determinants within the system design process. They provide a means for comparison when investigating individual cases of production system design.

Finally DRAMA II has been developed with an accompanying narrative for each component of design[10]. This provides some description on the major determinants upon design for components and also builds upon the literature and the case study and survey findings to develop a generalised approach to design for each component. It is recognized that the approaches presented are somewhat idealised and are not in reality enacted in practice in their entirety. However they do represent a synthesis on the part of the author of what the literature and practitioners would currently perceive as a *best practice* approach. The intention in so doing is not to be prescriptive in advocating a single approach, but to provide any researcher using the DRAMA II model as a framework for enquiry with a benchmark against which to compare production system design processes they might observe within organizations they are studying. By mapping the actual process of design, both for the overall process and for individual components of design, they are then able to compare with the generic and idealised frameworks provided by DRAMA II. Differences between the observed approach to design and that represented by the generic DRAMA II model can then be identified, explored and then accounted for by the researcher. The findings for an individual company might be that the approach to production systems design is fallible or else can be accounted for by a specific industrial, market, organizational, political or social context within which the company operates. Alternatively the

9 As shown in Figure 9.3.

10 See section 9.3 for the DRAMA II description of the production system design components.

organization may be using advanced methods which advance the theory and practice of production systems design and so warrant the adaptation of the generic approach provided by DRAMA II. Whatever the case, DRAMA II provides not only the structure for research enquiry, but also provides a means of exploring organizational and decision making processes, the relationships and determinants between and upon design activities, and a generic approach to production systems design against which observed and actual practice can be compared. The main utility of the model is seen as providing a structure for the analysis of manufacturing decisions on the formulation of strategy and its translation into choice of manufacturing processes. Thus it provides a means for qualitative and organizationally-based research enquiry into the process of production systems design to supplement the more technical modelling approaches[11]

9.5 DRAMA II for the Development of Process Design Methodologies

In addition to its use as an analytical tool for the researcher, DRAMA II has utility for the practitioner. Organizations could use the assessments of their design process conducted by researchers or those conducted by their own personnel using the DRAMA II model to develop a process design methodology for their own particular needs. Two process design methodologies have indeed been produced using the DRAMA model: the process design methodology specifically for use in developing flexible assembly systems for the electronics industry (see Bennett, ed., 1990) and the more generalised methodology contained within the book by Bennett and Forrester (1993) geared towards the design and implementation of market-focused downstream manufacturing systems.

The process by which individual design methodologies can be derived has been illustrated in sections 2.5 and 2.6 which demonstrate how the ICL case and the wider research within the electronics assembly industry was used to develop the original DRAMA methodology and its associated design option guides (DOGs) and methodology flowchart for flexible assembly systems in that industry. Practitioners keen to develop a process design

[11] Refer to section 4.4 for a review of modelling approaches.

methodology using DRAMA for their own operations are advised to adopt a similar approach in the development of DOGs and associated generalised methodology flowcharts. For this reason the method of deriving the methodology is not duplicated here. However the practitioner is advised to also refer to the DRAMA II model which provides a more comprehensive view of relationships between components and with the market and environment, and the generic approaches described earlier in this chapter against which they can compare their current methods. The practitioner could, if they so desire, use the generic and idealised approaches to design from section 9.3 in a prescriptive manner as a basis for developing their own company/industry specific methodology.

9.6 DRAMA II in the Context of Production Systems Design Theory

The DRAMA II model has been seen to have generic applicability for linking corporate and manufacturing strategy analysis and the formulation of production system designs. DRAMA's use as a generic tool for analysing manufacturing activities is facilitated by structuring each part of the model in a manner that allows a systematic and logical approach to be taken when using it to investigate decision processes associated with the design and implementation of manufacturing facilities. DRAMA II offers the potential for both researchers and practitioners to model the design and decision processes for translating strategies at the higher levels of organization into physical system design, implementation and operation. As such, it provides a means of assessing how manufacturing strategies shape the design of operations and, conversely, how evaluation of existing systems and design projects can help shape strategic decisions following their evaluation.

As has been discussed in Chapter 4, there has in the past been a common attitude among academics and industrialists was that strategy was something that accountants and marketing specialists dealt with to the exclusion of manufacturing managers. Production personnel were simply not involved with strategy formulation and analysis, rather they concentrated on the operational planning and control of activities with a limited time horizon. Since the work of Skinner (1969; 1978; 1985) there have been numerous calls for the design of manufacturing operations to be considered as an important element in the corporate strategy of an organization (see Abernathy et al, 1981; Hayes, 1981; and Wheelwright, 1981). In Chapter 4 the work of Porter (1985) was shown to be germane to this new view of manufacturing and demonstrates how corporate management texts can provide lessons for manufacturing managers wishing to adopt a top-down and market-orientated approach to operations. Others advocated the virtues of deriving competitive advantage from the approach to manufacturing taken by exemplars (Schonberger, 1986; Hayes et al, 1988). Valuable and influential as these works have been, it was argued that they do not provide a detailed structure and framework of analysis for the detailed analysis of manufacturing decision making.

The work of Hill (1985; 1993) goes further by considering how to manage operations with a strategic perspective. Hill compares manufacturing management practice and performance in an international context and then provides lessons for the translation of corporate policy and market strategy into process choice and the development of a manufacturing infrastructure. Previously, Wild (1980) had considered the role of manufacturing in business policy and set up a policy framework which included the interaction of the operations management function with the external environment at all levels. In a similar way the work of Platt and Gregory (DTI, 1988) proposes that an organization should start with a strategic view of the business as a whole and, in turn, develop a business strategy, product strategy and manufacturing strategy prior to planning the manufacturing facilities. Hill and the Cambridge group provide an interesting insight into the activity of strategy formulation and translation, but they adhere rigidly to an overtly top-down and market deterministic view of manufacturing system development. A further criticism is that they say very little on the subject of human resource management and organization which, it goes without saying, constitute crucial factors in the success of any manufacturing strategy.

As far as the link with production system design is concerned, there have been few attempts to translate manufacturing strategy into decision processes for technology and work organization. Exceptions to this are Hill (1993), who addresses the matter in his chapter on process choice and Kantrow's aptly named article "The strategy-technology connection" (Kantrow, 1980). More recently Schroeder (1990) has considered the impact of production system technology on the development of corporate strategy.

The main contribution of DRAMA II to the field of production systems design theory is that it effectively links strategy formulation with more detailed systems design activities at the operational level of the organization. Review of the literature and theory in the areas of manufacturing strategy and production system design discloses a missing link in the understanding of how strategy is translated into system design through the organizational decision process. DRAMA II assists in understanding the relationship between corporate strategy and the design of operations systems by offering an empirical model for analysis which incorporates all levels of manufacturing decision making. The incorporation of a number of existing models and systems design approaches in the development of DRAMA II means that the basic model is multi-perspective. DRAMA II advocates an open systems approach in the analysis of components in the higher domains of managerial decision making, while a closed systems approach is adopted when progressing down to the lower domains. This fits well with the Kast and Rosenzweig (1970) notion of a "hierarchy of systems" whereby higher levels of socio-technical analysis demand a more open approach.

The research methodology employed when developing and using the DRAMA model borrowed from Checkland's (1981) soft systems approach with its movement and feedback between the real and abstract world. A soft systems approach would also be relevant whenever the realities of actual human decision making are being considered as is the case when using DRAMA II. DRAMA II's hierarchical dimension, which allows for a high degree of structural analysis, is derived in part from the conceptual form of the GRAI model (Doumeingts et al, 1986). This is complemented by a longitudinal, 'through time' dimension which evolved following the use of Mintzberg's (1976) model for analysing unstructured strategic decisions, which allows for lateral analysis of the decision making and design processes when developing new production systems.

In its pragmatic mode DRAMA II, like most manufacturing strategy theory, advocates a top-down and market-driven approach to strategy formulation and its translation to the level of operational design. However, when used for the analysis of system design, it also recognises more readily than most other theories that bottom-up and lateral forces are extremely important in shaping and evolving strategy. DRAMA II also recognises a correlation between the production system design process and a phase-wise and cyclical movement through the model's components, from consideration of "Market and Environment" to the "Evaluation" and back. It recognises that there exists a host of interconnects between components, both within the same domain (eg: simultaneous consideration of the "Physical System", "Control and Integration" and "Work Design") and hierarchically (eg: "Organization" affecting "Manufacturing Strategy" and the functional design of the operational system).

The research that underpins the development of DRAMA II is distinctive compared with most research in the area which tends to consider manufacturing from a senior management perspective. This research project has covered this aspect with its programme of senior management interviews, but largely comprised a longitudinal, and even in many ways bottom-up, analysis of a number of manufacturing companies. By using this method of enquiry it has been possible to identify the existence and nature of feedback and feed-forward information that permeates organizations during process of production systems design.

DRAMA II's principal asset, therefore, is that it offers a comprehensive framework of enquiry when considering the design of a production system. It recognises direct and indirect linkages between the market and strategy in the higher domains of organizational decision making and the decision making processes that occur in the tactical and operational levels. It offers a flexible model by virtue of its modular design which enables the design process to be divided into a number of separate components. Finally DRAMA II can be used as a model for developing detailed and industry specific methodologies for operations systems design. As has been shown in the case of the original DRAMA methodology within ICL, such methodologies can then be evolved as a set of guiding principles highlighting the viable options for an organization and their related features.

9.7 Summary

This chapter has demonstrated how the basic DRAMA model has been evolved and developed into the more comprehensive DRAMA II model. In so doing the determining factors and the relationships within the design process for production systems have been identified and incorporated into the model. DRAMA II provides a generic, idealised and, what might be termed "best practice", approach to design for each of the ten DRAMA II components. The primary purpose for this is to provide a benchmark against which the researcher or practitioner can compare actual and observed system design activities. The chapter went on to explain how the DRAMA II model can be used as a framework for research analysis by the academic community when studying production system design processes. Moreover it was reiterated that DRAMA II has relevance for practitioners and it was shown how the model can be adopted to assist in the development of application specific design methodologies. Finally the contribution of DRAMA II to the theory of production systems design and, most notably, its links to strategy was presented. Indeed the main use of the model is seen as providing a structure for the analysis of manufacturing decisions on the formulation of strategy and its translation into choice of processes.

It is argued that DRAMA II has generic applicability: certainly the model holds across the defined range of organizations and operations studied within this research project. DRAMA II represents a generalisation of the DRAMA model to make it valid as an analytical tool across a wide range of manufacturing contexts. The term "analytical tool" is important to stress and will be explained here as it reflects a change in emphasis in the use of the model. The original DRAMA methodology for electronics assembly systems design was developed very much with the practitioner in mind. DRAMA II is geared more for use by researchers investigating the production system design process. It is therefore largely retained at the conceptual level of analysis and enables the user to tailor the generic model to their own particular organizational or operational requirements.

Chapter Ten:
CONCLUSIONS

10.1 Introduction

The detailed research findings of this study, from the analysis of case and survey data, have been presented in detail in Chapters 7 to 9. Chapter 7 considered production systems design within the context of strategic decision making, whereas Chapter 8 then went on to evaluate the process of translating plans and strategies into tactical and operational decisions for production. Both chapters adhered to the structure of the DRAMA model by considering each component of design in turn. Chapter 9 then demonstrated the evolution of the basic model into the extended, more widely validated, DRAMA II model. After presenting DRAMA II, the chapter went on to illustrate how the model can be used by the researcher as a framework for research enquiry into the process of production systems design and also showed how it could be utilised by the practitioner in developing application specific design methodologies. It was then argued that DRAMA II's contribution to theory on manufacturing management and production systems design is its ability to translate and link strategic decisions on manufacturing with the tactical and operational concerns of designing, implementing and operating production systems.

This concluding chapter does not intend to cover all the issues contained within Chapters 7-9 again; it is a concise summary of the major research findings and relates back, in the main, to the original aims and objectives of the research project. Firstly it considers the two research hypotheses set out at the start of the study as needing to be tested. It then discusses the extent to which DRAMA II, given the findings of the research, can claim to be a truly generic model of systems design. Finally, in summary, the aims and objectives of the study are considered and the extent to which these have been satisfied is discussed. The summary also suggests areas for future research into production systems design

10.2 Hypothesis One

The first hypothesis is:

"Production systems design can be represented by a generic process model across a defined range of operational and organizational contexts".

To reiterate, this hypothesis turned upon the extent to which the production systems design process has generalizable properties and features across different industrial and organizational contexts and could, therefore, be represented by a single model of design. The research has considered this using the original DRAMA model and associated methodology as a starting point and then using this basic framework to adopting a number of levels of organizational analysis, from strategic choices to the more routine activities of equipment selection and deciding exact methods of work.

The original DRAMA model and methodology, being developed for use in the electronics assembly industry, exhibited some limitation in the case study analysis by nature of its specificity. The basic DRAMA model, showing components in relation to hierarchical domains of decision making, did have some relevance and use in analysing the design process across the range of industries and companies studied, but was rather too generalised to provide any more than a conceptual view. Because of its properties and simplicity the basic DRAMA model was retained, but a more detailed DRAMA II was developed to assist in a more detailed representation of production systems design. The main strength of DRAMA II, and its main advantage over the previous DRAMA model, is that it considers the *process* of design rather than attempting to identify discrete *design options* available to the systems designer. Design options vary considerably between industries particularly when designing the operating system, but the process of design including the main determinants on the decision process, the relationships between different components and the generalised *best practice* approach to designing new production systems is not considerably dissimilar across different applications. It is more a matter of variations in emphasis and different weights for some of the relationships and determining factors rather than these factors being significantly different.

The conclusion in relation to hypothesis one is, therefore, that production systems design can be represented by a generic process model across the range of operational and organizational contexts examined in this research. However it is recognized that limitations exist in the model's application for specific purposes. DRAMA II now provides a framework which assists in the analysis of operations systems design and more fully assists the researcher in the analysis of the production systems design process within organizations. The model is most effective at the conceptual level of analysis and cannot purport to provide guidance in all aspects and levels of production system activity in all circumstances. Systems will always be developed in unique and specific ways to satisfy different requirements and specifications: no one system design project is identical in every detail to another. To argue, however, that there are no common principles and similarities, and that lessons cannot be drawn from one situation for use within a different context, is to deny the existence of any theory of production management and design. Clearly this is not the case, and DRAMA II represents a model capable of providing a framework for identifying similarities and differences within each of its components and domains of decision making across different applications.

10.3 Hypothesis Two

Hypothesis two states that:

> *"Production systems design is most strongly determined by market and environmental factors as reflected within corporate and manufacturing strategies".*

This second hypothesis was developed because the researcher wanted to investigate the commonly held assumption in prescriptions for systems design and operation that market determines strategy and design, and not the other way. The thesis has therefore explored the relationships between markets, strategy and process choices.

The survey of production system design was probably most enlightening in respect to the hypothesis. It was found that customer/market demand and competitive threat accounted for 82.2% of the collective stimuli for new product development[1], but only around 55.1% as an influence upon the process of marketing strategy formulation[2] and 44.6% of the total factors stimulating the need to design new production systems[3]. On the basis of these figures one might argue that market and environmental issues are major determinants, but not the only ones and that their influence lessens the more one moves away from the strategic domain of decision making and into the tactical and operational areas. This is self-evident as systems designers will tend to have less contact with customers and external parties, given the nature of their job, than those employed in marketing, sales or other customer liaising departments. However the hypothesis does not merely consider direct market and environmental influences such as customers and competitors, but also their indirect influence via corporate and marketing strategy formulation. When one considers this, the influence of market and environment is greater as corporate and marketing strategies are key parameters to many of the DRAMA II design components. The research also indicated that production systems design projects are frequently seen within the organization as technical projects. Indeed, "advances in manufacturing technology" and "advances in product technology" were given overall weighting figure of 24.6% and 12.2% as factors stimulating the need to design new production systems.[4] Thus, taken overall for all companies surveyed, direct market and environmental determinism as a factor behind new systems development came out to the already quoted figure of 44.6% versus direct technological determinism (product and process) at 36.8%[5]. However there were variations between industries. Table 10.1 shows that the electronics industry placed less importance on technology as a stimulus for new production systems design than the other industries: somewhat surprising given the high-tech nature of the industry, but probably explained by the high levels of competition in the industry.

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1 Figures from Table 6.2.

2 Figures from Table 6.3.

3 Figures from Table 6.12.

4 ibid.

5 ibid.

Table 10.1: Market and Technological Determinism as Factors in Production Systems Design[6]

(Figures show the degree of influence for each factor)

Factor	*Electronics Assembly*	*Electrical Engineering*	*Mechanical Engineering*	*Carpet Manufacture*	*Overall*
Market and Environment	55.5%	35.0%	33.4%	54.0%	44.6%
Technology	20.0%	38.3%	45.9%	40.0%	36.8%

So, in relation to the hypothesis, it was found that market considerations, as interpreted by organizations in their marketing and manufacturing strategies, do play their part in shaping the design of production systems. Likewise, the currently available technology also determines systems configuration and the observed tendency towards a technological fix amongst many practising engineers was plain to see in a number of the cases studied. Indeed, if one were to prescribe an approach to the design of effective production systems within a market economy one would logically argue the need for an overriding market driven approach coupled with the adoption of the latest and most appropriate manufacturing technologies. However it must be recognized that, despite the appeal of a market-focused approach to systems design, production system design in practice often does not follow such a logical and idealised course.

The evidence from the case study observations and the conclusions of the organization theory literature is that market, environmental and strategic factors are not, in themselves, the only influences upon the decision making process for new systems. Much of the "open systems orthodoxy" identified in the organizational development literature by Silverman (1970) and Reed (1985) amongst others could also be a criticism of most of the literature on manufacturing strategy and production systems design. The current author is as guilty as any other in taking this stance on occasions which underplays and can distract from the effect of internal influences upon design from within the organization. In just the same way as organization size and power-control relations, in addition to market, strategy and

[6] ibid.

technology, are seen as important determinants of organization structure, likewise they influence and shape eventual systems designs. Organization structure, conflict, culture and inertia (largely governed by a company's history) all have their influence upon the system design process: they explain why the design process and eventual configuration of facilities differ between organizations, even where companies are offering comparable products to the same markets. The second hypothesis is therefore rejected as merely a partial explanation of the determinants involved in production system design.

10.4 DRAMA II: Generic Model for Production Systems Design?

Beyond merely testing the selected hypotheses, this research has had the principal aim of developing a generic process design methodology. Chapter 9 described and presented this model and demonstrated how it might be used by the research community as a framework for analysing design activities. Furthermore it was shown that DRAMA II still retained, and actually enhanced, the ability to act as the initial model from which application and industry specific design methodologies for new production systems might be developed, whereby discrete design options and specific methodologies for each component might be developed.

Within the limitations of this project is has only been possible to assess the generic applicability of DRAMA II within the four chosen industry sectors. With this in mind it is impossible at this point to uphold that the model is applicable to every organizational and industrial situation. In the absence of absolute proof, however, there appears to be no apparent reason to project that DRAMA II does not have generic properties across the full range of manufacturing situations. The model is adaptable and has never claimed to identify every single relationship in all circumstances, or the exact importance of every determinant and influence to cover every production system design project. Instead it is the responsibility of the user to adopt the framework to identify the key factors and nuances in the design process for each application.

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egies, was rejected as merely a partial explanation of the imperatives upon the process roduction system design. Although seen as a major influence, the relationship was seen le largely indirect at the level of systems design and, in any case, the decision process bject to many other influences including technology, organizational size, structure and re, politics, and relationships of power and control. Although, in an idealised world, would espouse the virtues of the design process being largely market driven, one has cognize that the actual process of design in many companies is far from this ideal and, result, can be slow to react and change. These considerations must all be taken into unt when conducting an analysis of a system design process using DRAMA II.

conclude the dissertation I will finally return the main aims and objectives of the rch project and suggest the extent to which these have been satisfied and achieved. main aim was to evaluate and translate the DRAMA model of production systems n into a form whereby it would have generic applicability across a wide range of facturing situations.[7] The development of the DRAMA II model (Decision Rules for ysing Manufacturing Activities) satisfies this aim. It comprises three mains elements: basic model from before, an extended model showing influencing factors and onships upon and between design components, and a series of generic approaches to n for each of the ten components of the model to facilitate comparative work in rch enquiry. DRAMA II provides a framework of analysis for researchers to use analysing production systems design processes and can also be used by practitioners ucture their design activities. The model blends theories of strategy formulation, ization and production systems design with current practice as observed within a er of companies from a range of industries. As such it has been developed on the of the firm foundations of academic rigour blended with empirical observation and trial relevance.

eneral aim was unpacked into two primary objectives: to further validate DRAMA model for production systems design within the UK electronics industry; and to der the applicability of DRAMA as a generic model for production systems design

the Aims and Objectives section (1.2) in Chapter 1.

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Appendix A

Pro Forma for Initial Site Visit

Type of production system:

Project	☐
Small Batch	☐
Large Batch	☐
Line	☐
Process	☐

The Corporate Context

1. Could you provide some basic information on your organization; ie:
    - its history?
    - number of manufacturing locations?
    - organization structure in this factory?
    - where this factory fits within this organization?
    - degree of autonomy for factory?
    - corporate objectives?
    - number of employees: overall company and this factory?
    - range of products/services?

2. Could you describe some of the major features of the markets in which your Company operates; ie:
    - Major customers and product/geographical markets
    - Major competitive pressures?
    - Nature of customer demands?
    - On what criteria does a customer normally choose between the products of competing companies in your industry?
    - Changes in customer requirements over the last five to ten years?

Manufacturing Strategy

3. How would you summarise your manufacturing strategy; ie:
    - What are your main priorities in manufacturing:
        - costs?
        - machine productivity?
        - quality?
        - inventory management?
        - any other?
        - output?
        - labour productivity?
        - customer service?
        - production yields?
    - Are manufacturing objectives quantified, or are they qualitative in nature?

Design and Operation

4. Describe the process of product design and introduction within your organization, specifying which personnel are involved and at what stage.

5. Describe the production facilities and manufacturing operations in your factory.

6. When where these facilities installed, and who was involved in the production system design process?

7. Describe the operations planning and control systems and procedures within the factory.

8. Summarise the personnel or employment policy within the company?

9. How would you describe the nature of work for employees within your factory?

10. Describe how quality is managed within your company.

Appendix B

Example Completed Initial Visit Report

LUCAS RISTS LIMITED

Manufacturers of wiring harnesses and electrical systems for the automotive industry.

Lucas Rists Wiring Systems Limited
Lower Milehouse Lane
Newcastle-under-Lyme
Staffordshire ST5 5BG UK

Manufacturers of electrical components for the automotive industry.

Type of production system:

	Project	☐
	Small Batch	☐
	Large Batch	✓
	Line	✓
	Process	☐

The Corporate Context

1. Basic Information on Organization

The origins of Rists as an organization go back to 1902, but it was not until 1927 that A. Rists Limited was founded by name. In its early days the company was a supplier of magneto fly wheels to the Ford plant at Dagenham in Essex for "Model T" production. The Company first produced cables in 1930. Its earliest factories were located in London and, later, Lowestoft in Suffolk, close to the customer base. Lucas took a majority shareholding in Rists in 1929, although the degree of management autonomy within the company remained high. Albert Rists in fact continued to run the company until the time of his death in 1960. It was not until 1963 that the formal announcement of Rists as a subsidiary of Lucas was made, and the name "Lucas" was omitted from the official title of the Rists company until 1991.

The location of Rists' main factory and headquarters has changed twice since the early days. Between 1939 and 1945 the company turned its capacity over to the war effort, producing wiring products for military vehicles and aircraft, including the Spitfire. The proximity of the Lowestoft factory to the East coast of England, thus within reach of German bombing raids from Continental Europe, caused the company to relocate its facilities to a requisitioned plant at Nuneaton in Warwickshire. Shortly after the war, Rists once again looked for new premises. A large industrial plot, formerly occupied by

Rolls Royce, became available in Newcastle-under-Lyme, Staffordshire, and Rists moved into the town in 1946. Rists remains the largest employer in Newcastle to this day.

1987 saw the signing of a joint venture agreement between Rists and Sumitomo of Japan, the major supplier of harnesses to Honda, a venture which was logical given the close design links between Honda and Rover, and the fact that Rists has been the major supplier to the Rover Group, and Austin-Rover/British Leyland in the past. This deal is seen as an important milestone in the company's development. It is seen as the means to learn and develop Japanese inspired technologies and work practices and so better serve the emergent market conditions in the United Kingdom, which were at the time subject to the influence of Japanese transplant factories and Rover's close collaboration with Honda. In return, Sumitomo gained a manufacturing presence in EC markets to add to their facilities in Japan and the USA.

Rists has its headquarters at the Newcastle site, but now comprises two separate, but closely aligned companies. Lucas Rists Wiring Systems Limited and Lucas SEI Wiring Systems Limited (the Rists-Sumitomo joint venture). Lucas Rists has its manufacturing activities based at Newcastle, but also has smaller plants at Accrington in Lancashire and Shrewsbury in Shropshire, and supplies the more specialist, lower volume customers such as Jaguar, Rolls Royce, older Rover designs (eg: Metro), Lotus Cars, JCB, Ford Transit and Massey-Ferguson amongst others. Rists also produces cables and wiring as well as fuseboxes. The main manufacturing site of Lucas SEI is at Ystradgynlais near Swansea in South Wales and is aimed towards supplying wiring harnesses to Japanese and so-called "Japanese-influenced" car producers. Production for Rover-Honda collaborative car designs (ie: 200/400/600 series Rovers and Honda derivatives) is performed at Ystradgynlais, whereas harness production for the new UK Toyota plant near Derby in carried out in an autonomous part of the Newcastle plant (Newcastle was preferable to Toyota as it is more local to Derby). The case centres upon Lucas Rists at the Newcastle plant, although inevitably the joint venture "sister" company exerts a great influence on operations and management practices at the Newcastle site. Both companies have their own management team, although the Managing Director and General Manager is the same person for both companies. Rists' organization, however, is still characterised by a very conventional functional and hierarchical structure, and therefore can be seen as a very traditional British company in terms of dysfunctionality within the firm. The company as a whole employs at total of around 4000, about 2500 of whom at based at the headquarters making the company the largest employer in the town of Newcastle-under-Lyme.

The main corporate objective of the company is based upon profit making and return for shareholders. However market and competitive condition have been difficult over the last ten to fifteen years and the return on investment achieved by the company is reported as being disappointing.[1] Although attempting to growth its markets in the UK, the company has inevitably concentrated on cost reductions within the existing

[1] Please note that Lucas Rists do not publicly report their financial position: rather performance is subsumed and reported within the public reports of Lucas Industries as a whole.

operations in an effort to improve performance. Most striking in the last three-four years has been the reduction in the number of indirect employees which has involved voluntary and compulsory redundancies, early retirements and reallocations of staff. Despite these actions senior managers remain concerned about the continued poor profit performance, particularly now in 1994 with the growing success and increasing production volumes of its major customer, Rover Group.

2. Major Features of Markets

Lucas Rists is the largest indigenous UK manufacturer and supplier of wiring harnesses to the automotive industry. However, in global terms, the company is a relatively small operator, a fact which is becoming increasingly critical as the industry moves towards worldwide competition and product designs for cars become standardised (although in many variants) across the various markets (witness Ford's "World Car", the "CDW27, later introduced as the Mondeo). In such circumstances it is now apparent that "big is beautiful" in the eyes of the major car manufacturers when making the choice amongst component suppliers: after all, it requires huge resources and a worldwide network of manufacturing facilities and distribution channels to supply components and parts to all plants and markets. This has had major ramifications within the harness industry, Rists being no exception.

In 1990 Rists took a radical review of the way it viewed its market. Previously it segmented the market on the basis of a combination of product types (for example: cars, specialists, trucks, etc.) and geographical markets (UK, European, etc). However, it was argued that useful as this was as a means of dividing the market into types and for sales organization, it provided very little by means of strategic direction and corporate purpose. The company now views its market on a European basis and categorises its customer base into segments, namely:

High Volume Cars:	The major manufacturers in Europe such as Ford, GM, Renault, Fiat and Volkswagen, etc.
Japanese Influenced:	"JI" includes the Japanese transplants and, as a result of its Honda links, the Rover Group.
Technology-Led":	Incorporates the advanced high performance motor vehicle manufacturers, predominantly German companies such as Mercedes and BMW, but also Jaguar of the U.K.
Hi Volume Trucks:	The larger commercial vehicle and lorry manufacturers.
Specialists:	Small UK-based companies producing low volume vehicles ranging from Rolls Royce, Land Rover and Lotus to Massey Ferguson and JCB.

The strategy developed as a result of this analysis was to concentrate upon the JI sector of the market because this was an area where Rists was acquiring considerable expertise and experience through its relationships with the Rover Group and Honda and was the growth market in Europe at that time. Rists strategists also saw it important for the Company to hold on to the technology-led, and specialist customers its possessed in its portfolio to continue its links with its more traditional U.K. based customers.

In addition to segmenting the market along more appropriate and meaningful lines, Rists have conducted detailed market research on the way in which the company is perceived by existing and potential customers. Firstly customers were asked to prioritise their requirements from harness suppliers and, as might be expected, quality of design and efficiency of service came out with the highest ranking. Cost was relegated to a lower rating, although Rists' managers did question this as what the customers might say they require in a written questionnaire can vary quite considerably to their actions in the cut and thrust of negotiating contracts and choosing suppliers. Furthermore, the respondents were asked to rate their perceptions of Rists' performance in comparison with its major competitors against the competitive factors of quality, delivery, service, price, etc. The results have provided a benchmark in terms of customer perceptions of Rists versus the competition. The responses have been analysed in detail and a number of areas identified where shortcomings exist. This has been fed into the process of strategy formulation and recently the exercise has been repeated in an attempt to detect any shifts in customer perceptions.

Manufacturing Strategy

3. Summary of Manufacturing Strategy

As part of the Lucas Group, Rists are issued guidelines in the development of corporate strategy and are required to issue a statement on this in the form of a *Competitive Achievement Plan* (the "CAP") which needs to be approved by Lucas Main Board. The CAP is reviewed annually and amended accordingly. The document contains highly confidential material on the company's analysis of market and competitive factors and its proposed response to the identified threats and opportunities. Objectives are stated for the company overall and for individual functions within the organization. Thus there is a statement of intent for finance, personnel, marketing and sales, information technology, operations and engineering, as well as a global statement for quality. However this acts against the formulation of a wider strategy for manufacturing and tends to amplify the problems of the functional organization of the company. Manufacturing strategy could be seen as containing elements from the operations function's CAP statement as well as parts from engineering and information technology in particular. There thus exists no fully integrated and explicit statement of manufacturing strategy within the company: rather is it a composite of separate functional strategies, some of which in practice even conflict with one another.

The emphasis within the CAP statement stress the need for cost reductions coupled with the maintenance of high quality standards, short design and production lead-times, and technical design leadership to facilitate quality and delivery reliability. However, stated in a largely narrative form, objectives are qualitative in nature and could be characterised as statements of intent, rather than being quantitative and capable of performance evaluation.

Design and Operation

4. Product Design

Wiring harness manufacturers have rather an unusual relationship with their customers, the vehicle producers, when it comes to product design. The basic design and specification of the harness is within the domain of the automobile manufacturer. In designing a new vehicle the manufacturer decides the layout of lighting, engine electrics, interior and cockpit design and the range and type of standard and optional electrical and electronic equipment available to the car purchaser. The means that design for the harness manufacturer comprises the activity of translation and clarification of already well-defined customer requirements rather than the fundamental design work that companies need to undertake in some other industries. Conventional harness design involves prototyping harnesses through a number of iterations until the vehicle manufacturer arrives at a final decision upon the detailed car design and location of components and accessories. There is a considerable degree of trial and error involved in this process with as many as fifteen iterations until a satisfactory design and its methods of manufacture are determined. The consequence is a prolonged lead-time for product introduction through extensive "proving" of the harness and, as a result, a slow and often indeterminable response to customers' requests.

The company strategy of Rists outlined above now clearly states the need to respond faster and more effectively to customer needs. Within the area of product design and engineering there has been a twin attack on the reduction of product introduction times and improved methods of dealing with the customer. This has involved the use of *Guest Engineers* and the development of *Computer-aided Engineering* (CAE). Lucas Rists now deploy their own design engineers (guest engineers) to work within customer companies to assist in the design of new vehicles. By having a harness "specialist" on the customer site during design it is possible to detect implications and problems for harness engineering and manufacture as a resultant of the emergent design at an early stage. The guest engineer can advise the customer on alternative solutions to simplify or improve the quality and reliability of the vehicle's electrical system. Guest engineers from the customers are also deployed within Rists and bring their own specific vehicle design knowledge to product design within the supplier organization. In relation to CAE, Rists have now developed "Electronic Data Interchange" (EDI) links with two of its customers and aims to expand this to others. As a result of this the vehicle manufacturer can send its basic CAD-based harness design to Rists via electronic media. Compare this with the existing practice of the customer sending a hard copy of the design which Rists would then manually translate and redraw for input to its own CAD system. Further refinements to this system are being made in order to enable automatic transferral of customer designs in hours rather than the weeks involved in manual interpretation, testing and transfer.

The use of guest engineers and the development of CAE indicate that the way in which Rists now deals with its customers has changed significantly over the last five years. Close relationships and the sharing of relevant information have replaced the "dealing at arms' length" approach used in the past by Rists and which characterises much of customer-supplier relationships in U.K. manufacturing industry. Increased involvement and improved communications with the customer through guest engineering and CAE/EDI have been implicitly accepted as the key to reducing product introduction times, improving quality and cutting response times to customer enquiries.

5. Production Facilities and Manufacturing Operations

Despite advances in the automation of certain aspects of manufacture, the production of wiring harness remains largely a labour intensive process. The production of wiring harnesses can be divided into two stages: Lead Preparation/Subassembly and Harness Assembly. Each will be considered in turn.

Lead Preparation and Subassembly
Lead preparation are the operations which Rists' managers see most capable of being automated. Lead Preparation is where individual leads that are used in the final product can be cut to length, their ends stripped of insulation and the requisite terminals and connectors attached. Until recently only those leads required in large standardised quantities could be produced in this way because of constraints of machine set-up and quality assurance. Those leads not produced in Lead Preparation are produced in the "Subassembly" area where complex, unique or small-batch leads are terminated (and sealed with plastic sleeves where necessary) by hand. As machines develop, however, increasing numbers of lead types in increasingly small batches are capable of being produced automatically. The latest machines installed by Rists are able to cut, strip, terminate and block multiple leads. The result is that the amount of manual subassembly work is expected to diminish over the next two to three years. In fact one of the goals stated by a module process engineer to the research team is that Subassembly should be reduced to its minimal necessary size so that leads can be produced more cost effectively in a one-stage manufacturing process. The final subassembly stage is to collate the various leads that make up whole harnesses, or modules within them, and to perform necessary terminating, taping, grommeting and other operations upon these prior to their being passed forward to Harness Assembly operations. These "Pre-Blocking" operations are where the Company attempt to remove some of the complexity and its associated work content away from (and thus ensuring a continuous flow at) the final assembly stage. Given the complexity and variety of this work, it is necessary a manual process and is expected to remain so into the future.

Harness Assembly
Harnesses are assembled on a pre-prepared wooden "board" which is, in effect, a template controlling harness size and shape. The board includes comprising work instructions, wire routing runs and requisite pegs and clips to hold leads in place whilst assembling the harness. Boards are thus dedicated to individual harnesses although, if intelligently designed, they can cater for a range of variants on a basic design. The design of the harness and board are, as a result, interdependent and the effective and efficient design of boards is an important element in providing a fast response to customer requirements. Traditionally boards are designed using full size hand-drawn print-outs of the harness design and attached to a board. Board design using this method is to a certain extent a trial and error process where the best location of board

"components" (pegs, clips and the like) are determined through "proving" and reproving. Holes for the insertion of board components were drilled manually which the locations being taken from the drawings. Accuracy and repeatability were particularly acute problems in this method. Two major developments have taken place recently in board design to improve the accuracy and speed of these activities. The first is the introduction of a computer controlled gantry facility incorporating a "laser" cutter which can be fed the x-y coordinates of holes to be inserted and then cut the holes in the board more accurately and consistently from board to board than can be achieved manually. Linked to this, the second development is to eliminate the need for paper print-outs and generate board designs on the CAD system in engineering. Coordinates are then downloaded from CAD to the laser machine which then produces the board. Although these boards still need proving, the greater accuracy and lack of human intervention in the process will result in a more accurate initial board at an earlier time, thus reducing the number of design iterations and cutting down design leadtimes.

There are two methods of harness assembly currently being employed by Lucas Rists. The first is the traditional method of "static board" assembly. In this method the assembly operator assembles the whole harness from start to finish, but still produces in batch quantities. The newly adopted approach, which is now increasingly replacing static board production, is that of "carousel" manufacture. This still uses boards of the type used in the traditional method, but involves stage building of the harness where operators perform tasks within the overall assembly process as the boards move sequentially between workstations to the next. Carousel manufacture, which is best thought of as a form of "line" production, has for some time been used by Rists' joint venture partner, Sumitomo, to good effect. Carousels were introduced to the South Wales Ystradgynlais plant when it opened and are now being used to replace static board methods at the Newcastle plant when new harnesses, specially designed for carousel assembly, are introduced. One of the consequences with the introduction of carousels and the need for "line balancing" has been the increased amount of work needing to be performed away from the carousel itself. This has in fact resulted in a reduction of work content at Assembly and the formation of small feeder assembly modules alongside the carousel to perform some of these supporting activities.

6. Production System Design and Installation

The conventional lead preparation/subassembly workstations and the static board assembly stations have been in place over some considerable period of time. New installations tended, until recently, to have been restricted to single point automation such as the introduction of new, more automated bench presses and automatic taping dispensers. The last five years, however, has seen considerable investment in the installation of facilities to support new production methods. A number of progressively more sophisticated cut, strip and terminating machine in Lead Preparation have been installed and carousels for final harness assembly are being introduced throughout the Assembly cells. These developments have largely been conducted as technical projects and there appears to have been only limited consultation with non-technical staff, including shopfloor employees, in the introduction of these facilities.

7. Operations Planning and Control

A major project within Rists since 1987 has been the introduction of a Materials Requirements Planning (MRP) system to assist in the planning and control of operations. A major difficulty in introducing MRP was the numbers of production and assembly levels in the bills of materials (BOMs) and the vast number of individual stock items to go into the inventory status (IS) file used in the manufacturing process across the company. MRP is now increasingly being seen as the means for effective planning of operations and the specification of dates for purchase orders and the commencement of manufacture in order to achieve the master production schedules (MPS) for final harnesses. However, in terms of "real-time" control of processes and inventory, a number of initiatives have been taken to move towards a Just-in-Time (JIT) mode of operation. There are a number of ways in which this has been effected:

- i Reduction in batch sizes throughout the process generally;
- ii Specifically, for harness assembly, the gradual removal of old methods where preblocked collections of leads were supplied to board assembly in batches of 25 to the kitting of leads and components in containers for use at carousels.
- iii Related to ii, the initiation of "kanban" control of materials movement between subassembly and final assembly areas, and delivery to "point of use" workstations on the carousels.

Lucas Rists then, in line with other manufacturers in the UK, are concerned with developing a "hybrid" system comprising a longer term planing and scheduling element provided by MRP and a series of operational control mechanisms based upon JIT-pull type principles.

8. Personnel/Employment Policy

Rather than a single unified personnel policy within Rists, items such as "terms of employment" and union recognition vary from plant to plant. In newer factories, most notably Ystradgynlais, conditions of employment allow for considerable employee flexibility and mobility within the factory. In addition there is a single union agreement in place at Ystradgynlais. However such conditions of work and terms of employment have been difficult to introduce at Newcastle, an older and more change resistant plant. Here a more traditional British management/worker relationship exists, although steps have been taken towards improving communication, participation and employee involvement using newly installed production cells (especially the Lucas SEI Toyota cell) and total quality initiatives as the catalysts for change.

9. Work Organization

In the lead preparation the jobs can best be described as a combination of machine-minding and machine-setting. The development of advanced manufacturing technology in terms of cut, strip and terminate machines has called for increased skill on the part of employees to set these machines and in the use of computer-numerically controlled (CNC) systems. The development of the lead preparation area has had implications upon Subassembly processes in terms of removing some of the more repetitive bench-press operations which, although previously not performed in large enough batch sizes to justify being produced by machine, are now capable of being economically handled by Lead Preparation.

It is in the Harness Assembly area, however, where the largest implications for work design lie. The move from static board to carousel manufacture can be seen as a move from jobbing operations to line conditions where jobs are "task-orientated" involving short repetitive cycle time. Compare this with work design for static board assembly where jobs are "product orientated", meaning that assembly personnel manufacture the product with a "make-complete" approach.

Cellular working was introduced to Lucas Rists in the mid 1980s and its introduction was greatly influenced by the movement towards cellular manufacturing within the wider Lucas Industries organization. Definitions of cellular manufacturing vary considerably, but within Rists it involves the establishment of customer-focused production cells or "modules", hence the titles of the Rover 800 module, Jaguar XJ40 module, etc. In addition to increasing the focus upon individual customers and product types, the group working inherent in cellular organization has been seen as providing a range of benefits. By breaking the manufacturing process into a series of small autonomous production units, the cellular approach leads to greater accountability across product lines. This is now being taken a stage further by the appointment of "business managers", who take product design, customer relations and production for the items produced in one or a restricted number of modules. Secondly it is argued that the opportunity for job rotation frequently results in more varied and interesting jobs for workers. Converse to this, however, has been the counter claim that job satisfaction can fall due to the reduced variety of parts processed in a dedicated module compared to the range within a functional department.

Employee participation and involvement is allowed for through the usual channels of Works Councils and suggestion schemes, but in the late 1980s a "Continuous Improvement Group" (CIG) programme was introduced to supplement these activities and to encourage employees to become involved in the development and improvement of the business. In 1992 management-led kaizen was launched to the Newcastle plant, although these had been in existence at Ystradgynlais for some years. Kaizen was introduced to provide another vehicle for involvement and enable the Company to take advantage of the immense and largely untapped knowledge and expertise to be found within its employees.

10. Quality Management

Rists, like an increasing majority of manufacturing organizations, now give the need for product quality and customer satisfaction the highest priority within its corporate objectives. Quality is not only seen as "nice to have", but "essential" in order to remain competitive and its products attractive to the customer. Rists have attempted to implement some of the elements of Total Quality Management (TQM) and, within this, run a combination of management initiated and voluntary ("quality circle") improvement groups. Since 1992 there has been significant process towards TQM have been made within Rists, largely due to the influence of the quality management systems in place at the Lucas SEI plant in South Wales. May 1992 saw the launch of the Japanese-inspired continuous improvement programme known as *kaizen* where the emphasis is laid upon improved efficiency, service and quality through manufacturing process improvements within the factory.

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Appendix C

Example Interview Questionnaire

<u>System Design Process - 5046 line</u>

1. Could you run through the system design process for the 5046 assembly line project:

   (i) main stimuli?

   (ii) what were the underlying terms of reference and requirements that had to be borne in mind?

   (iii) how did these requirements change over time?

   (iv) how was the system justified: procedure?

   (v) who took the major decisions during the design process of 5046?

   (vi) describe your role in the system design process?

   (vii) who did you communicate with during the system design process? *(seniors, subordinates, vendors, prod.design, mktg?)*

   (viii) where any new forms of work organisation invoked during the system design process? *(formal/informal).*

   (ix) who else was involved in the design process? *(no. of man hours; participative approach: hinders progress?)*

   (x) what do you see is the role of external vendors in the development of new systems? How early are they involved?

   (xi) was the project well coordinated? *(ie: how long did it take; project management; timescales/pressures?)*

   (xii) what principle lessons can be drawn from your experiences for successful design and implementation of new systems?

2. Do you think it is possible to allow for future product designs within a single production system design based on current requirements?

Current Philosophy of Manufacture

3. Why flowlines instead of single stage workbench layout?

4. Why was parts kitting abandoned? If your volumes were lower and customisation higher, would kitting become more attractive?

5. Which types of flexibility are most important and need to be incorporated within your assembly operations:

- new product introduction?	*- delivery?*
- product variety (variety and volumes of products)?	*- volume?*
	- expnsion/contraction?
- product mix?	*- labour?*
- materials handling/routing?	

Can any of the above be integrated within a single system infrastructure? Do you see a trade-off between flexibility and "traditional" efficiency in the accomplishment of overall effectiveness?

6. Why deliver directly on to the line? In lower volume areas do you need to buffer material in a central Stores?

7. How are the Design/Manufacturing/Marketing interfaces managed?
   How often do you and your colleagues communicate personally with personnel from other plants and across functional/departmental boundaries?

Success Criteria

8. Do (CompanyName) perform post-evaluation of production systems? If so, what measures do you use in measuring the success or otherwise of a new manufacturing facility?

Appendix D

Survey Questionnaire

KEELE UNIVERSITY
STAFFORDSHIRE

MANUFACTURING STRATEGY AND PRODUCTION SYSTEMS DESIGN SURVEY QUESTIONNAIRE

MAIN PRODUCTS OF COMPANY? *(please state)*:

____

____

1. **What are the main stimuli for the development of new products in your organization:**

		Weight
	Customer/market demand?	( )
	Product technology?	( )
	Process technology?	( )
	Competitive threat?	( )
Others? *(please state)*:	__________	( )
	__________	( )
	Total	*(100)*

2. **To what extent do the following factors influence the process of marketing strategy formulation:**

		Weight
	Corporate objectives?	( )
	Customer needs?	( )
	Competitors?	( )
	Product diversity/range?	( )
	Market geography?	( )
	Product technology?	( )
	Production process technology?	( )
	Own manufacturing competences?	( )
Others? *(please state)*:	__________	( )
	__________	( )
	Total	*(100)*

3. **On what basis do customers evaluate and choose between the products of competing manufacturers in your industry:**

		Weight
	Price?	( )
	Quality?	( )
	Ability to supply specials/custom products?	( )
	Delivery performance?	( )
	After sales service?	( )
Others? *(state)*:	__________	( )
	__________	( )
	Total	*(100)*

4. **What have been the most significant changes in the market environment affecting manufacturing over the last ten years:**

		Weight
	Increased competition?	( )
	Reduced volume/variant?	( )
	Reduced product life cycles?	( )
	Increased product variety?	( )
	Number of optional extras?	( )
	Increased quality?	( )
Others *(please state)*:	__________	( )
	__________	( )
	Total	*(100)*

5. Does your company have a documented manufacturing strategy statement?

tick one

YES	( )
NO	( )

IF NO, GO STRAIGHT TO (6)

IF YES, briefly summarise or state the strategy below:

____
____
____
____
____
____
____

6. Who in your organization is involved in the formulation of <u>Manufacturing</u> strategy:

		Weight
(a) Executive Functions	Chief Executive?	( )
	Manufacturing Director?	( )
	Finance Director?	( )
	Marketing Director?	( )
Others? *(please state)*:	____________	( )
	____________	( )
	____________	( )
(b) Management Functions	Production Managers?	( )
	Engineering Managers?	( )
Others? *(please state)*:	____________	( )
	____________	( )
	____________	( )
	Total	*(100)*

7. Where do the greatest priorities lie within manufacturing:

		Weight
	Costs?	( )
	Machine productivity?	( )
	Labour productivity?	( )
	Product quality?	( )
	Service and response?	( )
	Inventory/stock levels?	( )
	Production yields?	( )
	Personnel development?	( )
Others? *(please state)*:	____________	( )
	____________	( )
	Total	*(100)*

8. Are your manufacturing objectives mainly quantitative or qualitative in nature:

tick one

MAINLY QUANTITATIVE	( )
MAINLY QUALITATIVE	( )

9. What proportion of your production operations are the following:

	Weight
"Make-to-order" jobbing?	( )
Small batch?	( )
Large batch?	( )
Mass manufacture?	( )
Continuous flow?	( )
Process manufacture?	( )
Total	*(100)*

10. To what extent is manufacturing vertically integrated? ***tick one***

Final Assembly/Processing of Bought-in Parts/Materials Only	( )
Components, Manufacture & Final Assembly/Processing Only	( )
Raw Material, Components Manufacture & Final Assy/Processing	( )

11. What are the major factors stimulating the need to design new production systems or redesign existing facilities:

	Weight
Changes in product market?	( )
Changes in customer needs?	( )
Competitive threat?	( )
New products?	( )
Advances in product technology	( )
Advances in manufacturing technology	( )
Others? *(please state)*: ______________________	( )
______________________	( )
Total	*(100)*

12. Which of the following best describe the structure of your manufacturing organization: ***tick more than one as appropriate***

5-6 levels from supervisor to M.D?	( )
3-4 levels from supervisor to M.D?	( )
Less than 3 levels from supervisor to M.D?	( )
Separate Systems Design and Production Functions?	( )
Separate Product Design and Production Functions?	( )
Product-focused?	( )
Process-focused?	( )
Matrix?	( )
Divisional	( )
Single site?	( )
Multiple site?	( )

13. Do you use temporary design teams/interdisciplinary task groups for the development of new production systems? ***tick one***

FREQUENTLY	( )
SOMETIMES	( )
NEVER	( )

14. What comparative weights are typically given to the following benefits when justifying investment in new production facilities:

		Weight
	Cost savings?	( )
	Market/customer responsiveness?	( )
	Quality improvements?	( )
	Inventory reductions?	( )
	Improved efficiency?	( )
	Improved working conditions?	( )
Others? *(please state)*:	____________________	( )
	____________________	( )
	Total	*(100)*

15. What measures are used for investment appraisal of new production systems:

		Weight
	Pay-back period?	( )
	Internal rate of return (IRR)?	( )
	Net present value (NPV)?	( )
Others? *(please state)*:	____________________	( )
	____________________	( )
	Total	*(100)*

16. To which extent do the following people participate in production systems design projects:

		Weight
	Board Level Directors?	( )
	Finance Personnel	( )
	Engineers/technical staff?	( )
	Senior Production Managers?	( )
	Junior Production managers?	( )
	Production supervisors?	( )
	Shopfloor personnel?	( )
Others? (please state):	____________________	( )
	____________________	( )
	Total	*(100)*

17. Which of the people listed above in (16) have primary responsibility for:

(a) Day to day management of systems design projects? *(please state)*:

1.____________________

2.____________________

(b) Making decisions concerning expenditure? *(please state)*:

1.____________________

2.____________________

(c) Making decisions concerning physical systems? *(please state)*:

1.____________________

2.____________________

18. What are your labour and material costs as a percentage of total costs of manufacture? *(please enter % figure)*:

LABOUR: ______%

MATERIALS ______%

19. Which of the following are used within your manufacturing operations:

	tick
Total Quality Management?	( )
Flexible Manufacturing Systems (FMS)?	( )
Cellular Manufacture?	( )
Computer-Aided Design (CAD)?	( )
Computer-Aided Manufacture (CAM)?	( )
Computer Integrated Manufacture (CIM)?	( )
Robotics?	( )
Material Requirements Planning (MRP)?	( )
Manufacturing Resources Planning (MRPII)?	( )
Just-in-Time (JIT)?	( )
Kanban?	( )
Other relevent concepts/ technologies? *(please state)* ____________________	( )
____________________	( )

20. Which of the following are the most important demands upon your production operations: *(please rank order)*:

	rank
Speed of new product introduction?	( )
Ability to offer a wide range of product types?	( )
Ability to provide a variety of product variants?	( )
Flexibility of materials handling/routing?	( )
Labour flexibility in terms of multi-skilling?	( )
Labour flexibility in terms of mobility?	( )
Delivery speed?	( )
Delivery reliability?	( )
Ability to alter volumes?	( )
Long term expansion/contraction of facilities?	( )
Others? *(please state)*: ____________________	( )
____________________	( )
____________________	( )

21. What formal or informal schemes are offered to employees to allow participation and awareness in the Company's operations:

	tick
Quality circles?	( )
Other quality improvement teams?	( )
Task forces?	( )
Suggestion schemes?	( )
Regular team briefing sessions?	( )
Working parties?	( )
Company newsletters?	( )
Others? *(please state)*: ____________________	( )
____________________	( )

22. Do you formally evaluate the success or otherwise of a new production facility once implemented?

	tick
ALWAYS	( )
SOMETIMES	( )
NEVER	( )

If ALWAYS or SOMETIMES, what measures do you use *(please state)*:

____

____

____

____

23. What measures are used to assess production performance in your organization:

		Weight
	Machine Efficiencies?	( )
	Labour Productivity?	( )
	Labour Costs?	( )
	Quality and Defective Levels	( )
	Delivery Performance?	( )
	Material Yields?	( )
	Inventory Levels?	( )
Others? *(please state)*:	________________	( )
	________________	( )
	Total	*(100)*

Thank-you for completing this questionnaire. Your cooperation and time in this matter is greatly appreciated.

Paul Forrester

Lecturer in Production Management
Centre for Graduate Management Studies
University of Keele

If you wish to receive a copy of the detailed results of this survey, please indicate so by inserting in your name and address below:

Name: ________________________________

Position: ________________________________

Company: ________________________________

Address: ________________________________

____

____

Appendix E

Detailed Survey Results

This appendix shows the individual responses of companies to the production systems design survey, as taken from a computer speadsheet, for each of the four selected industrial sectors:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
1. What are the main stimuli for the development of new products in your organisation:													
- Customer/market demand	80	30	60	50	50	70	80	30	50				55.56
- Product Technology	10	10	20	30	20	10	10	30	20				17.78
- Process Technology	0	10	5	0	0	0	0	20	0				3.89
- Competitive Threat	10	50	15	20	30	20	10	20	30				22.78
Others: -													0.00
2. To what extent do the following factors influence the process of marketing strategy formulation:													
- Corporate objectives	30	0	0	0	0	20	10	10	0				8.75
- Customer needs	50	50	30	50	0	50	40	40	40				43.75
- Competitors	0	50	20	10	0	0	30	10	20				17.50
- Product diversity/range	0	0	40	5	0	15	0	20	10				11.25
- Market geography	20	0	0	5	0	0	5	0	0				3.75
- Product technology	0	0	5	20	0	15	15	20	30				13.13
- Prod'n process technology	0	0	5	0	0	0	0	0	0				0.63
- Own manuf'g competences	0	0	0	10	0	0	0	0	0				1.25
Others: -													0.00
-													0.00
3. On what basis do customers evaluate and choose between the products of competing manufacturers in your industry:													
- Price	20	30	20	20	0	20	30	30	20				21.11
- Quality	20	30	40	30	40	30	50	40	40				35.56
- Supply specials/customs	20	0	40	0	5	30	0	10	0				11.67
- Delivery performance	20	0	0	0	40	20	10	20	20				14.44
- After sales service	20	10	0	20	15	0	10	0	20				10.56
Others: - Product performance		30											3.33
- First to market				20									2.22
- Company/brand loyalty				10									1.11
-													0.00
-													0.00
4. Most significant changes in market/environment affecting mfg over the last ten years:													
- Increased competition	0	100	20	10	30	20	50	10	30				30.00
- Reduced volume/variant	30	0	0	0	0	0	0	10	0				4.44
- Reduced product life cycles	50	0	40	40	40	20	30	50	40				34.44
- Increased product variety	0	0	20	0	30	20	10	10	0				10.00
- Number of optional extras	10	0	10	0	0	30	0	10	0				6.67
- Increased quality	10	0	10	40	0	10	10	10	30				13.33
Others: - Flexibility/volume changes				10									1.11
-													0.00
-													0.00
5. Does your company have a documented manufacturing strategy:													
- YES	1	1	1	1	0	0	1	1	0				67%
- NO	0	0	0	0	1	1	0	0	1				33%

(If yes, summarised in file COMMENTS)

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
6. Who is involved with the formulation of manufacturing strategy:													
- Chief executive	0	10	10	10	0	0	0	0	20				5.56
- Manufacturing director	10	25	40	30	0	40	40	30	30				27.22
- Finance director	0	25	10	0	60	20	20	10	10				17.22
- Marketing director	0	0	0	0	0	0	0	0	0				0.00
- Engineering/Tech. director													0.00
Others: - General Manager (Site)	20												2.22
- Operations Director			20										2.22
- Production Managers	5	20		30	40	10	20	20	20				18.33
- Engineering Managers	20	20	20	30	0	20	20	20	20				18.89
Others: - Systems Manager	10												1.11
- Materials Manager	20							10					3.33
- Financial Controller	10												1.11
- Personnel Manager	5							10					1.67
- Design Manager						10							1.11
-													0.00
7. Where do the greatest priorities lie within manufacturing:													
- Costs	20	50	20	30	0	30	30	10	30				24.44
- Machine productivity	0	0	20	0	0	0	0	10	0				3.33
- Labour productivity	0	0	30	0	35	10	0	0	10				9.44
- Product quality	30	50	20	30	20	30	30	30	30				30.00
- Service and response	20	0	0	30	10	20	20	30	20				16.67
- Inventory/stock levels	20	0	5	5	0	10	10	10	10				7.78
- Production yields	0	0	5	5	35	0	0	10	0				6.11
- Personnel development	10	0	0	0	0	0	10	0	0				2.22
Others: -													0.00
-													0.00
-													0.00
8. Manufacturing objectives:													
- Mainly quantitative	0	0	0	1	0	0	1	1	0				33%
- Mainly qualitative	1	1	1	0	1	1	0	0	1				67%
9. What proportion of your production operations are the following:													
- Make to order jobbing	0	0	50	40	0	20	0	10	40				17.78
- Small batch	100	0	50	60	0	80	50	60	60				51.11
- Large batch	0	0	0	0	40	0	0	0	0				4.44
- Mass manufacture	0	0	0	0	60	0	0	0	0				6.67
- Continuous flow	0	100	0	0	0	0	50	0	0				16.67
- Process manufacture	0	0	0	0	0	0	0	30	0				3.33
10. To what extent is manufacturing vertically integrated:													
- Final assy/processing	100	90	0	100	0	0	75	10	100				53%
- Components, etc..	0	10	100	0	100	100	25	60	0				44%
- Raw materials, etc..	0	0	0	0	0	0	0	30	0				3%
11. What factors stimulate the need to design new production systems or redesign existing facilities:													
- Changes in product market	50	0	10	0	0	30	20	10	10				14.44
- Changes in customer needs	30	0	30	30	0	20	30	10	20				18.89
- Competitive threat	0	100	20	0	30	20	20	10	0				22.22
- New products	20	0	10	70	10	30	20	10	50				24.44
- Advances in product tech'y	0	0	20	0	60	0	10	30	20				15.56
- Advances in mfg tech'y	0	0	10	0	0	0	0	30	0				4.44
Others: -													0.00
-													0.00
-													0.00

12. Which of the following best describe the structure of your manufacturing organization:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- 5-6 levels	1	0	0	0	0	0	0	1	0				22%
- 3-4 levels	0	1	1	0	1	1	1	0	1				67%
- < 3 levels	0	0	0	1	0	0	0	0	0				11%
- Separate sys des/prod'n fn.	0	0	1	1	0	0	0	0	1				33%
- Separate prdt des/prd'n fn.	1	0	0	1	0	0	1	1	1				56%
- Product-focused	0	0	1	1	1	1	1	0	1				67%
- Process-focused	1	0	0	0	0	0	0	1	0				22%
- Matrix	1	0	0	0	0	0	1	1	0				33%
- Divisional	0	0	0	1	0	0	0	0	0				11%
- Single site	1	0	0	1	0	1	1	0	0				44%
- Multiple site	0	0	1	0	1	0	0	1	1				44%

13. Do you use temporary design teams/ interdisciplinary task groups for the development of new prod'n systems:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Frequently	1	0	0	1	0	0	1	0	0				33%
- Sometimes	0	0	1	0	0	1	0	1	0				33%
- Never	0	1	0	0	1	0	0	0	1				33%

14. What comparative weights are typically given to the following benefits when justifying investment in new production facilities:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Cost savings	0	70	80	20	50	40	40	30	20				38.89
- Market/customer req'ts	30	0	0	30	0	0	0	30	60				16.67
- Quality improvements	10	30	10	25	20	20	40	20	10				20.56
- Inventory reductions	50	0	10	5	0	10	10	20	0				11.67
- Improved efficiency	0	0	0	20	30	20	0	0	10				8.89
- Improved working conditions	10	0	0	0	0	10	10	0	0				3.33
Others: -													0.00
-													0.00
-													0.00

15. What measures are used for investment appraisal of new systems:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Pay-back period	0	100	90	100	75	50	100	0	100				68.33
- Internal rate return (IRR)	100	0	10	0	25	50	0	100	0				31.67
- Net present value (NPV)	0	0	0	0	0	0	0	0	0				0.00
Others: -													
-													
-													

16. To what extent do the following people participate in production systems design projects:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Board level directors	0	0	5	0	0	0	0	0	0				0.56
- Finance personnel	0	0	0	0	0	0	0	10	0				1.11
- Engineers/technical staff	40	70	75	45	70	70	50	50	80				61.11
- Senior production managers	30	10	0	10	10	20	20	20	20				15.56
- Junior production managers	10	10	0	30	0	10	15	10	0				9.44
- Production supervisors	10	10	20	10	20	0	10	5	0				9.44
- Shopfloor personnel	10	0	0	5	0	0	5	5	0				2.78
Others: -													0.00
-													0.00
-													0.00

17. Who has primary responsibility for:

(a) Day to day management of design:

	1	2	3	4	5	6	7	8	9	AVERAGE
- Board level directors	0	0	0	0	0	0	0	0	0	0%
- Finance personnel	0	0	0	0	0	0	0	0	0	0%
- Engineers/technical staff	1	1	1	1	1	1	1	1	1	100%
- Senior production managers	0	0	0	0	0	0	0	1	0	11%
- Junior production managers	0	0	0	1	0	0	1	0	0	22%
- Production supervisors	0	0	0	0	0	0	0	0	0	0%
- Shopfloor personnel	0	0	0	0	0	0	0	0	0	0%
Others: -										
-										
-										

(b) Making decisions on expenditure:

	1	2	3	4	5	6	7	8	9	AVERAGE
- Board level directors	1	1	1	0	1	0	0	1	1	67%
- Finance personnel	1	1	0	0	0	1	1	1	0	56%
- Engineers/technical staff	0	0	0	1	0	0	0	0	1	22%
- Senior production managers	1	0	0	0	0	1	1	0	0	33%
- Junior production managers	0	0	0	1	0	0	0	0	0	11%
- Production supervisors	0	0	0	0	0	0	0	0	0	0%
- Shopfloor personnel	0	0	0	0	0	0	0	0	0	0%
Others: -										
-										
-										

(c) Making decisions on phy. system:

	1	2	3	4	5	6	7	8	9	AVERAGE
- Board level directors	0	0	0	0	0	0	0	0	0	0%
- Finance personnel	0	0	0	0	0	0	0	0	0	0%
- Engineers/technical staff	1	0	1	1	0	1	1	1	1	78%
- Senior production managers	1	0	0	0	1	0	1	1	0	44%
- Junior production managers	0	0	0	1	0	1	0	0	0	22%
- Production supervisors	0	0	0	0	0	0	0	0	0	0%
- Shopfloor personnel	0	0	0	0	0	0	0	0	0	0%
Others: -										
-										
-										

18. Costs as a percentage of total manufacturing costs:

	1	2	3	4	5	6	7	8	9	AVERAGE
- Labour	5	8	4	4	36	10	20	5	20	12%
- Materials	85	82	76	84	54	75	70	70	70	74%
- Overheads	10	10	20	12	10	15	10	25	10	14%

19. Which of the following are used within manufacturing operations:

	1	2	3	4	5	6	7	8	9	AVERAGE
- TQM	1	1	0	1	0	1	1	1	0	67%
- FMS	1	1	0	0	0	0	0	0	0	22%
- Cellular manufacturing	1	1	1	1	0	1	1	1	1	89%
- CAD	0	1	1	1	1	1	1	1	1	89%
- CAM	1	1	1	0	1	0	0	1	0	56%
- CIM	1	1	0	0	0	0	0	1	0	33%
- Robotics	1	1	0	0	0	0	1	1	0	44%
- MRP	1	1	1	1	0	1	1	1	1	89%
- MRPII	0	1	1	1	0	1	0	1	0	56%
- JIT	1	1	0	1	0	1	1	1	1	78%
- Kanban	1	1	0	1	0	0	1	1	0	56%
Others: -										0%
-										0%
-										0%

20. Which of the following are the most important demands upon your production operations (rank order):

	- Speed of new prod. intro.	4	1	1.5	3	1	1	2	1	1	1.7
	- Ability to offer prod range	2	6	7	7.2	3	4	5	4	4	4.7
	- Ability to offer prd varnts	5	6	1.5	7.2	8	2	6	3	5	4.9
	- Flex'y matls hand/routing	3	6	7	7.2	8	7.5	9	10	8	7.3
	- Lab flexy: multi-skilling	6	6	3	4	8	7.5	7	8	6	6.2
	- Lab flexy: mobility	7	6	7	5	5	7.5	8	7	9	6.8
	- Delivery speed	8	6	7	7.2	3	7.5	4	5	2	5.5
	- Delivery reliability	9	6	7	1	3	7.5	1	2	3	4.4
	- Ability to alter volumes	1	6	7	6	8	3	3	6	7	5.2
	- Long term expan/contract	10	6	7	7.2	8	7.5	10	9	10	8.3
Others:	- High quality				2						
	-										

21. What formal/informal schemes are offered to employees to allow participation/awareness in the company's operations:

	- Quality circles	1	0	0	0	0	0	1	1	0	33%
	- Other qlty improvem't teams	1	1	1	1	0	1	1	1	1	89%
	- Task forces	0	0	1	0	0	0	0	1	0	22%
	- Suggestion schemes	1	1	1	1	1	1	1	1	1	100%
	- Regular team briefing	1	0	1	1	1	1	1	1	0	78%
	- Working parties	1	0	0	0	0	0	1	0	0	22%
	- Company newsletters	1	1	0	1	1	1	1	1	0	78%
Others	- Gen. qlty culture/involvemt		1								11%
	- Coffee talks (all staff wk)				1						11%
	-										0%
	-										0%
	-										0%

22. Do you formally evaluate the success of a new production facility once implemented:

- Always	0	1	1	1	0	0	1	0	0	44%
- Sometimes	1	0	0	0	1	1	0	1	1	56%
- Never	0	0	0	0	0	0	0	0	0	0%

(Measures used summarised in file COMMENTS)

23. What measures are used to assess production performance:

	- Machine efficiencies	0	0	20	0	0	0	0	10	0	3.33
	- Labour productivity	0	0	30	0	40	30	20	0	10	14.44
	- Labour costs	0	0	30	0	25	10	10	0	10	9.44
	- Quality/defective levels	20	50	20	16.7	35	30	30	30	40	30.18
	- Delivery performance	60	40	0	16.7	0	20	30	50	40	28.52
	- Material yields	0	0	0	16.7	0	0	0	0	0	1.86
	- Inventory levels	20	10	0	16.7	0	10	10	10	0	8.52
Others	- Unit costs				16.7						1.86
	- Daily build v target				16.7						1.86
	-										0.00
	-										0.00

1. What are the main stimuli for the development of new products in your organization:							
- Customer/market demand	80	80	100	10	50	100	70.00
- Product Technology	0	20	0	30	10	0	10.00
- Process Technology	0	0	0	0	0	0	0.00
- Competitive Threat	20	0	0	60	40	0	20.00
Others: -							0.00

2. To what extent do the following factors influence the process of marketing strategy formulation:							
- Corporate objectives	40	20	10	20	10	0	16.67
- Customer needs	40	60	80	10	20	50	43.33
- Competitors	20	10	10	20	30	0	15.00
- Product diversity/range	0	0	0	10	0	0	1.67
- Market geography	0	0	0	0	20	0	3.33
- Product technology	0	10	0	40	20	30	16.67
- Prod'n process technology	0	0	0	0	0	0	0.00
- Own manuf'g competences	0	0	0	0	0	20	3.33
Others: -							0.00
-							0.00

3. On what basis do customers evaluate and choose between the products of competing manufacturers in your industry:							
- Price	40	15	10	50	50	30	33.05
- Quality	40	40	40	30	25	50	38.14
- Supply specials/customs	0	20	10	10	10	0	8.47
- Delivery performance	0	25	40	0	15	20	16.95
- After sales service	20	0	0	0	0	0	3.39
Others: -							0.00
-							0.00
-							0.00
-							0.00
-							0.00

4. Most significant changes in market/environment affecting mfg over the last ten years:							
- Increased competition	20	20	0	70	40	0	25.00
- Reduced volume/variant	0	10	0	0	10	30	8.33
- Reduced product life cycles	20	40	60	10	10	50	31.67
- Increased product variety	0	10	20	20	20	0	11.67
- Number of optional extras	20	0	0	0	0	0	3.33
- Increased quality	40	20	20	0	20	20	20.00
Others: -							0.00
-							0.00
-							0.00

5. Does your company have a documented manufacturing strategy:							
- YES	1	1	1	0	0	0	50%
- NO	0	0	0	1	1	1	50%

(If yes, summarised in file COMMENTS)

6. Who is involved with the formulation of manufacturing strategy:							
- Chief executive	40	30	20	30	0	20	24.14
- Manufacturing director	30	30	20	40	60	20	34.48
- Finance director	30	10	20	10	40	10	20.69
- Marketing director	0	10	10	0	0	20	6.90
- Engineering/Tech. director	0	0	0	20	0	0	3.45
Others: -							0.00
-							0.00
- Production Managers	0	10	10	0	0	0	3.45
- Engineering Managers	0	10	10	0	0	10	5.17
Others: -			10		0		1.72
-							0.00
-							0.00
-							0.00
-							0.00
-							0.00

7. Where do the greatest priorities lie within manufacturing:							
- Costs	30	20	20	30	40	25	27.50
- Machine productivity	0	5	0	0	10	0	2.50
- Labour productivity	0	10	0	20	10	0	6.67
- Product quality	30	30	30	25	30	50	32.50
- Service and response	40	30	50	20	10	25	29.17
- Inventory/stock levels	0	5	0	5	0	0	1.67
- Production yields	0	0	0	0	0	0	0.00
- Personnel development	0	0	0	0	0	0	0.00
Others: -							0.00
-							0.00
-							0.00

8. Manufacturing objectives:							
- Mainly quantitative	1	0	0	1	1	0	50%
- Mainly qualitative	0	1	1	0	0	1	50%

9. What proportion of your production operations are the following:							
- Make to order jobbing	0	0	0	20	10	0	5.00
- Small batch	10	60	0	20	10	0	16.67
- Large batch	10	40	50	20	30	0	25.00
- Mass manufacture	0	0	0	0	0	0	0.00
- Continuous flow	80	0	50	40	50	100	53.33
- Process manufacture	0	0	0	0	0	0	0.00

10. To what extent is manufacturing vertically integrated:							
- Final assy/processing	90	100	100	60	40	100	82%
- Components, etc..	0	0	0	40	30	0	12%
- Raw materials, etc..	10	0	0	0	30	0	7%

11. What factors stimulate the need to design new production systems or redesign existing facilities:							
- Changes in product market	0	10	0	30	0	20	10.00
- Changes in customer needs	0	10	20	0	40	50	20.00
- Competitive threat	0	0	0	10	20	0	5.00
- New products	0	0	20	20	20	0	10.00
- Advances in product tech'y	0	30	20	20	20	15	17.50
- Advances in mfg tech'y	0	50	40	20	0	15	20.83
Others: - Quest for improved quality	50	0					8.33
- Quest for reduced cost	50	0					8.33
-							0.00

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
12. Which of the following best describe the structure of your manufacturing organization:													
- 5-6 levels	0	1	0	1	0	0							33%
- 3-4 levels	1	0	1	0	1	1							67%
- < 3 levels	0	0	0	0	0	0							0%
- Separate sys des/prod'n fn.	0	0	1	0	1	0							33%
- Separate prdt des/prd'n fn.	1	1	1	1	1	0							83%
- Product-focused	1	1	1	1	0	0							67%
- Process-focused	0	0	0	0	1	1							33%
- Matrix	0	1	1	0	0	0							33%
- Divisional	0	0	0	1	1	0							33%
- Single site	0	0	1	0	1	1							50%
- Multiple site	1	1	0	1	0	0							50%
13. Do you use temporary design teams/ interdisciplinary task groups for the development of new prod'n systems:													
- Frequently	1	1	1	0	0	0							50%
- Sometimes	0	0	0	1	0	1							33%
- Never	0	0	0	0	1	0							17%
14. What comparative weights are typically given to the following benefits when justifying investment in new production facilities:													
- Cost savings	80	60	40	50	30	20							46.67
- Market/customer req'ts	5	10	0	0	20	20							9.17
- Quality improvements	10	10	30	20	25	20							19.17
- Inventory reductions	5	0	30	20	5	20							13.33
- Improved efficiency	0	20	0	10	15	20							10.83
- Improved working conditions	0	0	0	0	5	0							0.83
Others: -													0.00
-													0.00
-													0.00
15. What measures are used for investment appraisal of new systems:													
- Pay-back period	50	100	100	0	50	100							66.67
- Internal rate return (IRR)	0	0	0	100	50	0							25.00
- Net present value (NPV)	0	0	0	0	0	0							0.00
Others: - Return on investment (ROI)	50												8.33
-													
-													
16. To what extent do the following people participate in production systems design projects:													
- Board level directors	0	10	0	0	0	0							1.67
- Finance personnel	10	0	0	0	0	0							1.67
- Engineers/technical staff	40	60	60	80	80	75							65.83
- Senior production managers	40	20	20	10	10	25							20.83
- Junior production managers	0	10	10	10	10	0							6.67
- Production supervisors	0	0	10	0	0	0							1.67
- Shopfloor personnel	10	0	0	0	0	0							1.67
Others: -													0.00
-													0.00
-													0.00

17. Who has primary responsibility for:							
(a) Day to day management of design:							
- Board level directors	0	0	0	0	0	0	0%
- Finance personnel	0	0	0	0	0	0	0%
- Engineers/technical staff	0	1	1	1	1	1	83%
- Senior production managers	1	0	0	0	0	0	17%
- Junior production managers	0	0	1	0	0	0	17%
- Production supervisors	0	0	0	0	0	0	0%
- Shopfloor personnel	0	0	0	0	0	0	0%
Others: -							
-							
-							
(b) Making decisions on expenditure:							
- Board level directors	0	1	0	0	1	1	50%
- Finance personnel	0	1	1	1	1	0	67%
- Engineers/technical staff	0	0	0	0	0	0	0%
- Senior production managers	1	0	1	1	0	0	50%
- Junior production managers	0	0	0	0	0	0	0%
- Production supervisors	0	0	0	0	0	0	0%
- Shopfloor personnel	0	0	0	0	0	0	0%
Others: -							
-							
-							
(c) Making decisions on phy. system:							
- Board level directors	0	0	0	0	0	0	0%
- Finance personnel	0	0	0	0	0	0	0%
- Engineers/technical staff	1	1	1	1	1	1	100%
- Senior production managers	0	1	1	1	1	0	67%
- Junior production managers	0	0	0	0	0	0	0%
- Production supervisors	0	0	0	0	0	0	0%
- Shopfloor personnel	0	0	0	0	0	0	0%
Others: -							
-							
-							
18. Costs as a percentage of total manufacturing costs:							
- Labour	16	40	40	25	30	15	28%
- Materials	64	40	50	60	50	60	54%
- Overheads	20	20	10	15	20	25	18%
19. Which of the following are used within manufacturing operations:							
- TQM	1	0	1	1	1	0	67%
- FMS	0	0	0	0	0	1	17%
- Cellular manufacturing	1	1	1	1	0	0	67%
- CAD	1	1	1	1	1	1	100%
- CAM	0	0	0	0	0	1	17%
- CIM	0	1	0	0	0	0	17%
- Robotics	0	0	0	0	0	1	17%
- MRP	1	1	1	1	1	0	83%
- MRPII	0	1	1	0	0	0	33%
- JIT	1	1	1	1	1	1	100%
- Kanban	0	1	1	1	1	0	67%
Others: -							0%
-							0%
-							0%

20. Which of the following are the most important demands upon your production operations (rank order):

- Speed of new prod. intro.	1	1	3	6	3	3	2.8
- Ability to offer prod range	7	7.5	10	9	5	9	7.9
- Ability to offer prd varnts	7	7.5	7	4	4	2	5.3
- Flex'y matls hand/routing	7	7.5	6	5	7	1	5.6
- Lab flexy: multi-skilling	7	7.5	9	8	9	4	7.4
- Lab flexy: mobility	3	7.5	5	7	8	5	5.9
- Delivery speed	7	3	2	1	1	6	3.3
- Delivery reliability	7	4	1	3	2	7	4.0
- Ability to alter volumes	2	2	4	2	6	8	4.0
- Long term expan/contract	7	7.5	8	10	10	10	8.8
Others: -							
-							

21. What formal/informal schemes are offered to employees to allow participation/awareness in the company's operations:

- Quality circles	0	0	0	1	1	0	33%
- Other qlty improvem't teams	1	0	1	0	0	0	33%
- Task forces	0	0	0	1	0	0	17%
- Suggestion schemes	1	1	1	1	1	1	100%
- Regular team briefing	1	1	1	1	1	1	100%
- Working parties	0	0	0	1	0	0	17%
- Company newsletters	1	1	1	1	1	1	100%
Others -							0%
-							0%
-							0%
-							0%
-							0%

22. Do you formally evaluate the success of a new production facility once implemented:

- Always	0	0	0	1	0	0	17%
- Sometimes	1	1	1	0	0	1	67%
- Never	0	0	0	0	1	0	17%

(Measures used summarised in file COMMENTS)

23. What measures are used to assess production performance:

- Machine efficiencies	0	10	0	0	0	10	3.33
- Labour productivity	0	20	30	20	0	10	13.33
- Labour costs	20	0	0	10	20	10	10.00
- Quality/defective levels	30	30	30	20	30	25	27.50
- Delivery performance	40	30	40	40	30	25	34.17
- Material yields	0	0	0	0	10	0	1.67
- Inventory levels	10	10	0	10	10	20	10.00
Others -							0.00
-							0.00
-							0.00
-							0.00

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
1. What are the main stimuli for the development of new products in your organization:													
- Customer/market demand	70	55	70	50	40	100	40	60	100	25	80	100	65.83
- Product Technology	0	20	20	10	0	0	30	0	0	25	10	0	9.58
- Process Technology	0	15	10	10	0	0	10	20	0	25	10	0	8.33
- Competitive Threat	30	10	0	30	60	0	20	20	0	25	0	0	16.25
Others: -													0.00
2. To what extent do the following factors influence the process of marketing strategy formulation:													
- Corporate objectives	50	25	10	10	20	15	5	40	0	0	20	40	20.09
- Customer needs	40	15	50	25	20	50	40	30	60	30	40	20	35.90
- Competitors	10	5	10	10	40	15	10	20	10	20	20	10	15.38
- Product diversity/range	0	5	10	0	0	0	5	0	0	20	0	10	4.27
- Market geography	0	5	0	0	0	0	10	0	10	0	0	0	2.14
- Product technology	0	10	10	25	10	0	30	0	10	10	10	10	10.68
- Prod'n process technology	0	15	10	20	0	10	0	0	0	10	0	0	5.56
- Own manuf'g competences	0	10	0	10	0	10	0	10	10	10	0	10	5.98
Others: -													0.00
-													0.00
3. On what basis do customers evaluate and choose between the products of competing manufacturers in your industry:													
- Price	70	25	40	30	20	25	50	60	10	50	40	40	38.66
- Quality	20	50	20	30	30	40	30	20	30	40	30	20	30.25
- Supply specials/customs	0	5	10	25	10	10	10	0	30	0	15	20	11.34
- Delivery performance	0	20	10	10	10	25	10	0	10	10	15	20	11.76
- After sales service	10	0	0	0	10	0	0	20	20	0	0	0	5.04
Others: - Performance characteristics			10	5	20								2.94
-													0.00
-													0.00
-													0.00
-													0.00
4. Most significant changes in market/environment affecting mfg over the last ten years:													
- Increased competition	60	10	20	20	30	10	60	70	0	50	50	80	38.33
- Reduced volume/variant	0	10	15	0	10	10	0	0	0	10	0	0	4.58
- Reduced product life cycles	10	15	15	20	10	20	20	0	20	20	0	0	12.50
- Increased product variety	30	5	10	30	10	25	0	0	40	10	10	0	14.17
- Number of optional extras	0	0	0	10	15	0	0	0	20	0	0	0	3.75
- Increased quality	0	30	20	0	25	35	20	30	20	10	40	20	20.83
Others: - Technology/product perf's.		30	20	20									5.83
-													0.00
-													0.00
5. Does your company have a documented manufacturing strategy:													
- YES	0	0	0	0	1	1	1	1	1	1	0	0	50%
- NO	1	1	1	1	0	0	0	0	0	0	1	1	50%
(If yes, summarised in file COMMENTS)													
6. Who is involved with the formulation of manufacturing strategy:													
- Chief executive	0	0	10	0	10	5	0	50	0	10	0	10	7.92
- Manufacturing director	0	85	0	30	30	40	50	50	20	40	40	50	36.25
- Finance director	0	15	0	10	10	0	20	0	0	5	10	0	5.83
- Marketing director	0	0	10	0	0	0	0	0	20	5	0	0	2.92
- Engineering/Tech. director	0	0	0	0	30	40	0	0	20	20	0	0	9.17
Others: -													0.00
-													0.00
- Production Managers	50	0	40	25	15	10	15	0	20	10	20	30	19.58
- Engineering Managers	50	0	40	35	5	5	15	0	10	10	30	10	17.50
Others: - Quality Manager									10				0.83
-													0.00
-													0.00
-													0.00
-													0.00
-													0.00
7. Where do the greatest priorities lie within manufacturing:													
- Costs	50	20	40	50	25	30	30	20	15	50	30	50	34.17
- Machine productivity	20	10	10	10	0	0	30	10	5	5	30	0	10.83
- Labour productivity	20	10	10	10	15	10	5	10	5	0	5	0	8.33
- Product quality	10	20	20	10	30	30	20	20	20	20	25	10	19.58
- Service and response	0	10	20	5	15	20	5	10	20	10	5	10	10.83
- Inventory/stock levels	0	10	0	10	15	10	5	10	15	10	0	20	8.75
- Production yields	0	15	0	5	0	0	5	20	10	5	5	10	6.25
- Personnel development	0	5	0	0	0	0	0	0	10	0	0	0	1.25
Others: -													0.00
-													0.00
-													0.00
8. Manufacturing objectives:													
- Mainly quantitative	1	1	1	1	1	0	1	0	1	0	0	1	67%
- Mainly qualitative	0	0	0	0	0	1	0	1	0	1	1	0	33%
9. What proportion of your production operations are the following:													
- Make to order jobbing	0	0	5	75	0	5	5	0	50	0	0	0	11.67
- Small batch	20	5	35	25	10	5	20	50	50	40	30	30	26.67
- Large batch	80	30	60	0	10	0	20	50	0	30	70	50	34.17
- Mass manufacture	0	10	0	0	40	10	35	0	0	0	0	0	7.92
- Continuous flow	0	15	0	0	40	40	0	0	0	0	0	10	8.75
- Process manufacture	0	40	0	0	0	40	20	0	0	30	0	0	10.83
10. To what extent is manufacturing vertically integrated:													
- Final assy/processing	0	0	0	0	0	0	0	0	0	0	0	0	0%
- Components, etc..	0	15	0	100	100	0	0	0	0	30	100	0	29%
- Raw materials, etc..	100	85	100	0	0	100	100	100	100	70	0	100	71%
11. What factors stimulate the need to design new production systems or redesign existing facilities:													
- Changes in product market	0	0	10	0	10	0	0	0	10	0	0	0	2.50
- Changes in customer needs	0	40	10	25	20	20	20	0	10	10	0	10	13.75
- Competitive threat	10	0	40	40	5	10	30	0	10	10	30	20	17.08
- New products	10	50	10	10	40	50	10	20	10	20	10	10	20.83
- Advances in product tech'y	50	0	10	0	5	10	0	40	30	20	10	0	14.58
- Advances in mfg tech'y	30	10	20	25	20	10	40	40	30	40	50	50	31.25
Others: -													0.00

12. Which of the following best describe the structure of your manufacturing organization:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- 5-6 levels	0	0	0	0	1	1	1	0	0	1	1	0	42%
- 3-4 levels	1	1	1	1	0	0	0	0	1	0	0	1	50%
- < 3 levels	0	0	0	0	0	0	0	1	0	0	0	0	8%
- Separate sys des/prod'n fn.	1	0	0	0	0	1	0	0	0	0	0	0	17%
- Separate prdt des/prd'n fn.	1	0	1	1	1	1	0	0	0	1	1	1	67%
- Product-focused	0	0	1	0	1	1	0	1	0	0	0	0	33%
- Process-focused	1	0	0	1	0	0	1	0	1	1	1	1	58%
- Matrix	0	0	0	0	0	1	0	1	1	0	0	0	25%
- Divisional	1	0	0	1	1	1	1	0	0	1	1	0	58%
- Single site	1	0	0	0	0	0	0	1	1	0	0	1	33%
- Multiple site	0	0	0	1	1	1		0	0	1	1	0	42%

13. Do you use temporary design teams/ interdisciplinary task groups for the development of new prod'n systems:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Frequently	0	0	0	0	0	0	0	0	0	0	0	0	0%
- Sometimes	1	1	0	0	1	1	1	0	0	1	1	0	58%
- Never	0	0	1	1	0	0	0	1	1	0	0	1	42%

14. What comparative weights are typically given to the following benefits when justifying investment in new production facilities:

- Cost savings	30	50	20	30	30	40	30	30	0	60	60	50	35.83
- Market/customer req'ts	30	20	15	10	10	20	15	30	50	10	10	10	19.17
- Quality improvements	10	0	20	10	10	15	15	30	30	10	0	10	13.33
- Inventory reductions	10	15	5	20	20	10	5	10	10	0	10	20	11.25
- Improved efficiency	20	15	40	20	30	15	30	0	10	20	20	10	19.17
- Improved working conditions	0	0	0	10	0	0	5	0	0	0	0	0	1.25
Others: -													0.00
-													0.00
-													0.00

15. What measures are used for investment appraisal of new systems:

- Pay-back period	100	100	100	100	0	50	100	0	0	0	100	100	62.50
- Internal rate return (IRR)	0	0	0	0	100	50	0	0	100	100	0	0	29.17
- Net present value (NPV)	0	0	0	0	0	0	0	100	0	0	0	0	8.33
Others: -													
-													
-													

16. To what extent do the following people participate in production systems design projects:

- Board level directors	5	5	20	0	0	0	0	20	0	0	0	0	4.17
- Finance personnel	10	5	10	5	0	5	5	5	0	10	0	0	4.58
- Engineers/technical staff	70	50	50	50	80	50	40	50	70	70	80	50	59.17
- Senior production managers	10	20	10	30	20	20	40	20	30	20	20	25	22.08
- Junior production managers	5	10	0	10	0	10	10	5	0	0	0	25	6.25
- Production supervisors	0	10	10	5	0	5	5	0	0	0	0	0	2.92
- Shopfloor personnel	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Others: - Quality Manager						10							0.83
-													0.00
-													0.00

17. Who has primary responsibility for:

(a) Day to day management of design:

- Board level directors	0	1	0	0	0	0	0	0	0	0	0	0	[illegible]
- Finance personnel	0	1	0	0	0	0	0	0	0	0	0	0	[illegible]
- Engineers/technical staff	0	0	1	1	0	1	0	0	0	0	0	0	50%
- Senior production managers	1	0	1	0	1	0	0	1	0	1	1	1	42%
- Junior production managers	1	0	0	0	0	0	1	0	1	0	0	0	8%
- Production supervisors	1	0	0	0	0	0	0	0	0	0	0	0	8%
- Shopfloor personnel	0	0	0	0	0	0	0	0	0	0	0	0	0%
Others: -													
-													
-													

(b) Making decisions on expenditure:

- Board level directors	1	1	1	1	1	0	0	1	0	0	0	0	50%
- Finance personnel	0	1	0	1	0	1	0	1	0	1	0	0	42%
- Engineers/technical staff	1	0	1	0	0	0	0	0	1	0	0	0	25%
- Senior production managers	0	0	0	0	1	1	1	0	1	0	1	1	50%
- Junior production managers	0	0	0	0	0	0	0	0	0	0	0	0	0%
- Production supervisors	0	0	0	0	0	0	0	0	0	0	0	0	0%
- Shopfloor personnel	0	0	0	0	0	0	0	0	0	0	0	0	0%
Others: -													
-													
-													

(c) Making decisions on phy. system:

- Board level directors	1	0	1	0	0	0	0	1	0	0	0	0	25%
- Finance personnel	0	0	0	0	0	0	0	0	0	0	0	0	0%
- Engineers/technical staff	1	1	1	1	1	1	1	1	0	1	1	1	92%
- Senior production managers	0	0	0	1	1	1	1	0	1	0	0	1	50%
- Junior production managers	0	0	0	0	0	0	0	0	0	0	0	0	0%
- Production supervisors	0	1	0	0	0	0	0	0	0	0	0	0	8%
- Shopfloor personnel	0	0	0	0	0	0	0	0	0	0	0	0	0%
Others: -													
-													
-													

18. Costs as a percentage of total manufacturing costs:

- Labour	5	n/a	14	25	12	20	30	10	5	10	8	30	15%
- Materials	70	n/a	36	50	60	60	50	80	60	70	82	60	62%
- Overheads	25	n/a	50	25	28	20	20	10	35	20	10	10	23%

19. Which of the following are used within manufacturing operations:

- TQM	0	0	0	0	1	1	0	1	1	1	0	1	50%
- FMS	0	1	0	0	1	0	0	1	1	1	0	0	42%
- Cellular manufacturing	0	1	0	0	1	0	0	1	1	1	0	0	42%
- CAD	1	0	0	1	1	1	1	1	1	1	1	0	75%
- CAM	0	0	0	1	1	1	1	1	1	1	0	0	58%
- CIM	0	0	0	0	1	0	0	1	1	1	0	0	33%
- Robotics	1	1	0	0	1	0	0	1	1	1	0	0	50%
- MRP	1	1	1	1	1	1	0	1	1	1	0	0	75%
- MRPII	1	1	0	0	0	0	0	0	1	1	0	0	33%
- JIT	0	1	0	1	1	0	1	1	1	0	0	1	56%
- Kanban	0	0	0	0	1	0	0	0	1	0	0	1	25%
Others: -													0%
-													0%
-													[illegible]

20. Which of the following are the most important demands upon your production operations (rank order):

- Speed of new prod. intro.	10	5	3	1	7.5	3	4	3	2	1	2	4	3.8
- Ability to offer prod range	4	10	7	6	4	7	7	7	1	2	1	7.5	5.3
- Ability to offer prd varnts	5	9	2	8.5	3	7	8	7	5	3	5	3	5.5
- Flex'y matls hand/routing	7	3	1	8.5	2	7	9	7	6	6	9	7.5	6.1
- Lab flexy: multi-skilling	8	6	6	2	7.5	7	10	7	9	10	8	7.5	7.3
- Lab flexy: mobility	3	7	9	3	1	2	2	7	8	7	7	2	4.8
- Delivery speed	2	8	4	4	7.5	7	5	1	4	4	3	1	4.2
- Delivery reliability	1	2	8	5	7.5	1	3	2	3	5	4	7.5	4.1
- Ability to alter volumes	6	1	5	8.5	7.5	7	6	7	7	8	6	7.5	6.4
- Long term expan/contract	9	4	10	8.5	7.5	7	11	7	10	9	10	7.5	8.4
Others: - High quality							1						
-													

21. What formal/informal schemes are offered to employees to allow participation/awareness in the company's operations:

- Quality circles	0	0	1	0	1	1	0	0	1	0	0	0	33%
- Other qlty improvem't teams	1	0	1	1	0	1	1	1	1	1	1	1	83%
- Task forces	1	0	0	1	0	0	1	1	1	1	1	0	58%
- Suggestion schemes	0	0	0	1	1	1	1	0	0	1	1	1	58%
- Regular team briefing	1	0	0	1	1	1	0	1	1	1	0	1	67%
- Working parties	1	0	0	0	1	0	1	1	1	1	0	1	58%
- Company newsletters	0	1	0	1	1	1	1	0	1	1	1	1	75%
Others -													0%
-													0%
-													0%
-													0%
-													0%

22. Do you formally evaluate the success of a new production facility once implemented:

- Always	0	1	0	0	1	1	0	1	1	1	0	0	50%
- Sometimes	1	0	1	1	0	0	1	0	0	0	0	1	42%
- Never	0	0	0	0	0	0	0	0	0	0	1	0	8%

(Measures used summarised in file COMMENTS)

23. What measures are used to assess production performance:

- Machine efficiencies	30	0	20	0	10	15	30	30	20	40	60	5	21.67
- Labour productivity	30	33.3	10	20	50	15	0	0	0	0	0	5	13.61
- Labour costs	20	33.3	40	20	10	20	20	0	10	20	20	40	21.11
- Quality/defective levels	5	33.3	20	20	20	20	20	20	40	20	10	20	20.69
- Delivery performance	0	0	10	0	0	20	10	40	20	10	0	5	9.58
- Material yields	0	0	0	20	0	0	10	0	0	10	10	5	4.58
- Inventory levels	15	0	0	20	10	10	10	10	10	0	0	20	8.75
Others -													0.00
-													0.00
-													0.00
-													0.00

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
1. What are the main stimuli for the development of new products in your organization:													
- Customer/market demand	60	60	60	60	80	60	90	60	10	100			64.00
- Product Technology	10	5	10	10	0	10	0	0	50	0			9.50
- Process Technology	10	0	10	5	0	0	0	30	40	0			9.50
- Competitive Threat	20	35	20	25	20	30	10	10	0	0			17.00
Others: -													0.00
2. To what extent do the following factors influence the process of marketing strategy formulation:													
- Corporate objectives	10	50	40	30	50	10	20	0	30	20			26.00
- Customer needs	30	20	30	30	10	40	40	50	20	50			32.00
- Competitors	20	15	0	20	30	30	10	50	5	20			20.00
- Product diversity/range	30	0	30	20	0	15	15	0	0	0			11.00
- Market geography	0	0	0	0	10	0	5	0	0	0			1.50
- Product technology	0	10	0	0	0	5	5	0	30	0			5.00
- Prod'n process technology	0	0	0	0	0	0	0	0	10	0			1.00
- Own manuf'g competences	10	5	0	0	0	0	5	0	5	10			3.50
Others: -													0.00
-													0.00
3. On what basis do customers evaluate and choose between the products of competing manufacturers in your industry:													
- Price	40	20	20	50	40	15	15	30	50	40			32.00
- Quality	25	50	20	40	40	55	15	35	25	30			33.50
- Supply specials/customs	15	10	20	5	10	15	20	0	0	0			9.50
- Delivery performance	15	10	10	5	10	15	15	35	25	30			17.00
- After sales service	5	10	0	0	0	0	5	0	0	0			2.00
Others: - Designs			30				30						6.00
-													0.00
-													0.00
-													0.00
-													0.00
4. Most significant changes in market/environment affecting mfg over the last ten years:													
- Increased competition	60	40	20	80	50	40	30	70	10	20			42.00
- Reduced volume/variant	0	10	10	0	0	0	10	0	0	0			3.00
- Reduced product life cycles	20	5	40	5	0	10	30	0	0	0			11.00
- Increased product variety	10	20	10	5	20	10	15	0	0	20			11.00
- Number of optional extras	0	0	0	0	0	0	0	0	0	0			0.00
- Increased quality	10	25	20	10	30	40	15	30	40	60			28.00
Others: - Environmental legislation									50				5.00
-													0.00
-													0.00
5. Does your company have a documented manufacturing strategy:													
- YES	0	0	1	0	1	1	0	0	0	0			30%
- NO	1	1	0	1	0	0	1	1	1	1			70%
(If yes, summarised in file COMMENTS)													
6. Who is involved with the formulation of manufacturing strategy:													
- Chief executive	20	15	0	30	20	10	25	20	20	40			20.00
- Manufacturing director	35	60	50	50	40	50	25	50	50	40			45.00
- Finance director	0	5	10	0	20	0	25	0	0	10			7.00
- Marketing director	0	20	20	0	0	10	10	0	0	10			7.00
- Engineering/Tech. director	35	0	20	0	0	10	0	0	20	0			8.50
Others: -													0.00
-													0.00
- Production Managers	5	0	0	10	10	10	15	20	10	0			8.00
- Engineering Managers	5	0	0	10	10	10	0	10	0	0			4.50
Others: -													0.00
-													0.00
-													0.00
-													0.00
-													0.00
-													0.00
7. Where do the greatest priorities lie within manufacturing:													
- Costs	30	30	40	60	40	25	40	30	30	20			34.50
- Machine productivity	20	0	10	5	10	10	0	10	15	10			9.00
- Labour productivity	20	0	0	5	0	5	0	0	10	5			4.50
- Product quality	15	50	30	20	40	40	25	30	15	20			28.50
- Service and response	5	5	20	5	10	15	25	10	10	20			12.50
- Inventory/stock levels	5	15	0	5	0	0	10	10	5	5			5.50
- Production yields	5	0	0	0	0	0	0	10	15	20			5.00
- Personnel development	0	0	0	0	0	5	0	0	0	0			0.50
Others: -													0.00
-													0.00
-													0.00
8. Manufacturing objectives:													
- Mainly quantitative	1	0	0	0	1	0	0	1	1	0			40%
- Mainly qualitative	0	1	1	1	0	1	1	0	0	1			60%
9. What proportion of your production operations are the following:													
- Make to order jobbing	10	20	10	10	0	10	25	0	0	0			8.50
- Small batch	0	10	10	30	20	30	25	0	5	0			13.00
- Large batch	65	70	80	60	80	60	50	20	15	20			52.00
- Mass manufacture	0	0	0	0	0	0	0	0	0	0			0.00
- Continuous flow	15	0	0	0	0	0	0	60	30	0			10.50
- Process manufacture	10	0	0	0	0	0	0	20	50	80			16.00
10. To what extent is manufacturing vertically integrated:													
- Final assy/processing	0	0	0	0	100	0	100	0	0	0			20%
- Components, etc..	0	0	100	100	0	100	0	0	0	0			30%
- Raw materials, etc..	100	100	0	0	0	0	0	100	100	100			50%
11. What factors stimulate the need to design new production systems or redesign existing facilities:													
- Changes in product market	0	10	20	0	10	10	25	0	0	20			9.50
- Changes in customer needs	0	25	10	0	20	10	25	30	5	40			16.50
- Competitive threat	5	50	40	50	40	50	25	10	0	10			28.00
- New products	5	10	10	0	5	5	15	0	10	0			6.00
- Advances in product tech'y	10	0	0	0	5	0	5	0	10	0			3.00
- Advances in mfg tech'y	80	5	20	50	20	25	5	60	75	30			37.00
Others: -													0.00

12. Which of the following best describe the structure of your manufacturing organization:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- 5-6 levels	0	0	1	0	0	0	1	0	0	0			20%
- 3-4 levels	1	1	0	1	1	1	0	0	1	1			70%
- < 3 levels	0	0	0	0	0	0	0	1	0	0			10%
- Separate sys des/prod'n fn.	1	0	1	1	1	1	0	0	1	0			60%
- Separate prdt des/prd'n fn.	0	1	1	1	0	1	1	0	0	0			50%
- Product-focused	0	1	0	0	0	0	1	0	0	0			20%
- Process-focused	1	0	1	1	1	1	0	1	1	1			80%
- Matrix	0	0	0	0	0	1	1	0	0	0			20%
- Divisional	1	0	1	0	0	0	0	0	1	0			30%
- Single site	0	0	0	1	1	1	0	1	1	0			50%
- Multiple site	1	1	1	0	0	0	1	0	0	1			50%

13. Do you use temporary design teams/interdisciplinary task groups for the development of new prod'n systems:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Frequently	0	0	0	0	1	1	1	0	0	0			30%
- Sometimes	1	1	1	1	0	0	0	0	0	1			50%
- Never	0	0	0	0	0	0	0	1	1	0			20%

14. What comparative weights are typically given to the following benefits when justifying investment in new production facilities:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Cost savings	25	60	50	35	30	30	20	60	40	40			39.00
- Market/customer req'ts	20	10	20	10	10	40	40	20	10	40			22.00
- Quality improvements	15	20	10	20	25	20	20	0	10	5			14.50
- Inventory reductions	15	10	5	10	10	0	0	0	10	5			6.50
- Improved efficiency	20	0	15	20	25	10	20	20	30	5			16.50
- Improved working conditions	5	0	0	5	0	0	0	0	0	5			1.50
Others: -													0.00
-													0.00
-													0.00

15. What measures are used for investment appraisal of new systems:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Pay-back period	80	70	90	100	80	0	100	100	80	100			80.00
- Internal rate return (IRR)	10	0	10	0	20	100	0	0	20	0			16.00
- Net present value (NPV)	10	30	0	0	0	0	0	0	0	0			4.00
Others: -													
-													
-													

16. To what extent do the following people participate in production systems design projects:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Board level directors	10	70	0	10	50	20	5	40	20	20			24.50
- Finance personnel	5	5	0	0	5	5	0	0	0	20			4.00
- Engineers/technical staff	40	20	40	60	30	40	35	40	40	50			39.50
- Senior production managers	40	5	40	20	15	20	35	10	40	10			23.50
- Junior production managers	5	0	10	10	0	5	10	5	0	0			4.50
- Production supervisors	0	0	10	0	0	5	5	5	0	0			2.50
- Shopfloor personnel	0	0	0	0	0	5	5	0	0	0			1.00
Others: - Marketing staff							5						0.50
-													0.00

17. Who has primary responsibility for:

(a) Day to day management of design:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Board level directors	0	1	0	0	1	0	0	1	0	0			30%
- Finance personnel	0	0	0	0	0	0	0	0	0	0			0%
- Engineers/technical staff	1	1	1	1	0	1	1	0	1	1			80%
- Senior production managers	1	0	1	0	0	0	1	0	1	0			40%
- Junior production managers	0	0	0	0	0	0	0	0	0	0			0%
- Production supervisors	0	0	0	0	0	0	0	0	0	0			0%
- Shopfloor personnel	0	0	0	0	0	0	0	0	0	0			0%
Others: -													
-													
-													

(b) Making decisions on expenditure:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Board level directors	1	1	1	1	1	1	1	1	1	1			100%
- Finance personnel	0	0	0	1	0	1	0	0	0	1			30%
- Engineers/technical staff	0	0	0	0	0	0	0	0	0	0			0%
- Senior production managers	1	0	1	0	0	0	1	0	0	0			30%
- Junior production managers	0	0	0	0	0	0	0	0	0	0			0%
- Production supervisors	0	0	0	0	0	0	0	0	0	0			0%
- Shopfloor personnel	0	0	0	0	0	0	0	0	0	0			0%
Others: -													
-													
-													

(c) Making decisions on phy. system:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Board level directors	0	0	0	0	1	1	0	1	1	0			40%
- Finance personnel	0	0	0	0	0	0	0	0	0	0			0%
- Engineers/technical staff	1	1	1	0	1	1	1	1	1	1			90%
- Senior production managers	1	0	1	1	0	0	1	0	0	0			40%
- Junior production managers	0	0	0	0	0	0	0	0	0	0			0%
- Production supervisors	0	0	0	0	0	0	0	0	0	0			0%
- Shopfloor personnel	0	0	0	0	0	0	0	0	0	0			0%
Others: -													
-													
-													

18. Costs as a percentage of total manufacturing costs:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- Labour	40	38.5	40	50	35	50	42	20	50	30			40%
- Materials	30	31.5	40	40	45	30	26	65	25	30			36%
- Overheads	30	30	20	10	20	20	32	15	25	40			24%

19. Which of the following are used within manufacturing operations:

	1	2	3	4	5	6	7	8	9	10	11	12	AVERAGE
- TQM	0	1	1	1	0	1	1	0	0	0			50%
- FMS	0	0	0	0	0	0	0	0	0	0			0%
- Cellular manufacturing	0	0	0	0	0	1	0	0	0	0			10%
- CAD	1	1	1	1	0	1	1	0	0	0			60%
- CAM	0	0	1	0	0	0	1	1	1	1			50%
- CIM	0	1	1	0	0	0	0	0	1	0			30%
- Robotics	0	0	0	0	0	0	0	0	0	0			0%
- MRP	1	1	1	1	0	1	0	0	1	0			60%
- MRPII	1	0	0	0	0	0	0	0	1	0			20%
- JIT	0	0	0	1	1	1	0	1	0	0			40%
- Kanban	0	0	0	0	0	0	0	0	0	0			0%
Others: -													0%
-													0%
-													0%

20. Which of the following are the most important demands upon your production operations (rank order):

- Speed of new prod. intro.	10	4	1	4	5	3	1	7	7.5	10	5.3
- Ability to offer prod range	8	3	2	3	1	2	4	7	7.5	9	4.7
- Ability to offer prd varnts	9	7	3	6	8	10	7.5	7	7.5	8	7.3
- Flex'y matls hand/routing	1	5	8	10	9	9	7.5	7	7.5	5	6.9
- Lab flexy: multi-skilling	3	9.5	9	8	10	7	7.5	7	2	6	6.9
- Lab flexy: mobility	·2	6	6	7	6	6	7.5	7	1	4	5.3
- Delivery speed	5	1	4	1	3	4	2	2	3	2	2.7
- Delivery reliability	4	2	5	2	2	1	3	1	4	1	2.5
- Ability to alter volumes	6	8	7	5	4	5	7.5	3	7.5	3	5.6
- Long term expan/contract	7	9.5	10	9	7	8	7.5	7	7.5	7	8.0

Others: -
-

21. What formal/informal schemes are offered to employees to allow participation/awareness in the company's operations:

- Quality circles	1	1	0	0	0	1	0	0	1	0	40%
- Other qlty improvem't teams	0	0	1	0	0	1	1	1	0	0	40%
- Task forces	0	1	0	0	0	0	0	0	0	0	10%
- Suggestion schemes	1	0	1	1	1	1	0	1	1	1	80%
- Regular team briefing	1	1	0	1	1	1	1	0	1	0	70%
- Working parties	0	1	0	0	0	1	1	1	0	0	40%
- Company newsletters	1	0	1	0	0	1	1	0	1	0	50%
Others -											0%
-											0%
-											0%
-											0%
-											0%

22. Do you formally evaluate the success of a new production facility once implemented:

- Always	1	1	0	0	1	0	1	0	1	1	60%
- Sometimes	0	0	1	1	0	1	0	1	0	0	40%
- Never	0	0	0	0	0	0	0	0	0	0	0%

(Measures used summarised in file COMMENTS)

23. What measures are used to assess production performance:

- Machine efficiencies	20	40	30	40	50	20	20	40	50	40	35.00
- Labour productivity	20	0	5	5	5	10	0	5	0	10	6.00
- Labour costs	20	30	5	20	20	5	20	5	25	10	16.00
- Quality/defective levels	15	10	30	10	10	20	30	10	10	0	14.50
- Delivery performance	5	0	30	25	10	30	30	10	0	30	17.00
- Material yields	20	10	0	0	5	0	0	20	15	10	8.00
- Inventory levels	0	10	0	0	0	15	0	10	0	0	3.50
Others -											0.00
-											0.00
-											0.00
-											0.00

Appendix F
Systems Design Survey: Case Study Companies[1]

Table F.1: Main Stimuli for the Development of New Products *(Figures in average weighting out of 100)*

Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Customer/Market Demand	60.0 (55.5)	56.7 (70.0)	55.0 (65.8)	60.0 (64.0)	58.1 (63.5)
Product Technology	12.5 (17.8)	16.7 (10.0)	6.7 (9.5)	8.3 (9.5)	11.2 (11.6)
Process Technology	3.8 (3.9)	- (-)	5.0 (8.3)	6.7 (9.5)	3.9 (6.2)
Competitive Threat	23.8 (22.8)	26.7 (20.0)	33.3 (16.3)	25.0 (17.0)	26.9 (18.7)

Table F.2: Influences upon the Process of Marketing Strategy Formulation *(Figures in average weighting out of 100)*

Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Corporate Objectives	7.5 (8.8)	26.7 (16.7)	31.7 (20.1)	33.3 (26.0)	16.3 (18.4)
Customer Needs	42.5 (43.8)	36.7 (43.3)	25.0 (35.9)	26.7 (32.0)	33.5 (38.0)
Competitors	25.0 (17.5)	16.7 (15.0)	18.3 (15.4)	11.7 (20.0)	18.5 (17.1)
Product Diversity/ Range	13.8 (11.3)	3.3 (1.7)	1.7 (4.3)	20.0 (11.0)	10.0 (7.4)
Market Geography	1.3 (3.8)	- (3.3)	1.7 (2.1)	- (1.5)	0.8 (2.6)
Product Technology	8.8 (13.1)	16.7 (16.7)	6.7 (10.7)	3.3 (5.0)	8.9 (10.7)
Production Process Technology	1.3 (0.6)	- (-)	5.0 (5.6)	- (1.0)	1.6 (2.2)
Own Manufacturing Competencies	- (1.3)	- (3.3)	3.3 (6.0)	5.0 (3.5)	1.9 (3.7)

[1] In all tables the figures in normal type are the average figures for the 13 case study companies, whilst the figures in brackets are the population averages for the overall survey (sample size, n=37).

Table F.3: Basis upon which Customers Exercise Choice amongst Competing Manufacturers *(Figures in average weighting out of 100)*

Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Price	25.0 (21.1)	35.0 (33.1)	38.3 (38.7)	26.7 (32.0)	30.8 (31.7)
Quality	37.5 (35.6)	36.7 (38.1)	33.3 (30.3)	31.7 (33.5)	32.1 (33.7)
Ability to Supply Specials/Customs	17.5 (11.7)	10.0 (8.5)	5.0 (11.3)	15.0 (9.5)	12.3 (10.5)
Delivery Performance	7.5 (14.4)	8.3 (17.0)	10.0 (11.8)	11.7 (17.0)	9.2 (14.7)
After Sales Service	5.0 (10.6)	6.7 (3.4)	6.7 (5.0)	5.0 (2.0)	5.7 (5.3)
Others *(see Note)*	7.5 (6.7)	- (-)	6.7 (2.9)	10.0 (6.0)	6.2 (4.2)

Note: *Others included "product performance", "first to market", "company/brand loyalty", "performance characteristics" and "designs".*

Table F.4: Significant Changes in the Market Environment Affecting Manufacturing over the last Ten Years *(Figures in average weighting out of 100)*

Change Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Increased Competition	47.5 (30.0)	36.7 (25.0)	33.3 (38.3)	40.0 (42.0)	40.0 (35.1)
Reduced Volume per Variant	- (4.4)	3.3 (8.3)	6.7 (4.6)	6.7 (3.0)	3.8 (4.7)
Reduced Product Life Cycles	22.5 (34.4)	23.3 (31.7)	11.7 (12.5)	21.7 (11.0)	20. (20.5)
Increased Product Variety	12.5 (10.0)	10.0 (11.7)	15.0 (14.2)	13.3 (11.0)	12.7 (11.9)
Number of Optional Extras Demanded	10.0 (6.7)	6.7 (3.3)	5.0 (3.8)	- (-)	5.8 (3.4)
Increased Quality Requirements	7.5 (13.3)	20.0 (20.0)	18.3 (20.8)	18.3 (28.0)	12.6 (20.8)
Others *(see Note)*	- (1.1)	- (-)	10.0 (5.8)	- (5.0)	2.3 (3.5)

Note: *Others included "flexibility/volume changes", "technology/product performance" and "environmental legislation".*

Table F.5: Companies Possessing a Documented Manufacturing Strategy

	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Percentage with Documented Manufacturing Strategy	75% (67%)	67% (50%)	33% (50%)	33% (30%)	54% (49%)

Table F.6: Involvement in the Formulation of Manufacturing Strategy *(Figures in average weighting out of 100)*

Director/Manager	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Chief Executive	5.0 (5.6)	33.3 (24.1)	3.3 (7.9)	11.7 (20.0)	12.5 (13.2)
Manufacturing Director	36.3 (27.2)	33.3 (34.5)	38.3 (36.3)	48.3 (45.0)	38.9 (36.1)
Finance Director	18.8 (17.2)	16.7 (20.7)	8.3 (5.8)	5.0 (7.0)	12.7 (11.3)
Marketing Director	- (-)	3.3 (6.9)	- (2.9)	13.3 (7.0)	3.8 (4.0)
Engineering Director	- (-)	6.7 (3.5)	10.0 (9.2)	18.3 (8.5)	8.1 (5.8)
Other Director	5.0 (4.4)	- (-)	- (-)	- (-)	1.5 (1.1)
Production Manager	12.5 (18.3)	3.3 (3.5)	21.7 (19.6)	1.7 (8.0)	10.0 (13.5)
Engineering Manager	20.0 (18.9)	3.3 (5.2)	18.3 (17.5)	1.7 (4.5)	11.5 (12.3)
Other Managers	2.5 (8.3)	- (1.7)	- (0.8)	- (-)	0.8 (0.8)

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Table F.9: Nature of Production Operations *(Figures in average weighting out of 100)*

Type	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
"Make-to-Order" Jobbing	17.5 (17.8)	6.7 (5.0)	- (11.7)	13.3 (8.5)	10.0 (11.2)
Small Batch	45.0 (51.1)	30.0 (16.7)	11.7 (26.7)	6.7 (13.0)	25.0 (27.3)
Large Batch	- (4.4)	23.3 (25.0)	40.0 (34.2)	71.7 (52.0)	25.0 (30.3)
Mass Manufacture	- (6.7)	- (-)	16.7 (7.9)	- (-)	3.8 (4.2)
Continuous Flow	37.5 (16.7)	40.0 (53.3)	18.3 (8.8)	5.0 (10.5)	26.2 (18.4)
Process Manufacture	- (3.3)	- (-)	13.3 (10.8)	3.3 (16.0)	3.8 (8.7)

Table F.10: Degree of Vertical Integration *(Figures in percent)*

Degree of Vertical Integration	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Low	41% (53%)	83% (82%)	- (-)	- (20%)	32% (31%)
Medium	59% (44%)	13% (12%)	58% (29%)	33% (30%)	42% (30%)
High	- (3%)	3% (7%)	42% (71%)	67% (50%)	26% (39%)

Table F.11: Factors stimulating the need to Design New Production Systems/Redesign Existing Facilities *(Figures in average weighting out of 100)*

Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Changes in Product Market	15.0 (14.4)	13.3 (10.0)	3.3 (2.5)	10.0 (9.5)	10.8 (8.5)
Changes in Customer Needs	20.0 (18.9)	3.3 (20.0)	20.0 (13.8)	11.7 (16.5)	13.5 (16.8)
Competitive Threat	40.0 (22.2)	3.3 (5.0)	5.0 (17.1)	31.7 (28.0)	21.5 (19.3)
New Products	15.0 (24.4)	6.7 (10.0)	33.3 (20.8)	8.3 (6.0)	15.8 (16.0)
Advances in Product Technology	7.5 (15.6)	16.7 (17.5)	18.3 (14.6)	3.3 (3.0)	11.2 (12.2)
Advances in Manuf'g Technology	2.5 (4.4)	23.3 (20.8)	20.0 (31.3)	35.0 (37.0)	18.9 (24.6)
Others *(see Note)*	- (-)	33.3 (16.7)	- (-)	- (-)	7.7 (2.7)

Note: *Others included "quest for improved quality" and "quest for reduced cost".*

Table F.12: Organization Structure for Manufacturing *(Figures in percent)*

Characteristics	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
5-6 Levels	- (22%)	67% (33%)	33% (42%)	33% (20%)	31% (30%)
3-4 Levels	100% (67%)	33% (67%)	67% (50%)	67% (70%)	69% (62%)
< 3 Levels	- (11%)	- (-)	- (8%)	- (10%)	- (8%)
Separate Systems Design and Production Function	25% (33%)	- (33%)	33% (17%)	67% (60%)	29% (35%)
Separate Product Design and Production Function	25% (56%)	100% (83%)	67% (67%)	67% (50%)	59.6 (62%)
Product-Focused	75% (67%)	100% (67%)	33% (33%)	33% (20%)	62% (43%)
Process-Focused	- (22%)	- (33%)	33% (58%)	67% (80%)	23% (51%)
Matrix	25% (33%)	33% (33%)	- (25%)	- (20%)	15% (27%)
Divisional	- (11%)	33% (33%)	67% (58%)	67% (30%)	38% (35%)
Single Site	50% (44%)	- (50%)	33% (33%)	- (50%)	23% (43%)
Multiple Site	25% (44%)	100% (50%)	33% (42%)	100% (50%)	62% (46%)

Table F.13: Use of Temporary Design Teams/Interdisciplinary Task groups for New Production Systems Design *(Figures in percent)*

Use of Teams	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Frequently	25% (33%)	67% (50%)	- (-)	- (30%)	23% (24%)
Sometimes	50% (33%)	33% (33%)	100% (58%)	100% (50%)	69% (46%)
Never	25% (33%)	- (17%)	- (42%)	- (20%)	8% (30%)

Table F.14: Quoted Benefits when Justifying New Production Facilities *(Figures in average weighting out of 100)*

Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Cost Savings	57.8 (38.9)	63.3 (46.7)	36.7 (35.8)	45.0 (39.0)	51.2 (39.2)
Market/Customer Requirements	- (16.7)	5.0 (9.2)	20.0 (19.2)	16.7 (22.0)	9.6 (17.7)
Quality Improvements	25.0 (20.6)	13.3 (19.2)	6.7 (13.3)	15.0 (14.5)	15.8 (16.4)
Inventory Reductions	30.0 (11.7)	8.3 (13.33)	15.0 (11.3)	10.0 (6.5)	16.9 (10.4)
Improved Efficiency	5.0 (8.9)	10.0 (10.8)	21.7 (19.2)	11.7 (16.5)	11.5 (14.6)
Improved Working Conditions	5.0 (3.3)	- (0.8)	- (1.3)	1.7 (1.5)	1.9 (1.8)

Table F.15: Measures used for Investment Appraisal for New Production Systems *(Figures in average weighting out of 100)*

Appraisal Measure	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Pay-Back Period	85.0 (68.3)	50.0 (66.7)	66.7 (62.5)	80.0 (80.0)	71.5 (69.3)
Internal Rate of Return	15.0 (31.7)	33.3 (25.0)	33.3 (29.2)	6.7 (16.0)	21.5 (25.5)
Net Present Value	- (-)	- (-)	- (8.3)	13.3 (4.0)	3.1 (3.8)
Return on Investment (ROI)	- (-)	16.7 (8.3)	- (-)	- (-)	3.8 (1.3)

Table F.16: Participation in Production System Design Projects *(Figures in percent)*

Employee Group	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Board Level Directors	1% (1%)	3% (2%)	3% (4%)	27% (25%)	8% (8%)
Finance Personnel	- (1%)	3% (2%)	5% (5%)	3% (4%)	3% (3%)
Engineers/Technical Staff	66% (61%)	60% (66%)	67% (59%)	33% (40%)	57% (55%)
Senior Production Managers	13% (16%)	23% (21%)	17% (22%)	27% (24%)	19% (21%)
Junior Production Managers	9% (9%)	7% (7%)	5% (6%)	5% (5%)	7% (7%)
Production Supervisors	10% (9%)	- (2%)	3% (3%)	3% (3%)	5% (4%)
Shopfloor Personnel	1% (3%)	3% (2%)	- (-)	- (1%)	1% (1%)
Others *(see Note)*	- (-)	- (-)	- (1%)	- (1%)	- (0%)

Note: *Others included "Quality Manager" and "Marketing Staff".*

Table F.17: Primary Responsibility for Day-to-Day Management of Systems Design Projects *(Figures in percent)*

Employee Group	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Board Level Directors	- (-)	- (-)	33% (8%)	33% (30%)	15% (11%)
Finance Personnel	- (-)	- (-)	33% (8%)	- (-)	8% (3%)
Engineers/Technical Staff	100% (100%)	67% (83%)	- (58%)	100% (80%)	69% (78%)
Senior Production Managers	- (11%)	33% (17%)	67% (42%)	67% (40%)	38% (21%)
Junior Production Managers	25% (22%)	33% (17%)	33% (8%)	- (-)	23% (11%)
Production Supervisors	- (-)	- (-)	- (-)	- (-)	- (-)
Shopfloor Personnel	- (-)	- (-)	- (-)	- (-)	- (-)

Table F.18: Primary Responsibility for Expenditure Decisions *(Figures in percent)*

Employee Group	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Board Level Directors	50% (67%)	- (50%)	100% (50%)	100% (100%)	62% (68%)
Finance Personnel	75% (56%)	- (67%)	33% (42%)	- (30%)	31% (46%)
Engineers/Technical Staff	- (22%)	- (-)	33% (25%)	- (-)	8% (14%)
Senior Production Managers	50% (33%)	100% (50%)	33% (50%)	67% (30%)	62% (41%)
Junior Production Managers	- (11%)	- (-)	- (-)	- (-)	- (3%)
Production Supervisors	- (-)	- (-)	- (-)	- (-)	- (-)
Shopfloor Personnel	- (-)	- (-)	- (-)	- (-)	- (-)

Table F.19: Primary Responsibility for Physical System Decisions *(Figures in percent)*

Employee Group	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Board Level Directors	- (-)	- (-)	33% (25%)	- (40%)	8% (19%)
Finance Personnel	- (-)	- (-)	- (-)	- (-)	- (-)
Engineers/Technical Staff	75% (78%)	100% (100%)	100% (92%)	100% (90%)	92% (89%)
Senior Production Managers	25% (44%)	67% (67%)	33% (50%)	67% (40%)	62% (49%)
Junior Production Managers	25% (22%)	- (-)	- (-)	- (-)	8% (5%)
Production Supervisors	- (-)	- (-)	33% (8%)	- (-)	8% (3%)
Shopfloor Personnel	- (-)	- (-)	- (-)	- (-)	- (-)

Table F.20 Cost Breakdown for Manufacturing *(Figures in percent)*

Cost	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Labour	11% (12%)	30% (28%)	9% (15%)	40% (40%)	22% (23%)
Materials	76% (74%)	58% (54%)	65% (62%)	34% (36%)	60% (57%)
Overheads	14% (14%)	15% (18%)	27% (23%)	27% (24%)	20% (20%)

Table F.21: Philosophies, Concepts and Technologies used in Manufacturing *(Figures in percent)*

Concept/Technology	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Total Quality Management	75% (67%)	100% (67%)	33% (50%)	67% (50%)	69% (57%)
Flex. Manufacturing Systems (FMS)	25% (22%)	- (17%)	67% (42%)	- (-)	23% (22%)
Cellular Manufacture	100% (89%)	100% (67%)	67% (42%)	- (10%)	69% (49%)
Computer-Aided Design (CAD)	100% (89%)	100% (100%)	67% (75%)	100% (60%)	92% (78%)
Computer-Aided Manufacture (CAM)	50% (56%)	- (17%)	33% (58%)	33% (50%)	31% (49%)
Computer Integrated Manufacture (CIM)	25% (33%)	- (17%)	33% (33%)	67% (30%)	31% (30%)
Robotics	50% (44%)	- (17%)	100% (50%)	- (-)	38% (30%)
Material Requirem'ts Planning (MRP)	100% (89%)	100% (83%)	100% (75%)	100% (60%)	100% (76%)
Manufact'g Resources Planning (MRPII)	75% (56%)	33% (33%)	67% (33%)	33% (20%)	54% (35%)
Just-in-Time (JIT)	75% (78%)	100% (100%)	67% (58%)	- (40%)	62% (65%)
Kanban	50% (56%)	67% (67%)	33% (25%)	- (-)	38% (32%)

Table F.22: Flexibility Demands upon Manufacturing *(Figures are average rank positions: 1=high)*

Factor	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Speed of New Product Introduction	1.4 (1.7)	3.3 (2.8)	7.5 (3.8)	5.0 (5.3)	4.1 (3.5)
Ability to Offer Wide Product Range	4.5 (4.7)	8.7 (7.9)	6.0 (5.3)	4.3 (4.7)	5.8 (5.4)
Ability to Offer Product Variants	3.9 (4.9)	6.0 (5.3)	5.7 (5.5)	6.3 (7.3)	5.4 (5.8)
Flex. of Materials Handling/Routing	7.4 (7.3)	6.0 (5.6)	4.0 (6.1)	4.7 (6.9)	5.7 (6.5)
Labour Flexibility: Multi-Skilling	5.9 (6.2)	8.0 (7.4)	7.2 (7.3)	7.2 (6.9)	7.0 (7.0)
Labour Flexibility: Mobility	7.1 (6.8)	5.0 (5.9)	3.7 (4.8)	4.7 (5.3)	5.3 (5.6)
Delivery Speed	6.1 (5.5)	3.3 (3.3)	5.8 (4.2)	3.3 (2.7)	4.7 (4.0)
Delivery Reliability	5.4 (4.4)	3.7 (4.0)	3.5 (4.1)	3.7 (2.5)	4.2 (3.7)
Ability to Alter Volumes	4.8 (5.2)	2.7 (4.0)	4.8 (6.4)	7.0 (5.6)	4.8 (5.5)
Expansion/Contract'n of Facilities	7.6 (8.3)	8.3 (8.8)	6.5 (8.4)	8.8 (8.0)	7.8 (8.3)

Table F.23: Participation and Awareness Schemes for Employees *(Figures in percent)*

Scheme	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Quality Circles	25% (33%)	33% (33%)	33% (33%)	67% (40%)	38% (35%)
Other Quality Improvement Schemes	100% (89%)	33% (33%)	33% (83%)	33% (40%)	54% (65%)
Task Forces	25% (22%)	33% (17%)	33% (58%)	33% (10%)	31% (30%)
Suggestion Schemes	100% (100%)	100% (100%)	33% (58%)	67% (80%)	77% (81%)
Regular Team Briefing Sessions	75% (78%)	100% (100%)	67% (67%)	67% (70%)	77% (76%)
Working Parties	25% (22%)	33% (17%)	67% (58%)	33% (40%)	38% (38%)
Company Newsletters	75% (78%)	100% (100%)	67% (75%)	67% (50%)	77% (73%)
Others *(see Note)*	25% (22%)	- (-)	- (-)	- (-)	8% (5%)

Note: *Others included "General Quality Culture/Involvement" and "Coffee Talks (all staff per week)".*

Table F.24: Formal Evaluation of Implemented Production Systems *(Figures in percent)*

Evaluation Conducted?	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Always	75% (44%)	33% (17%)	67% (50%)	67% (60%)	62% (46%)
Sometimes	25% (56%)	67% (67%)	33% (42%)	33% (40%)	38% (49%)
Never	- (-)	- (17%)	- (8%)	- (-)	- (5%)

Table F.25: Measures used to Assess Production Performance *(Figures in average weighting out of 100)*

Type of Measure	Elec. Ass.	Elec. Eng.	Mech. Eng.	Cpt. Mfg.	TOTAL
Machine Efficiencies	5.0 (3.3)	- (3.3)	13.3 (21.7)	30.0 (35.0)	11.5 (17.8)
Labour Productivity	20.0 (14.4)	16.7 (13.3)	37.8 (13.6)	8.3 (6.0)	20.1 (11.7)
Labour Costs	12.5 (9.4)	10.0 (10.0)	20.1 (21.1)	18.3 (16.0)	15.0 (15.1)
Quality/Defective Levels	32.3 (30.2)	26.7 (27.5)	19.4 (20.7)	18.3 (14.5)	24.8 (22.4)
Delivery Performance	22.3 (28.5)	40.0 (34.2)	- (9.6)	11.7 (17.0)	18.8 (20.2)
Material Yields	- (1.9)	- (1.7)	- (4.6)	10.0 (8.0)	2.3 (4.4)
Inventory Levels	7.5 (8.5)	6.7 (10.0)	8.3 (8.8)	3.3 (3.5)	6.5 (7.5)
Others *(see Note)*	- (3.7)	- (-)	- (-)	- (-)	- (0.9)

Note: *Others included "Unit Costs" and "Daily Build versus Target".*