AN INVESTIGATION OF NATURE OF THE WORKING RELATIONSHIP BETWEEN PRODUCT DESIGN AND PRODUCTION FUNCTIONS IN MANUFACTURING COMPANIES

A Thesis submitted for the Degree
of Doctor of Philosophy
by

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K S Pawar

I DEDICATE THIS THESIS TO MY WIFE BHUPINDER, SONS GURMEJ AND GAVINDER AND TO MY LATE GRANDMOTHER GULAB KAUR.

ASTON UNIVERSITY

SUMMARY

AN INVESTIGATION OF THE NATURE OF THE WORKING RELATIONSHIP BETWEEN PRODUCT DESIGN AND PRODUCTION FUNCTIONS IN MANUFACTURING COMPANIES

Submitted by Kulwant Singh Pawar for the degree of Doctor of Philosophy, 1985.

This thesis reports the results of a longitudinal study examining the working relationship between product design and production functions in manufacturing companies. It primarily concentrates upon the management of these functions during the course of a new product design. The effective management of interfaces (such as market/design/production) poses rather obscure problems due to a number of operational incompatibilities which in turn arise because of conflicting requirements of these functions.

The findings of this study have identified a number of key factors (eg market needs, product cost, project duration, project planning control, inter-departmental communications) which management needs to be concerned with when preparing product specification. Similarly, the research has also shown that in addition to the above factors, management also needs to consider a number of crucial parameters (eg in-house technical expertise, standardisation, modification procedures and design for assembly concept) during the design stage of a new product. These factors have been critically analysed in relation to the effectiveness of new product design performance.

In order to examine the design/production relationship during the course of a new product design, the literature relating to new product development as well as the reasons for success and failure of new product designs has been critically reviewed.

Following review of literature, specific hypotheses were developed based upon the underlying assumption that the nature of the working relationship between product design and production directly influences the product design performance.

To test this assumption, field research was conducted in twenty participating firms. The data, collected through questionnaires, interviews and observations has been presented in the form of Case Studies. The analysis of the data has been compared and contrasted with the relevant published work.

Key Words: Product design, Design management, Production management, Product specification, Innovation.

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VOLUME I

CHAPTER 1

INTRODUCTION

1.1 Why is there a need to examine the relationship between product design and production.

In many industries, until a few years ago, the design of a product and its subsequent economic manufacture was typically the responsibility of one individual; today this is true only in smaller companies. Here the designer is expected to have a sufficiently broad background that he can produce a design that is sound functionally and can be manufactured economically in the desired quantities. Thus he performs a dual role of product designer and production specialist.

In recent years, technological advancements, increasing product complexity, and a trend toward multi-disciplinary design have made it difficult, if not impossible, for a designer to have a complete knowledge of the production processes and materials that are available for a product and also have the know-how for sound functional design. Consequently most of today's design problems require a team effort to develop and manufacture new products.[1] The design process therefore can be compared with the organisation of an orchestra or a cricket game, when the team effort determines the final outcome.

The product design process requires a team effort both to decide on what product to develop and how to provide effective solutions. The team leader has to co-ordinate all the specialist support and use his own managerial and technical judgement to decide between the alternatives with which the designers are confronted.

The main objective of a design team is usually to produce products that offer maximum value to the customer at the least cost to the company.(2) The team needs to be aware of the performance features and combine these with cost constraints imposed by the resources available for the particular project. The product specification therefore needs to make a major contribution to the cost-effectiveness of the design project, by reflecting the realistic needs of the market.

The first task in a development programme is therefore to determine what should in fact to be designed and an appropriate organisation is needed to achieve an effective and realistic definition. One of the problems is that this obvious and essential step is sometimes inadequately considered; the resulting specification defines only a few of the main parameters to be met, and may leave open too wide an area of design objectives to be interpreted by the design team as the work progresses. The designers are then faced with the issue not only how to convert the specification into hardware through the design and development process, but also in deciding what in fact they are designing. In these circumstances the final product may not achieve the anticipated commercial success. (3)

Once customer needs are satisfactorily defined the design problem falls directly on the development team. Here multi-disciplinary specialisms, such as electrical or mechanical engineering, are often needed. Since several specialists may be involved during the design process of a product, it is imperative that their efforts are all harmonised effectively if the company is to be competitive.

Due to the existence of a group of specialists in the organisation many different interfaces may become important. These include the interface relationships between management and design in determining the technical environment; the commercial/design interface in the specification of need; design/development interface; the influence of standardisation policy on design proceedure across the design/manufacturing interface, etc. In fact the list of interfaces can be very long indeed and will be determined by the size of the company and product complexity. [4]

The problems which these interfaces create tend to be obscure and are sometimes difficult to define; solutions to them cannot always be found in quantitative evidence. The ultimate conclusions therefore have to be made from the qualitative information available from industry.

The primary purpose of this research project is to investigate the nature of the functional relationship between design and production departments in manufacturing companies. It is intended to identify and investigate the factors which influence this relationship.

1.2 Background to this project

The project was initiated by Dr Mark Oakley, who, applied and successfully obtained financial support from the Science and Engineering Research Council (SERC) to investigate the nature of the working relationship between product design and production functions. Mark Oakley, initially, realised the need for research in this area because his extensive research, industrial and teaching had led to the view that this relationship was imperfectly understood that widespread loss of potential competitive advantage was occuring. This view was also shared by many designers and managers in industry. In fact, preliminary pilot investigation, prior to his application to SERC, confirmed this point of view.

Once the funds were available the author of this thesis was appointed to undertake detailed research in this area. The objectives for the author were to plan and organise the overall design of the project as well as undertake the field work. In addition to this, finally, to collate and present the results.

The main aims of the study were:

(i) to identify the nature of the functional relationships between product design and production departments.

(ii) to analyse these relationships in terms of effectiveness of new product designs.

(iii) to propose a 'code of good practice' to assist in the effective management of design.

The research was undertaken in 3 stages:

Stage I — Compilation of the results of other researchers in the topic area. Identification of a sample of firms to form the basis of the investigation.

Stage II — Derivation of the most suitable methods of research in view of the characteristics of the firms selected. Field research to identify and analyse the factors of importance within the terms of reference of the study.

Stage III — Reconciliation and interpretation of the results obtained. Formulation of the code of good practice.

This thesis, comments upon the first two stages of the research programme, but includes also a substantial element of the interpretive work in the third stage. Further 'Stage III' work has resulted in publications (3), (27), (158), (159) and the code of good practice has emerged as a book (2) which in turn has been incorporated in part in other significant publications. (160), (161). This thesis has been developed upon the basic assumption that the nature of the working relationship between design and production functions directly influences the product design performance. In order to examine this relationship a number of detailed hypotheses were developed (See Chapter Three).

Whilst undertaking the research, the author, was attempting to maintain a balance between the interests and the requirements of the participants. For example, this project represented the interests of the SERC which provided the financial support and the interests and the requirements of Dr Mark Oakley who had to ensure that balance was maintained between the academic standards and the constraints set out in his application to SERC. In addition to this, the author was keen to obtain wider, yet thorough, understanding of problems associated with the management of design process, and simultaneously develop an ability to organise and undertake effective research.

1.3 Summary of Findings

The following includes a summary of the findings of this research.

Product Specification

In the process of preparing product specifications, the main findings of this study were as follows:

- Major contributors in this process were design managers and other senior management personnel.
- There appeared to be a general absence of financial specialists, production engineers, production management personnel, buyers, estimators and more remarkably designers.
- There was a lack of adequate attention given to factors such as market needs, project duration, product cost, development costs, technical characteristics of a product and existing production resources. These were frequently left to the discretion of designers to consider.
- The firms in which product specifications were prepared either completely verbally or in written form were found to have fewer problems during subsequent design and development process than those where product specifications were prepared partly verbally, and partly in written form.
- There was a positive relationship found BETWEEN the extent of

involvement of different functions, comprehensiveness and format of the product specification AND subsequent design and development performances.

- There was a positive relationship found BETWEEN extent of involvement of different functions, comprehensiveness and format of the product specification AND the firms' sales performance.

Design Stage

Considering this stage the chief findings of this study were as follows:

- There was a very limited involvement of production engineers, methods engineers,estimators, production management personnel during the design stage of a product. Majority of these functions contributed to the process after the formal handover from design to production.
- There was a poor inter-departmental communication during the design process.
- Majority of the firms gave extensive consideration to technical performance features of a product but industrial design characteristics were generally ignored.
- Features such as production control, labour skills, product cost, development costs were given limited consideration during the design process.
- Approximately fifty per cent of the firms gave extensive consideration to production facilities and techniques, existing products and standardisation. The remainder gave limited consideration to these features during the design stage.
- There was a general lack of awareness and appreciation of importance

of 'design for assembly concept'.

- A positive relationship was found BETWEEN extent of production involvement AND degree of standardisation and modifications carried out.
- There was a direct relationship BETWEEN extent of production involvement AND product design performance from production point of view. Similarly, there was a relationship BETWEEN extent of production involvement AND the degree of consideration given to product design parameters.

1.4 Plan of the Thesis

The thesis consists of two volumes, Volume One contains the main text, which is divided into five chapters including this introductory chapter. The second volume is supplementary information containing Appendices in the form of Case Studies. The thesis has been split into two volumes for the sake of convenience and clarity which otherwise would tend to interrupt the flow of the main presentation. By having two separate volumes the reader can refer to the cases as and when necessary whilst reading the main text without having to flick pages backwards and forwards.

The diagrams, charts and tables etc have been used in volume one where it was thought appropriate. Similarly the organisational structure relating to the case studies used in volume two.

Chapter 2

Here, the views of researchers and writers on the product design and development cycle is examined. The phases involved in the product design process are considered and this is followed by a review of recent studies related to why new products fail or succeed. Then the literature related to the compilation of product specifications is reviewed. The remainder of the chapter is devoted to earlier studies into the management of design and development processes. This aspect is dealt with in two broad categories:

(a) factors affecting the management of the interface between design and production functions.

(b) factors affecting the management of product design and development activities.

Finally, conclusions drawn from this literature are presented.

Chapter 3

The first part of this chapter sets down the foundation for the further research which this thesis reports. Specific operational hypotheses are devised in order to improve aspects of knowledge which were found to be absent or incomplete as a result of the analysis in Chapter Two. These hypotheses are formed with reference to the imposed constraints and guidelines of this study, as is the design of the research devised to test the hypotheses.

The second part of this chapter outlines the research data collected in the form of 20 case studies, which are fully described in the Volume Two.

Chapter 4

This consitutes an analysis and discussion of the data in light of models devised in Chapter 3. The chapter is divided into two major sections. The first section deals with data relating to the product specification whilst in the second, analysis and discussion is presented of the data concerning the product design stage.

Chapter 5

In this concluding chapter the picture is completed by relating the results of this study to the published data reviewed in Chapter 2.

CHAPTER 2

A REVIEW OF LITERATURE RELATING TO PRODUCT DESIGN AND DEVELOPMENT CYCLE

2.1 Introduction

In this chapter, earlier studies relating to product design and development are reviewed. Although the main aim of the research reported in this thesis is to investigate the nature of the relationship between product design and production functions in manufacturing firms, it is important to understand the overall nature of design and development processes to put the relationship between product design and production in a true perspective. Hence, this chapter commences by reviewing literature relating to the phases involved in product design. This highlights the fact that in order to fully understand the problem at hand one needs to examine the starting point of the design cycle, namely, the customer. Accordingly this is discussed in some detail and is followed by an examination of literature relating to product specifications.

The next phase which is the core of the thesis - the management of design and production process - is critically reviewed. This aspect of the literature is divided into two distinct sections.

(i) the literature relating to the management of design and production functions.

(ii) the literature relating to the factors affecting the management of the product design and development process.

The chapter ends with conclusions derived from this literature review.

2.2 A typical design process

Although the main aim of the thesis is to examine the working relationship between design and production in manufacturing firms, it is necessary to have an overall understanding of the typical design process. This section of the chapter, therefore, briefly describes the stages involved in new product designs. Figure 1 shows an idealised model of a typical design process. The terminologies and number of stages may differ depending upon the type of product being designed, but essentially the general concept remains the same.

(a) Idea generation

Ideas can be generated either from the market or from the existing technology. Market ideas are usually derived from customer needs. However identification of market needs can then lead to the development of new technologies and products to meet those needs. Market needs can also be identified by observing the performance of other products on the other hand, ideas can be obtained from available technology.

(b) Product Selection

Not all new ideas need to be developed into new products. Hence product selection analysis needs to be carried out to screen and reject poor ideas. In order to select goods ideas from poor ones, product selection criteria (eg selling price, product quality, sales volume, competitive advantage, and technical risk etc) are employed.

(c) Preliminary product design

This stage is concerned with developing the best design for the new product idea. If the preliminary design is approved, a prototype(s) may be built for further testing and analysis.

(d) Prototype construction

Prototype construction usually closely resembles the final product and can be made by hand or by existing production equipment.

(e) Testing

Testing of prototype is aimed at verifying market and technial performance of products.

(f) Final Design

During the final design phase, drawings and specifications for the product are developed. As a result of prototype testing, certain changes may be incorporated into the final design. If changes are made, the product may be tested further to ensure final product performance.

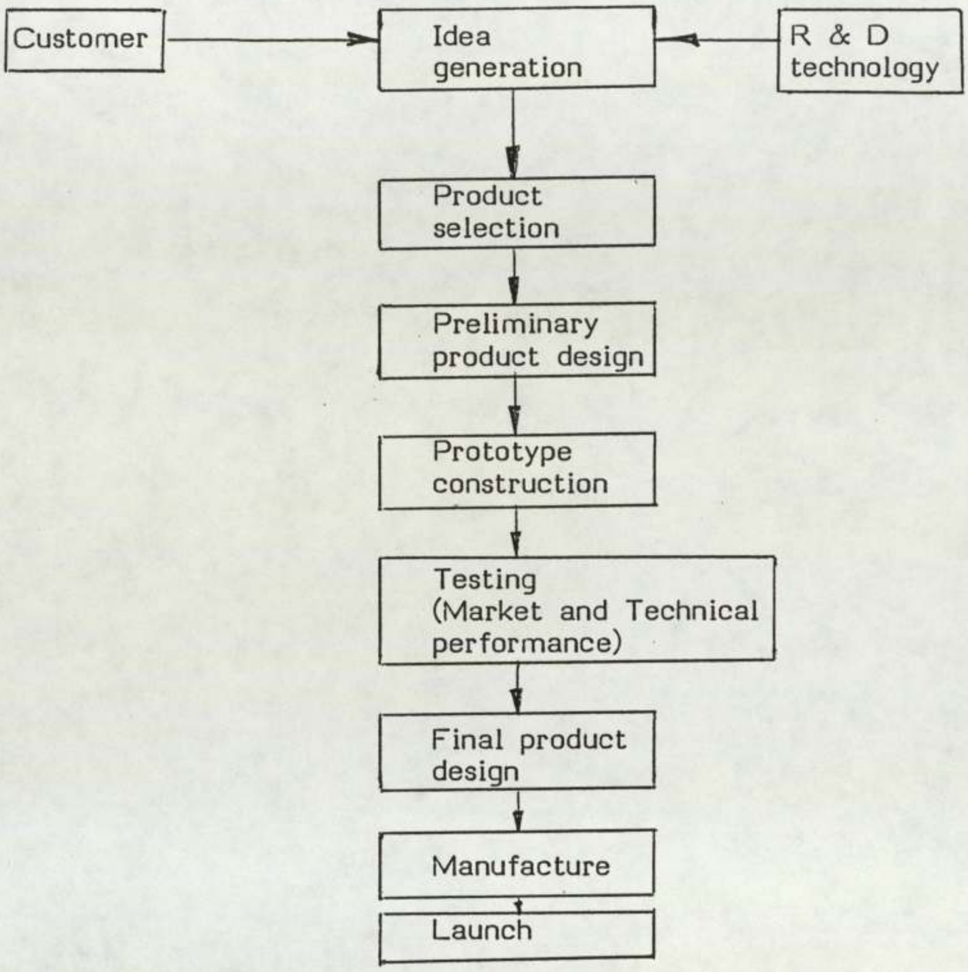

Figure 1 A typical design process

2.3 The need to consider Customer or Market Requirements

Any examination of the design process will, sooner or later, force the conclusion that success in design is not entirely dependent upon organisational structure or good administrative practice. It is possible to conceive an approach to product design which apparently exhibits every desireable manifestation of logical good practice and efficiently generates products which are sound from a technical point of view, yet is consistently unsuccessful because these products fail to achieve acceptance by customers. In such cases, it is likely that the defect will reside in the firm's perception of its relationship with markets and individual customers - an inability to recognise that the success of a business is determined by satisfactying customer s' aspirations, not just by satisfying technical competence in products which are assumed to be satisfactory but which may be outmoded or inappropriate in other ways(5). Ideally, a new product design should start with the customer and finish with the customer(6). Mitigating against this vital practice, is a widespread tendancy to view the design process as a series of successive steps or stages(7). Thus even a distinguished recent contribution(8) perpetuates the problem by analysing design operations in this stepwise manner. Other writers take a similar approach. Whilst the terminology employed to describe the steps may vary, the descriptions are essentially the same(9). Anything more than a passing reference to the importance of effective feedback of information or the development of vital inter-relationships, is the exception rather than the rule.

This suggests that unless product designs are effectively managed, the chances will be greatly increased that indecision or conflict will predominate and lead to sub-standard results. In particular, the interfaces between design and other functions in the company assume vital importance at certain stages in the design process. For example, the nature of the relationship between design and production departments has been seen to greatly assist(10) or seriously obstruct(11) the overall design effort.

To avoid the problem of conflict or indecision, it is necessary to move away from the step-by-step concept of design and view this activity in a cyclic and interactive manner (Figure 2). Whilst the design department is in the main stream of translating ideas into products desired by the customer, it is only one of many components in the design process.(12)

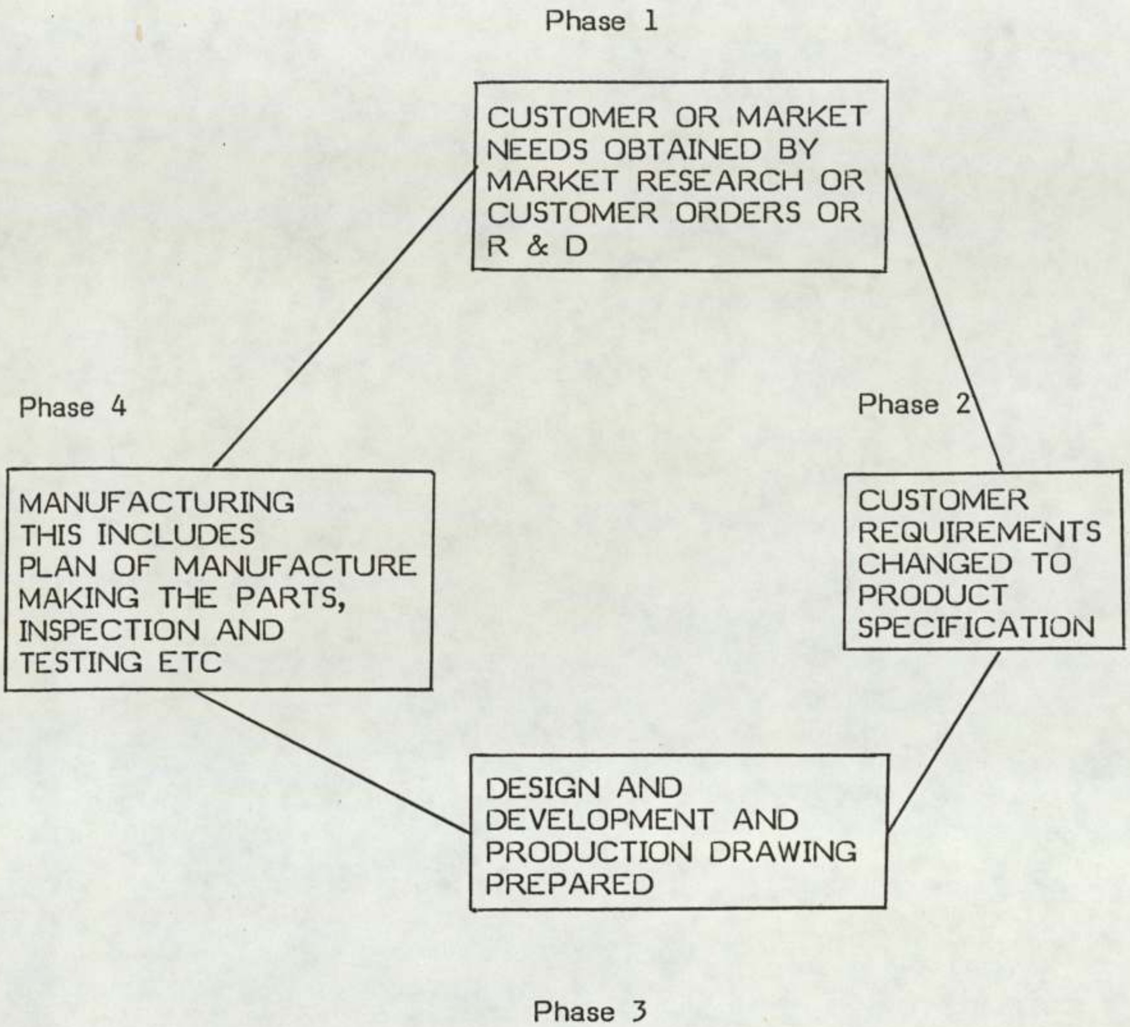

Figure 2 **A diagrammatic representation of the key stages involved in a typical design project**

It is generally accepted that the importance of market needs was not fully realised until after the second world war.(13) Up to this time, manufacturers largely considered intuition, trial and error to be adequate for managing the market activities of their business. If any kind of research was carried out, this was usually confined to the technical variety. Nowadays, however, the picture is somewhat different. Market research, when properly conducted, is just as valuable to a firm as its technical research, although the state of the art is not be so advanced. It has been stated that, managements seldom know as much about the performance of the marketing function as about manufacturing.[14].

The initiation of the design process can be from many different sources which can be broadly grouped into two main categories: (i) external to the firm and (ii) internal. An example of the first category is the the project may be initiated when a customer approaches the company. This may take the form of drawings or a written description of the product or project objectives;[15] a combination of these two, rough sketches or simple verbal requests are other possibilities. In the ensuing communications between customer and producer, the original instructions or requests may result in changes before a mutually acceptable customer specification is achieved. It can be argued, however, that although the customer should provide adequate details about requirements, the emphasis should be on the producer to ensure that relevant information regarding the project is obtained before embarking on the design process. Here some companies involve their designers to make sure that relevant information is extracted from the customer. An important point to note is that although the original idea may come from the customer, internal members of the organisation may also play an important part in the initial stages of the design process.

At the other end of the spectrum when the Research and Development (R&D) function of an organisation makes a new technological break-through, this work needs to be co-ordinated and transformed into commercial benefits for the firm. This means that as well as ensuring commercial viability of the project it is also necessary to ensure that the product is economical to manufacture. Such transformations are usually carried out by the engineering and the marketing functions of the organisation. Skill therefore lies in the management of these functions in ensuring that co-ordination amongst them exists, if the company is to remain competitive.

Thus, the initiation of a design process may be internal or external [16]; in either case the central role of the marketing function is very important indeed if the design project is to succeed.

The marketing function of an organisation becomes critical at two stages of the design process. Firstly, at the pre-design and development stage and secondly at the post-design stage (sometimes referred to as the product launch stage). This research project is mainly concerned with the first stage, which is usually known as Market Research. Market Research activity, essentially, consists of gathering, analysing and interpreting facts and opinions that concern marketing so that decisions regarding future product developments are taken in the light of marketing data to minimise the risk element during the product launch.

The purpose of market research then is to determine who and where customers are; what they need, want and will buy; where and how they will buy; and how much they will pay.[17] Market research activities can be related to a number of aspects of the organisation such as product or service, sales methods and policy etc so the type and the extent of market research carried out will vary from company to company - depending on the nature of the problem. In the last few years, numerous studies have been conducted to find out why new products fail and how success can be distinguished from failure, but new product failure rates still remain high[18] with the majority of failures related to marketing.[19]

One reason why firms have been slow to act on research findings has been presented by Calantone and Cooper[20] who documented examples of research which has not been translated into meaningful and tangible guides for action. For example, one notable study of new product success factors, Project SAPPHO, found that "an understanding of user's needs" was the number one factor in success, a finding of interest to the researchers and academics. But how can this finding assist practising managers in industry and what steps can they take to become more "aware of the user needs?" The answer is not provided by the research. Cooper[18] suggests that a managerial guide is required to fulfill this need and he proposed a process model.

2.3.1. Why new products fail or succeed - A review of recent studies

Some new products fail and some succeed. But what is failure? What is success? How many fail? How many succeed? Why?

There are no entirely satisfactory answers to the above questions, mainly due to problems of intractable definitions. Not only is there the usual difficulty in defining a new product - everyone uses a different definition - but also what constitutes a failure to one company could be a success to another. Moreover failure rate figures are applied to products at various stages of development. Some are quoted in terms of the percentage of new ideas which lead to one success whilst others estimate the failure rate of products placed into test markets.

A new product is a success if it meets the company's 'success criteria', otherwise it must be classified as a failure. In practice, however, these 'success criteria' rarely exist and the new product is a success if the company's management just feels that the results are good[21]. This feeling is probably subjective and empirical, yet it can work reasonably well, particularly if the company has launched a number of new products so has past experience of critical stages in their development. However, when a company defines its 'success or failure criteria' this usually depends on a number of factors such as its financial and human resources, its attitudes, plans, policies and many others. It is important therefore that the wealth of information which exists on the failure or success rate of new products is treated with care.

It has been reported[22] that as few as 20% of new products actually launched into the market become commercial successes. Another study[23] puts the figure at 33% but also shows that for each ultimately successful product, an average of 58 ideas will have been discarded, some at a very early stage but others after the investment of much time and effort.

The reasons behind these high rates of failure have been explored by a number of researchers. For instance Cooper investigates the causes of new industrial product failures for a sample of 144 actual product cases[24]. The major reasons for failures were:

(1) underestimated competitive strength and/or competitive position in market (36.4%);

(2) overestimated number of potential users (20.5%);

(3) product's price set too high (18.2%); and

(4) technical difficulties/deficiencies with product (20.5%).

On the otherhand Gold[25] suggests that many firms wrongly estimate the anticipated technological benefits of innovation when devising product plans. In particular, the time required to achieve effective performance of an innovation is over-estimated. In some firms these weaknesses might be accounted for by shortages of experienced personnel available to conduct project appraisals. Some researchers argue that this weakness is somewhat compensated for by the existence of an entreprenurial person[26] in the company, but others claim[27] this to be highly debatable.

Some reasons why new products are more successful include efficient development, the role of 'key individuals' and effective communication[28,29]. Similarly Globes' study showed that ten radical innovations were dominated by technological and internal variables with external factors least important[30]. Success factors included:

(1) a recognition of a technical opportunity;

(2) proficient internal R&D management;

(3) well-executed venture decisions;

(4) ample development funds;

(5) a technical entrepreneur;

(6) a need (market) recognition.

Both internal (technological) and external (markets) variables helped decide the fates of six successful innovations studied by Roberts and Burke(31):

(1) Market needs were recognised and R&D was changed with satisfying these needs;

(2) When a technical success did not have a specific market need, the product was adapted to suit the identified need;

(3) Research managers communicated the possibility of a technical breakthrough clearly to other departments, which facilitated the identification of a market need;

(4) Communication existed between engineers and scientists in the operating departments.

In another investigation, detailed case studies of three significant high technology new products revealed an intricate and balanced new product process as the key to information acquisition and risk management(32). The entire new product process could be viewed as a goal-directed, stepwise process; improving a series of information activities and evaluation points. The process was reportedly characterised by a phenomena termed "incremental commitment" where resources were committed to the project such that uncertainty and amounts committed were balanced. The process itself was multidisciplinary and integrated, with input from marketing, engineering, R&D and production. Extensive market studies, especially near the beginning of each project, were common to all three products and played a key role in shaping the success of the products.

Townsend's study of one radical innovation and subsequent incremental innovations shows that successful innovations depend on key factors such as the existence of information and internal communication and highly developed testing and screening procedures[33]. Other factors noted by the study were market related.

Gronhang analysed 36 products in 15 small and medium sized Norwegian firms[34]. Highly novel products tended to originate from outside the company, whilst medium and low novelty products came from within. The most successful were medium novelty products. The magnitude of R&D input was positively correlated with number of new products. Also the study showed that a strong competitive environment led to less novel products, but a more systematic search for ideas. Effective internal and external communications systems were seen to be essential for successful innovations.

Cooper[35] reported three factors to be the most critical determinants of new product success:

Successful firms had technical and production energy and proficiency; had a 'good fit' between the product and the company in terms of R&D, engineering and production; had 'in-house' technical and production knowledge; and undertook the technical and production activities well.

The other two factors were market related.

Rothwell's study of the textile industry(36) found that firms employing qualified scientists and R&D engineers were more able to produce successful breakthroughs and more radical innovations stemmed from those firms with a technically qualified chief executive. An open and flexible management structure, the existence of a 'product champion', effective external communication, and several other controllable variables were related to positive new product outcomes.

A frequently cited British study, Project SAPPHO, identified a pattern of differences between a paired sample of 43 successful and unsuccessful innovations(28). Of the 122 variables measured, 41 were found to discriminate between successes and failures and five underlying factors that separated successes from failures were identified:

(1) understanding of user's needs;
(2) efficiency of development
(3) characteristics of management and managers
(4) effectiveness of communications (internal and external)
(5) magnitude of marketing efforts.

Other conclusions were that many variables leading to product outcomes were, to a large extent, amenable to better management control, particularly in the area of marketing. But product outcomes - success versus failure - could rarely be reduced to a single variable. Finally the investigation yielded a rank order list of what variables appear important in deciding new product results.

Project SAPPHO was reconstructed on a smaller scale in the Hungarian electronics industry(37). In this study, the sample size was limited to 12 product pairs and featured a different pairing technique. Inspite of the differences in research designs and obvious contrasts between the two countries, the Hungarian results were strikingly similar to the British SAPPHO. The following characteristics were highly associated with successful innovations:

(1) market need satisfaction;
(2) effective communication (internal and external);
(3) efficient development;
(4) a market orientation;
(5) the role of "key individuals".

In another study undertaken on European and Japanese firms measured the impact of the external environment and industry maturity on the innovation process.(38) Successful innovations, when compared with failures:

(1) had no initial difficulties in marketing;

(2) had a real product advantage;

(3) had market needs recognised prior to production;

(4) had more customer contact;

(5) involved top management initiation.

Other factors which were related to success included advance planning, use of outside consultants, the absence of patent protection and responses to government actions.

A West German study investigated products that were commercialised versus those that were abandoned.[39] The source of the idea - whether market pull or technology push - had a marked impact on commercialisation, with market pull products fairing better. All products were incremental innovations.

The SAPPHO researchers conducted a study in five countries in the textile industry.[40] Incremental innovations were found important to short-term prosperity. Successful firms had superior marketing programs and frequent customer contact in this textile industry study. Successful firms understood user's needs better and were able to assess whether these needs could be fulfilled economically. Specific sales strategies were matched to market requirements.

An American study of new products by Rubenstein et al, identified fifty-four significant facilitators for success, but no single characteristic of success or failure could be detected.[41] Furthermore, one person's facilitators could be someone else's barrier. Some of the important facilitators included:

(1) existence of a strong product champion;

(2) marketing factors, such as need recognition;

(3) strong internal communications;

(4) superior techniques for data gathering analysis and decision making;

(5) planned approaches to venture management.

In summary it can be said that the majority of the studies indicate that there is no easy explanation for what makes a new product a success because success does not depend on one or even a few variables. However, there is agreement amongst researchers that a large number of characteristics determine the degree of new product success. The "success formula" is a complex one; and that success depends on several parameters, while failure can result from a single error.

In fact, all studies indicate that an adequate marketing input is essential to the successful product development lack of market research remains the most common failure. A majority of the studies conclude that the ultimate success of a new product is determined in the market place and market information plays a critical role in the shaping of product and launching strategy. However these studies fail to give an indication of the stage of product development at which the market research should be carried out. For instance is the product design likely to render success if the market research is carried out at the beginning of the design process or throughout the design process or both. Furthermore should the market research be carried out by the designers as suggested by Burns and Stalker[42] or will a greater degree of success be achieved if marketing specialists are engaged in this activity? How should marketing data be communicated to the product designer? Should the marketing function actively participate throughout the design process? If yes, how does this affect the product design performance? These and many other questions still need to be substantiated with evidence. Perhaps above all, what criteria has been used in these studies to measure success? It is therefore important to be cautious when considering the results of these studies.

Similarly many studies speak of interfaces[43,44] between R&D and marketing, of coordination between key internal groups and of multi-disciplinary inputs to the new product process. It is unclear, however, what constitutes 'key internal groups' and how can this information assist a project manager who has to actually manage the product design process. This type of information needs to be converted into some sort of guidelines for practicing design managers, so that functions such as Marketing, R & D, Sales, design engineering, production, estimating, purchasing and accounts etc can be brought in at the 'right' stages of the design process in order to achieve successful product design. An attempt has been made by Flurscheim to discuss engineering design interfaces but the information is based on his experience rather than on research.[44]

2.4 Compiling Specifications

The initiation of a design project may occur in one of several ways. Most straight forward may be the case where a customer makes a direct request for a new product. The request may range in form from a vague oral statement to a submission of requirements fully substantiated by drawings, written statements or experimental data - although even in this case, extensive negotiation and clarification may be required before a mutually acceptable specification can be formulated.(45)

If a company does not operate this type of business, but instead is serving a large or mass market, then some kind of market research must supply the necessary information. In this case, the market research activity acts as the customer's 'agent' and its job is to ensure that the correct information is offered and incorporated in the specification. It is essential that the specification is drawn up jointly by the two parties - by the customer (or agent) and by the company - and that agreement is reached on all major project parameters before design work begins. The parameters must include cost, time, performance and all other essential features.(44,46) In addition, the specification should indicate the sequence of the project and the involvement of different skills from inside and outside the company.

Support for this approach comes from Mayall(47) who puts forward the view that it is the responsibility of a professional designer to insist that a comprehensive specification is agreed at the beginning of a project. It may be argued that it is the customer's responsibility to provide adequate information at the start of a project but in practice, the good designer will satisfy himself that all relevant information has been extracted. In doing this, he will also wish to examine manufacturing programmes to determine production quantities, available processes, tooling restrictions, size limitations.[48] This is particularly important when an external designer is being employed on a project; in addition there are many company-based designers who lack intimate knowledge of their company's production systems and for whom this stage is also highly important.

When preparing production specifications, companies may concentrate their efforts on acquiring information about user's requirements and in the process may overlook their own manufacturing capabilities. This deficiency arises generally because of a lack of production involvement at this stage. It seems to be a common view that the project conception is the sole responsibility of the design department and in practice no-one is likely to challenge the designer's 'rights' over the technical content of specifications.[49] However, it has been shown that considerable benefits can be gained by involving at this stage (and subsequently) not only production personnel but also specialists such as process planners, financial controllers and marketing staff.[50] Usually this results in substantial cost savings without loss of product quality or increase in project duration.

The dangers of embarking on design work without an adequate specification - perhaps with just some broad notions - are illustrated by Lock.[45] He discusses how projects are likely to diversify from the original objectives under such circumstances. The result may be excessive design costs, high units costs and delayed product launch; he terms the phenomenon 'creeping improvement sickness' and identifies the quest for perfection as the basic problem. This point is further argued by Zarecor [51] who claims that designers and engineers are generally interested in exploiting technology and consequently tend to over-design. Hence, it is paramount that performance levels are specified before design starts and are adhered to when working towards a solution. He supports his argument by citing a case where a design team managed to double the performance of a product with only a 20% increase in costs. However, the added performance simply was not required by the market nor would it accept an increased price.

These comments and examples are interesting, but it is still unclear what is the common practice in industry regarding procedures for compiling specifications. For example, in addition to the participation of the designer and the customer (or representative) it seems to be largely a matter of circumstances as to who else is involved - or excluded.[52]

2.5 The Management of the Design and Development Process

Once the specification for a product has been devised and all the customer's needs understood and clarified design work can begin. It is important at this stage that the designer is careful to maintain an open and progressive attitude.(53) The designer will find that problems are solved through the combination of a systematic approach and close communication with the others in the organisation. Very rarely will the designer solve all problems himself so he must be able to ask questions and obtain answers from the others in the organisation or outside the company if necessary.

This raises two important issues firstly,the management of the product design process itself and secondly, the people who are engaged in or associated with the design activity. The problems affecting these categories can be quite different but management needs to be fully conversant with the nature of them so that an effective course of action can be taken when difficulties arise. In order to appreciate the nature and scope of these problems it is important to investigate the issues related to this activity.

This section of the chapter sets out to explore the relevant factors associated with the management of design and development process. First of all the factors related to management of design and production functions are examined and this is followed by a review of the issues concerning the product design process.

2.5.1 Factors affecting the Management of Design and Production functions.

Managing inter-departmental coordination: A review of related studies with a particular emphasis on design and production functions.

Recent studies[54,55] have pointed out the importance of organisational factors and their influences on the technical and commercial success of new products. Causes of new product failure have been associated with the absence of clearly defined goals, mal-functioning of channels of communications, poor interdepartmental cooperation and inadequate definition of project responsibilities.[54,55,56,57]

According to Souder[54], interdepartmental cooperation is needed at various stages of new product development process. Factual and evaluative types of information have to be exchanged between various functional groups for effective decision-making. Indeed, the R & D, design and development, production, marketing and finance functions are interdependent[54] as they all exist to contribute to the achievement of organisational objectives.

In an empirical study of customer initiated projects, Aram and Javian[58] observed that directness of communication between various functions was related to success of highly complex projects. However, cooperation between internal groups is necessary in all cases, but it is most essential in the more complex and uncertain situations where technological content (as well as the market targets) are relatively novel.[59].

In order to resolve the problem of interunit conflict, one needs to determine the underlying reasons for its existence. The essence of the problem of interunit conflict often lies in the different (and sometimes contradicting) subgoals of the various functions that may be involved in the product design process[60,61]. Such organisational and behavioural factors as the specialised grouping of functions and the professional specialisations of personnel often lead to differential perceptions and appreciation of the technical tasks at hand. Figure 3 shows[62] some of the possible relationships among these variables. The potential result of such differential perceptions, exposures and goals is intergroup conflict, as summarised in the March and Simon's[62] model in Figure 4. An understanding of these relationships helps clarify the specific problems that may be encountered at departmental interfaces and assists in selecting effective methods for managing these interfaces.

The influence of the organisational structure on inter-departmental relationships.

Although companies appreciate the importance of innovation for their future survival and growth, few seem to understand the need for an appropriate organisational structure for the successful development of new products.[63] Booz, Allen and Hamilton[64] conducted a survey on development problems among United States companies which had been relatively successful with new products and found that eight companies out of ten mentioned organisation as a problem and over half of all

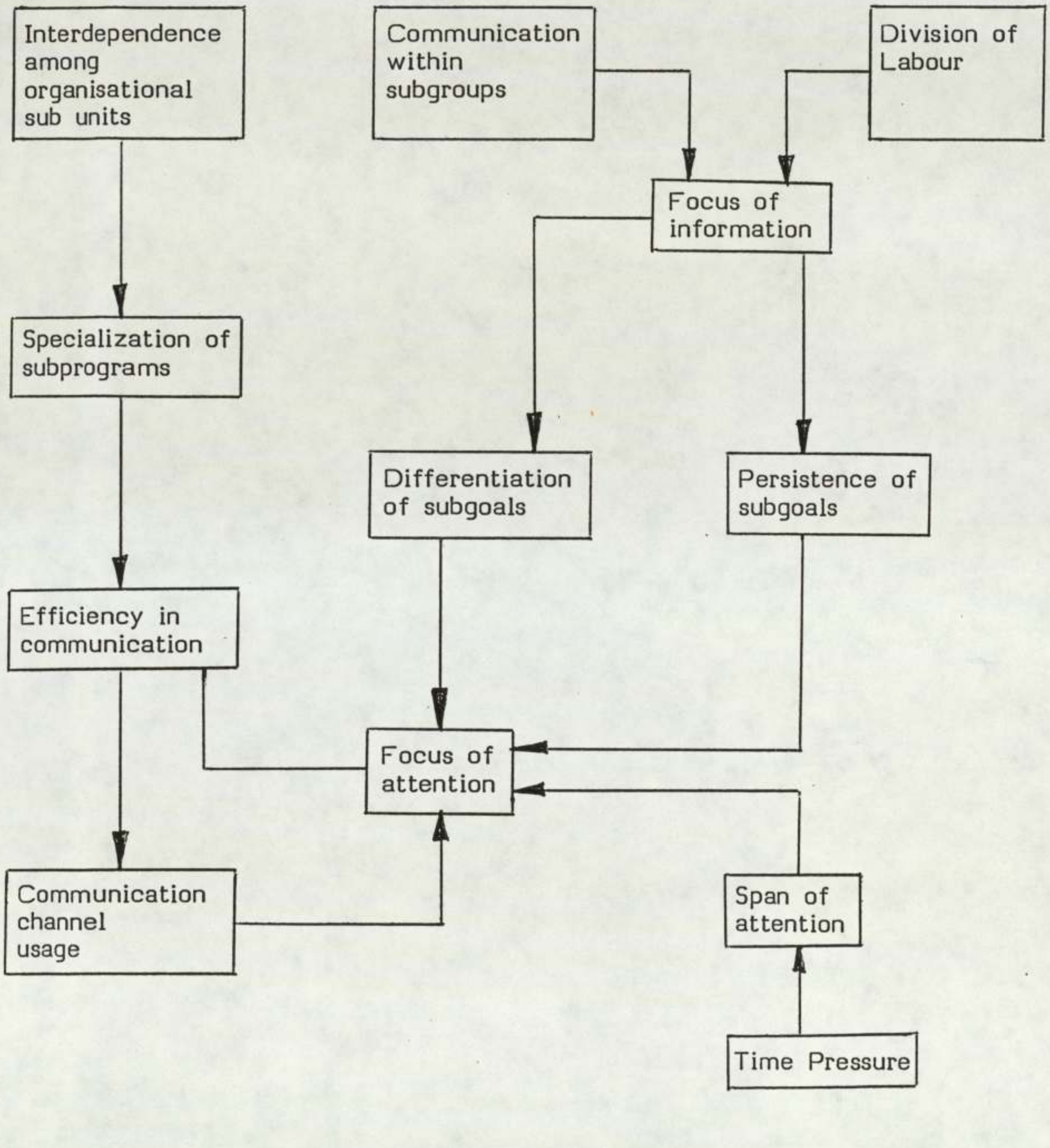

Figure 3 **Model of factors affecting selective attention. from March and Simon[62]**

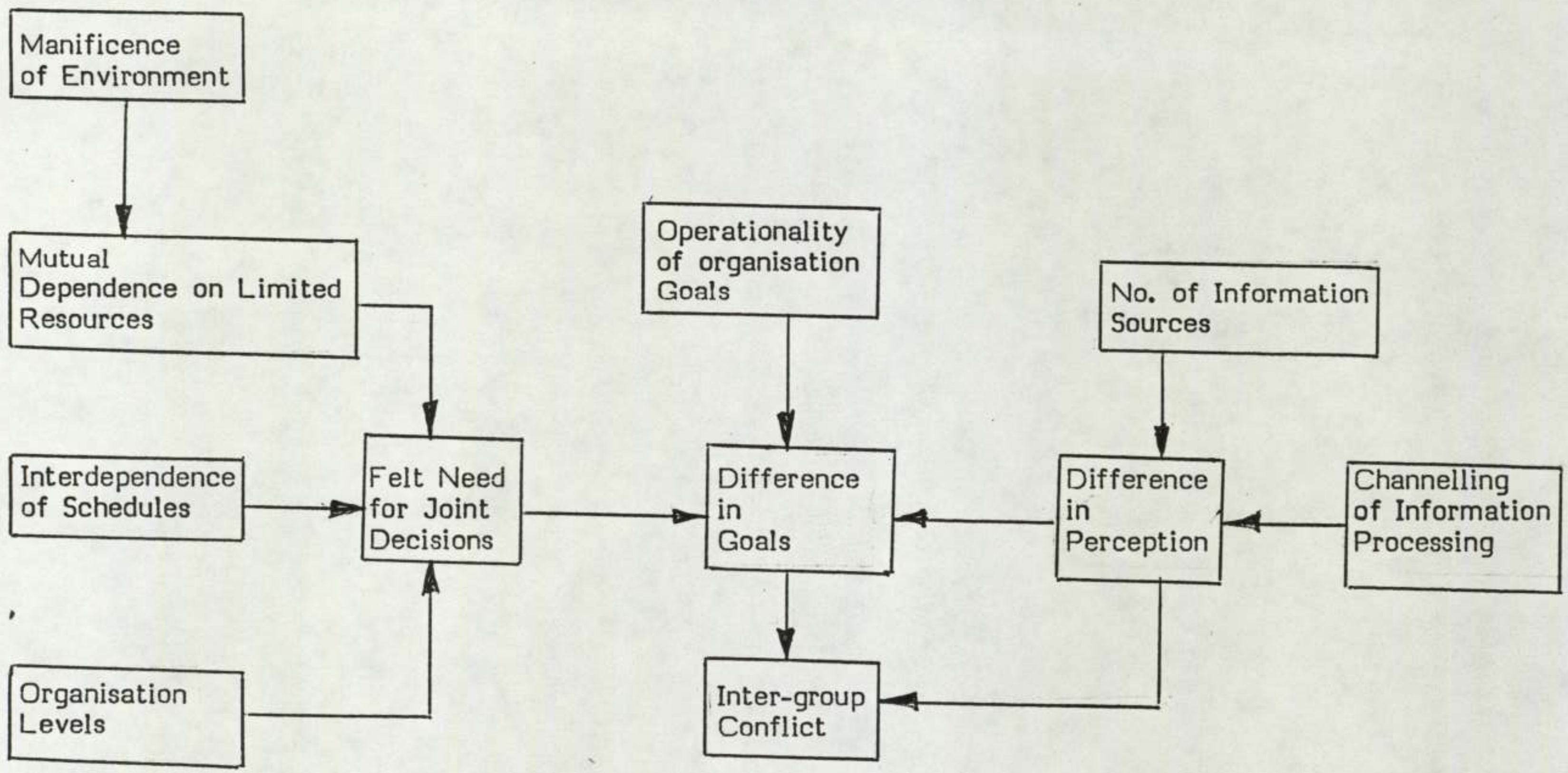

Figure 4 Model of intergroup conflict
From March and Simon [62]

problems concerned organisation - four and a half times as many as those of the next most important factor.

In order to identify the origin of the problem it is necessary to back track and determine why is there a need for an organisation to be split into departments or functions. In a study by Lawrence and Lorsch,(65) the appropriate structure and functioning of organisations was investigated using the 'organisation and environment' approach. As organisations grow, in order to cope effectively with their external environment, they develop segmented units, each of which has its major task, the problem of dealing with some aspects of conditions outside the firm. For example, in a manufacturing company with production, sales and design units, production deals with production equipment, raw materials and labour requirements; the sales function faces problems in the market; the design department has to cope with technological developments, government regulations etc. This differentiation of functions and tasks is accompanied by differences in cognitive and emotional orientation among the managers in different units, and differences, too, in the formal structure of different departments. For instance the design department may have long-term time horizons and a very informal structure, while production may be dealing with day-to-day problems in a rigidly formal system, with sales facing the medium term effects of competitor's advertising with moderate formality.

In spite of this, the organisation is a system which has to be coordinated so that a state of collaboration exists in order to obtain for members the benefits of effective transactions with the environment. The basic necessity for both appropriate differentiation and adequate integration to perform effectively in the external environment is at the core of Lawrence and Lorsch's model of organisational functioning.[65] However, greater differentiation brings with it potential for greater inter-departmental conflict as the specialist groups develop their own ways of dealing with the particular uncertainies of their own sub-enviroments. These differences are not just minor variations in outlook but may involve fundamental ways of thinking, behaving and functioning.

Based on an analysis of existing literature, Lawrence and Lorsch generated several hypotheses regarding the differentiation and integration of organisation subsystems.[65] These hypotheses generally conform with the findings of Turner[66]; Berman[67]; Collier[68]; Gunber, Poensgen and Prakke[69] and Dean[70]. Of particular interest in the discovery that as an organisation becomes larger and more differentiated, the communication links become weaker. The natural tendency is to communicate with others within the same department, with whom one shares common problems and experiences. Departments undertake work of different kinds requiring different methods; they operate to different time horizons and at a different pace. These conflicting functions performed by departments reinforces the importance of mechanism to achieve adequate integration.

Mechanism for integrating inter-departmental relationships

One of the most common problem of conflict appears in the relationship between design and production functions. On the one hand design and development is primarily concerned with satisfying functional and aesthetic aspects of product design. On the other hand is production whose primary obejctive is to manufacture these products as economically as possible. The design function may seek variety and diversity in order to satisfy a broad range of customer tastes, so designers are usually employed for their creative, and imaginative flair(71) while production seeks order, stability and long uninterrupted production runs.(72) Because of these contradictory basic requirements and objectives, conflict may arise at the interface of the two functions. But the integration of these functions is essential, since without this integration the wider organisation may not remain viable.

In deciding on methods to achieve better integration between functions in an organisation, it is imperative that the following points are adequately considered.(73)

(a) the degree of integration required
(b) the difficulties in achieving this that are inherent in the situation
(c) the costs of alternative integrating mechanisms.

Only when due regard is given to these points should one go ahead and attempt to achieve the desired integration. It is also important to realise that problems of integration vary from one industry to another because of factors such as size of the firm, and nature of business etc.[74]

Galbraith[75] examined different types of integration mechanisms. His findings indicate liaison groups to be most effective in mediating between product design and process design personnel; he observed uncertainty to be very high at this stage. A liaison group was found to be effective, where the primary need was to supplement the formal hierarchy and provide a quick reaction capability to avoid damaging schedule disruptions.

Allen[76] found that at the informal level, R&D personnel depend on a few "gatekeepers" as information sources. The "gatekeepers", who are high performers and consequently have high status in the organisation, act as mediators and linking pins[77] between R&D scientist/engineers and others in the firm. Chakrabarti and O'Keefe[78] observed the multidimensional nature of the informal roles performed by such key communicators in R&D laboratories. Some of the interdepartmental conflicts are resolved through coordination by such key persons[79] and through good internal communications[80,81,82,83,84,85]. Another example of informal coordination between different functional groups is that performed by a "product champion". A "product champion" bridges the organisational gaps as a result of a personal interest in an idea and a desire to have the idea implemented.

Lawrence and Lorsch[74] suggest that the resolution of interdepartmental conflict is best dealt with by managers working in a problem solving mode to face the issues and work through to the best overall solution - rather than smoothing over the issues to avoid conflict or letting the party with greatest power force its solution on others.

One example of a problem concerning integration between two departments has been the focus of a study carried out by Sykes and Bates.(86) They studied a British company with six sales departments and eighteen different plants. In this firm, a constant conflict existed between the sales and the production departments. While production wanted to limit the range of products in order to increase the output volume and reduce unit costs, the sales department continually attempted to force production to comply with the customers' exact specifications regardless of the case for standardisation. This company overcame these difficulties by setting up a Sales Organisation Liaison Department (SOLD) between sales and production. Integration was significantly improved by the establishment of this new coordinating department and by setting up new procedures.

Another case,(87) concerns the problems of integration between purchasing staff, design engineers and production personnel. Conflicts arose because the engineers preferred to specify exactly what they wanted without leaving any discretion to the buyer; by training and functional responsibility the engineers looked first for quality and reliability, while buyers were required to take low cost and quick delivery into account as well. Conflict with production personnel arose because they would often seek extremely short delivery times (under pressure themselves from sales) or require materials in uneconomic sizes or batches. In an attempt to ease the problems in dealing with other departments, the buyers had adopted various devices. Some mainly to protect themselves, others in a more constructive attempt to improve 'integration'. Among the latter were the use of direct contact to persuade other departments to take purchasing criteria into account, and an attempt to modify the workflow pattern in order to stablize the situation.

Thompson identified[88] three main categories of integrative mechanism.

(i) integration via standardisation - this involved the establishment of rules or procedures which channel the actions of each job holder or department into a direction consistent with the actions of others.

(ii) Integration via plans and schedules - this is somewhat more flexible than standardisation in that plans can usually be modified fairly quickly.

(iii) Integration via 'mutual adjustment' - this entails the transmission of information directly between people and the mutual adjustment of their actions in the light of that information.

Galbraith[89] discusses various integrating mechanisms in detail. He makes the point that as information processing requirements in an organisation rise conditions of greater change and complexity so the bureaucratic approach is able to cope with decreasing effectiveness. He lists four alternative mechanisms for integration. Child[73], in Table 1, lists various forms of lateral integration; the more sophisticated approaches lower in the list tend to subsume those higher up.

1 Bring about direct contact between managers or employees who share a problem.

2 If departments are required to have a substantial amount of contact, one or more of their staff can be given special responsibility to act as a liaison officer with counterparts in other departments.

3 If a development or problem arises which calls for the contribution of several departments until its completion or solution, then it would probably be appropriate to set up a temporary task force to deal with it, with members drawn from those departments.

4 If such inter-departmental problems recur, then permanently established group or teams provide a method of integration.

5 If the management of lateral relationships becomes a problem, perhaps because of their complexity, then a special integrating role can be set up, that of a 'coordinator' or similar title. It may be necessary to endow the 'coordinator' with a department of staff as was done in the case of SOLD.[84]

6 A further development of the separate integrating role is to decide that it should have a definite claim upon the resources of functional departments. Indeed these may disappear as separate departments. In industry such integrator managers are often product managers in charge of the total operations required to market, develop, produce and service a product.

7 The most elaborate and sophisticated method of ensuring lateral integration is to establish a matrix system. Here an attempt is made to combine integration of personnel within functionally specialised departments within their integration.

Table 1 **Integrating Mechanism**
Adapted from J Child[73]

2.5.2 Factors affecting the management of the product design and development process

So far, the importance of communication, coordination of different functions and mechanisms available to achieve this has been discussed. In order to complete the picture, it is also important to consider the design process and examine those factors relating to product design which the designer needs to be concerned or involved with. For instance, when the designer embarks upon the designing of a new product in order to meet the requirements laid down in the specification he may well be selecting the process(es) by which it will be manufactured. In doing this, he may be limiting the methods to least desireable from a production point of view.(90) The design of the product often determines whether the production department can set up manufacture with relatively simple operations or will incur costly, unpredictable or even unnecessary steps in production. In order to avoid the problems of uneconomical product designs, the designer needs to consult and liaise with the different functional specialists in the organisation (or outside the firm, if not available in-house). These are:

- manufacturing specialists - to assist in the selection of the 'right' processes or techniques of manufacture;
- managerial staff - to provide expertise in the area of project management such that the project is run according to the planned schedule;
- financial experts - to ensure that the design is within the budgeted costs and target price;
- design or engineering colleagues - to provide assistance with the attainment of performance levels as laid down in the product specification etc.

In this part of the chapter, different aspects of the product will be investigated which the designer needs to satisfy from production points of view. For example, who should be involved in the design process? What parameters of the product should be considered during the design process and what should be the extent of consideration? Finally, how do these factors affect the overall 'design for production' philosophy?

The factors influencing product design can be divided into two categories of requirements which the designer needs to satisfy:(91)

(a) The requirements laid down in the product specification.

(b) The production criteria or requirements.

(a) <u>The need to satisfy product specification requirements</u>

The main requirements can be listed as:

Technical requirements

Design and Development costs

Product cost

Project duration - to meet the planned launch or delivery date.

(b) <u>The need to satisfy the production criteria or requirements.</u>

These are:

- Production facilities and techniques
- Assembly techniques
- Labour skills
- Existing products and standardisation
- Production control

Others Material Aspects (such as choice, handling and storage), transportation, packaging and servicing.

It is unlikely that all factors will be the sole responsibility of the product designer; management and others in the organisation may play an important role in the whole process.

(a) The need to satisfy product specification requirements

Technical requirements

The technical requirements of a product are usually determined by two means:

(i) The product specification is dictated or compiled by the customer - who usually specifies the prime requirements of the product design.

(ii) The company is designing a product on its own initiative and which is to be marketed - here the technical requirements of the product are usually determined by the company (through the marketing department or by other means) and laid down in the form of product specification.

Irrespective of which method is used to dertermine the technical requirements, the task of the product designer is to comply with these requirements.

Upto now the term 'technical requirements' has been used rather loosely; it is difficult to be precise about technical considerations unless a particular product is considered. However it is appropriate to use a definition suggested by Brewer(92) - "the ability of a product to perform required function under the stated conditions for a stated period of time".

The designer therefore needs to consider these four key elements in order to satisfy the technical requirements of a product design. Leech[93] argues that these technical aspects of product design need to be clearly stated in the product specification and he proposes four areas which require careful and detailed attention from the technical point of view. They are:

Function

the designer needs to be clear about the function which the product is required to perform.

Functional requirements

this consists of many areas again dependent on the type of product to be designed. Usually aspects such as performance, life, reliability etc need to be considered.

Safety

any special safety requirements or precautions need to be taken into account.

Environment

Many issues may be important depending upon the mature of the product. A typical example is provided by Leech [93] of an aircraft engine lists the following characteristics:

Ambient temperatures

" pressures

Climate

Vibration

Acceleration

Other environmental factors.

Most accounts of the management of technical aspects of product design are for specific products; Sherwin[94], Leech[93] and Whyte[95] all illustrate points by means of case histories. From these types of studies, it appears that some companies fail to manage functional design aspects as Parkinson[96] shows out in his comparative study between Britain and West Germany. He found that greater importance was given to the technical design of the product in West Germany. Product attributes were seen to be more important and value engineering was given a greater role, usually being performed by a separate 'in-house' team or by independent consultants. In the British company this was more likely to be left to the design engineer. Bergen[97] in a study of the British and West German scientific instrument industries draws similar conclusions to those of Parkinson[96].

However, for the effective management of 'design for function' Cain[98] suggests that the following points must be observed:

- interpret the design requirements as accurately as possible,
- convert the requirements into engineering functions,
- find the best means to suit the function in all respects,
- always design for the highest efficiency, and wherever possible, for simplicity and reliabilty. For this point support also comes from Niebel and Baldwin(99), Whitehead(100) and Leedham.(101)

However it is important to note that these points are fairly broad and for a specific product would need to be clearly defined. If they are not precisely defined then there is a danger of failure to achieve the desired functional results - this may lead to total rejection by the customer. This can only be prevented by ensuring that the functional requirements are considered as a prime objective of the product design process.(102).

On the other hand, the designer also needs to appreciate the dangers of 'over-design'. Over-design usually occurs when products are designed to produce a higher performance, a greater reliability or a longer service life than the user requires or wishes to pay for.(103) This point is emphasised by Zarecor(104) who claims that designers and engineers are generally interested in exploiting technology and consequently tend to over-design. He supports his argument by citing a case where a design team managed to double the performance of a product with only a 20 per cent increase in costs. However, the added performance simply was not required by the market nor would it accept an increased price. Lock(105) terms this phenomenon as 'creeping improvement sickness'. Twiss and Weinshall(103) provide further highlight the problem and give a number of reasons why it happens:

- imprecise specification or imperfect understanding of customers needs.
- the designer's or manufacturer's professional desire to achieve a high degree of technical excellance.
- anticipated of possible future requirements which could be satisfied by a 'stretched' version of the product.
- lack of appreciation by the design engineers of the manufacturing cost penalties caused by excessively close tolerances.

Twiss and Weinshall argue that, a firm or a designer should aim for the 'least acceptable' quality standards and thereby achieve reduction in overall product cost.

The whole argument appears to revert back to the initial stages of the design process, namely the importance of clear and precise product specification. If the initial specification is comprehensively prepared and management ensure that adequate control is maintained on the designer regarding meeting the technical requirements, then problems associated with departure from the specification will not arise. Hence there will be a greater likelihood that the customers technical needs will be satisfied.

Design and Development Costs

The total cost of a new product is made up of constituent parts such as:[106]

Design

Manufacture

Distribution

The design cost includes such activities as feasibility studies, market surveys, concept development, research and product development, revision and preparation of specifications. The manufacture stage which is next in the order of activity contributes to cost through material, machine time, labour time, materials handling, assembly and production planning and control costs. As far as distribution is concerned there are the costs of packaging, transport, storage and advertising ie all the associated aspects of product launch. A firm invests capital or incurs costs in a product from the inception stage until it is launched and delivered to the customer.[107] Only when a firm starts to generate revenue from the sales of the product does it almost cease to incur expenditure on development.

Oakley[108] argues that inadequate attention paid to the importance of development costs is often the cause of unsuccessful outcomes on projects. He supports this claim by citing a case study of a small engineering company where this was the major weakness in the product design and development process. Support for this argument also comes from Topalian.[109]

In general, the literature emphasises the importance of carefully identifying the company's in-house weaknesses and strengths regarding its financial resources and managerial control over development costs. Twiss examines the relationship between development costs and the duration of the project and also endorses the importance of the finance available for a project. Furthermore, he claims that very few companies are aware of the shape of their cash flow profile (shown in Figure 5). Many companies continue with their product developments, regardless of cost factors which can have catastrophic effects unless they are strictly monitored and controlled. This view is also shared by Oakley[108], Sharpe[110], and Brichta and Sharp[111].

This brief literature review enforces the importance of adequate consideration of development costs of a project. The total development costs should be calculated in the early stages of the design process and laid down in the product specification so that management can maintain control over them.

Product Cost

At this initial stage of the design process, a firm ought to carry out an analysis in order to decide and fix the selling price of the product which is to be designed. The techniques used to fix the selling price will vary from company to company and will depend on factors such as company policy (a firm may have a policy of adding a certain

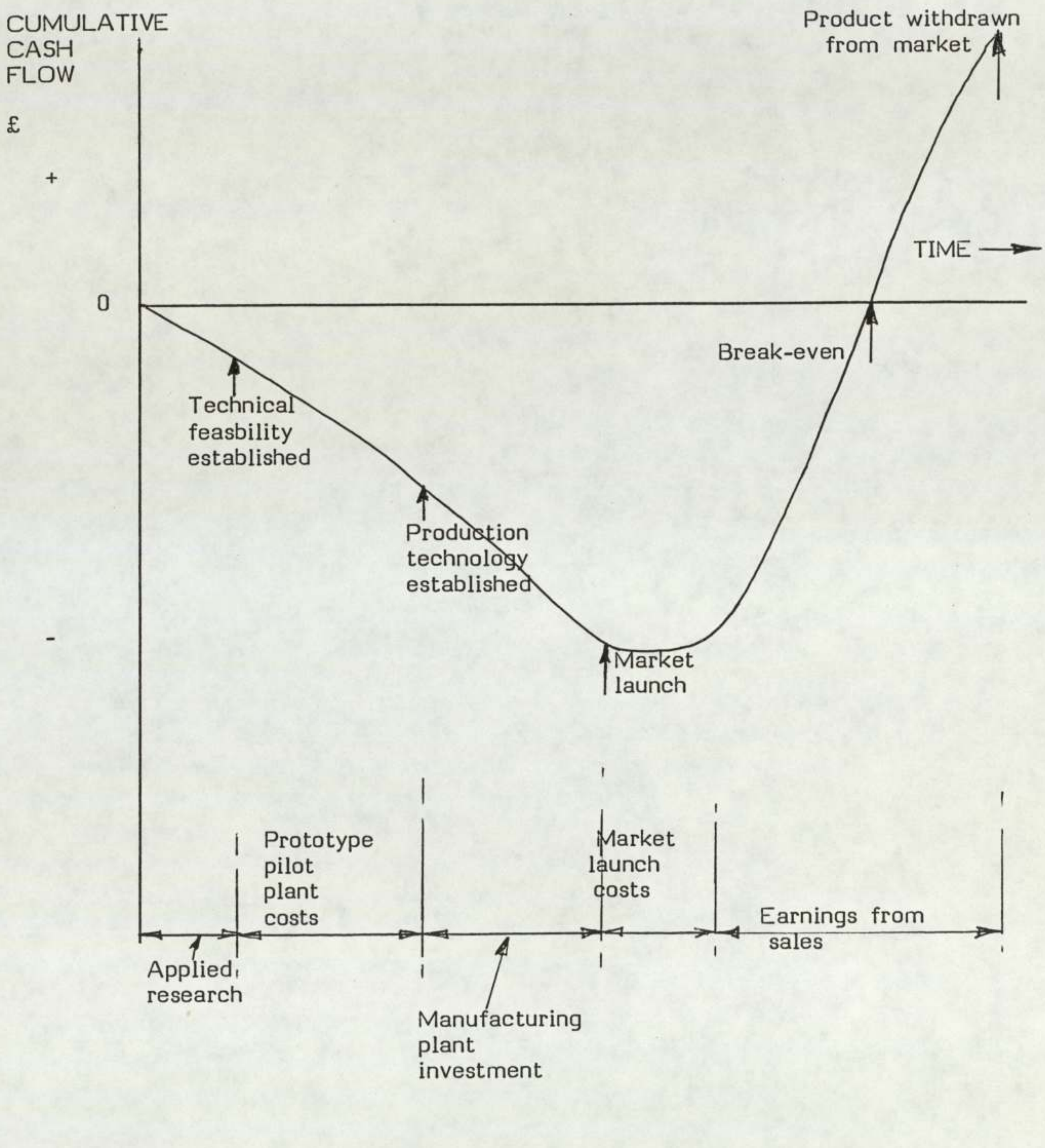

Figure 5 **Project cumulative cash flow diagram**

Adapted from Twiss B C[107], 'Managing Technological Innovation', Longman, London, 1980.

percentage of the actual cost of making which has incurred) or it is determined by the market forces.

Irrespective of the method used to determine the selling price, it is important to specify this price in the product specification, so that the economics of the product design can be gauged against it. Furthermore, the designer is usually concerned with the unit cost which he can achieve by changing the design and still maintain the technical requirements. In order to do this he needs to understand the constituents of the product cost. This is conveniently illustrated by Pitts[112] in the form of a diagram (Figure 6). As Niebel and Draper[113] point out, the designer ought to be concerned with the central problem of "what does it cost?" (product cost) so that his line of thinking is channelled in the right direction. This argument is further endorsed by Sharpe[110].

Project duration

Several studies[107,114] highlight the importance of the project duration, (project duration is usually defined as the time taken from the inception of a project until it is delivered to the customer) by indicating that successful innovators are usually those who are first to the market. This therefore calls for efficient and effective design and development work.

However, it has been noted earlier, that initiation of the development

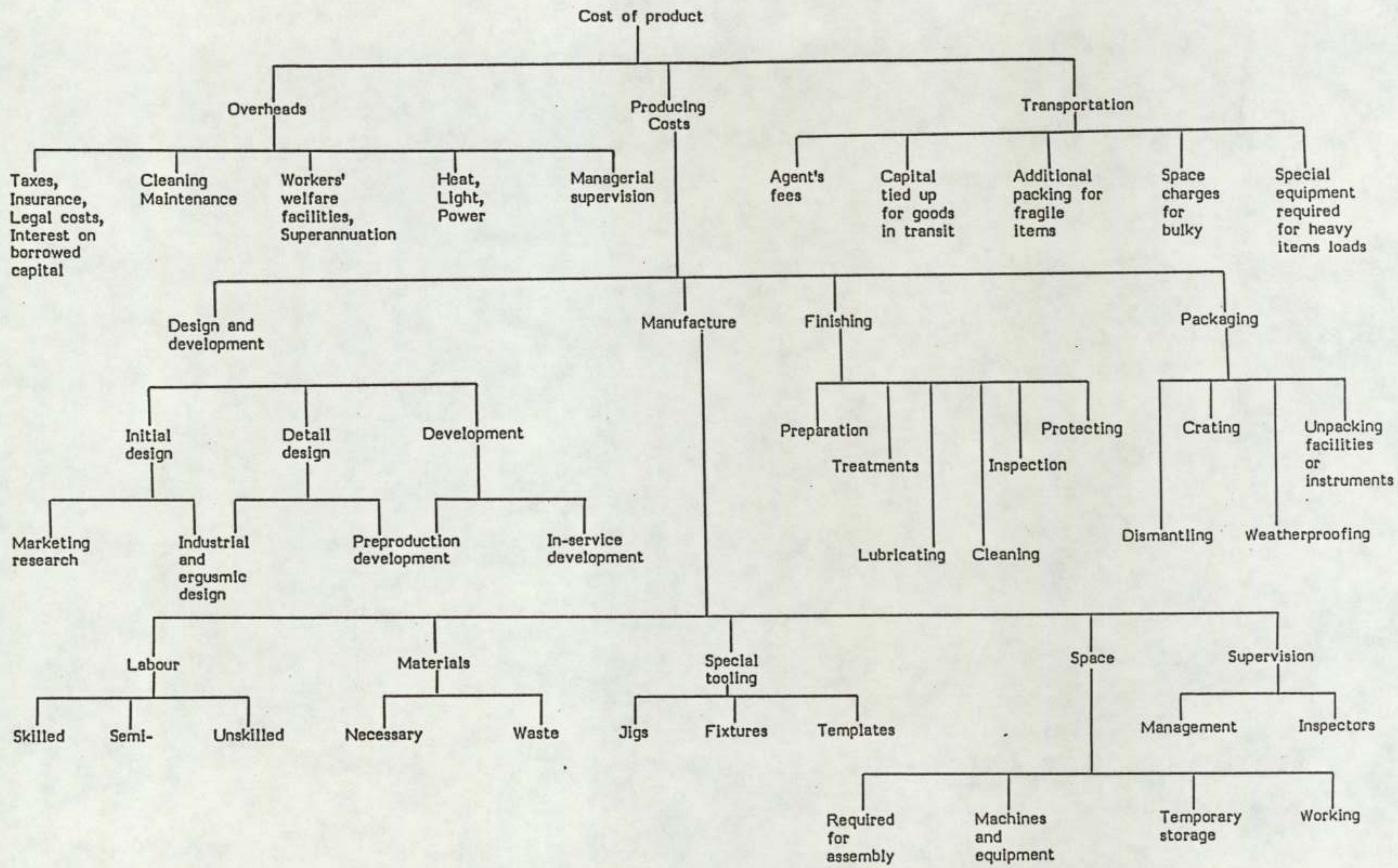

Figure 6 The breakdown of product costs

Adapted from G Pitts(112), Techniques in engineering design, Butterworths, 1973, London.

process usually via one of two methods; namely

(i) when a firm is making a product to the customer's specification or order

(ii) when a firm, through its own initiative decides to start the design process.

Taking the first situation Leech[115] points out the obvious importance of meeting the delivery date where a customer has protected himself by writing into the contractual agreement penalty clauses if the manufacturer does not deliver a product by an agreed date. Sometimes, however, there will be an absolute date, beyond which a product is not acceptable to the customer. He clarifies this argument by citing an example: An exhibition stand is of no value if it is delivered to the customer after the exhibition for which it was intended. In a case like this, penalty clauses can be very severe indeed.

Considering the second situation, Leech again points out that a product may not have a real value if it does not reach the customer in time. This is particularly true for products which are dependent upon seasonal demands; for example, heating appliances launched in March as opposed to October the previous year. In a situation like this a product will often decrease in value the later it is delivered. In both situations careful planning and control of delivery time or launch date is required, if the maximum benefits from the new product are to be achieved.[116,117,118]

The importance of project control is explored by Sharpe(110). He says that, when the designer is continuing with the product design. This whole process takes place against the background of increasing financial commitment which is of concern to management. If the design process costs too much or if the product is too late to catch the market, the investment return may become too low to justify its contiuance.

The development costs and product cost need to be continually monitored and reviewed to ensure that they do not exceed the intended limitations. In order to achieve this, Sharpe emphasises the importance of effective collaboration between marketing, design and production functions during the design stage. He does not, however, indicate how this should be done, or at what stage of the design process. The focus of his recommendations are unclear; for example, when referring to production, does he mean shop-floor workers, production superivisors, production managers, production engineers or production planners etc? Also when urging effective collaboration - does this mean daily or weekly meetings or some other mechanisms. No empirical evidence is offered to support these arguments which appears to be based on opinion.

Several other writers(101,119,120,121,122,) similarly emphasise the importance of close collaboration between different functions but also fail to provide substantive evidence to support these views - and remedies.

However, the pattern which emerges from these references is the crucial nature of the role played by management in controlling and encouraging close collaboration between different functions. Earlier the importance of organisational structure and other associated factors as means of reducing inter-departmental conflict was stressed. Another aspect which is continually enforced by the literature is the importance of effective project control. The type and intensity of control required will vary from one project to another and a wealth of text books describe in detail the techniques used such as PERT, Bar charts etc. The literature generally fails to stress the importance of the dangers if inadequate control of a project is maintained although Twiss[123] highlights some points and also explains the essence of project control.

Throughout the duration of a project it is necessary to ensure that information on the present situation is available and constantly monitored and related to the plan. Twiss argues that it is the absence of adequate information about the current state of a project that is the most frequent cause of poor control. This is particularly true when diverse functions of the organisation are involved in the project. In this case, lack of adequate communication systems between different parts of the organisation may cause failure in effective project control.[124,125,126] This is especially true when project duration is long and the commercial viability of a project is likely to change during its course. Consequently, the organisational structure is most important when attempting to maintain effective project control.

Management, for the effective project control system, require, the ability to:

- assess the progress of each task in terms of cost and duration,
- identify those tasks which are falling behind schedule and assess the likely effect they will have on the overall progress of the project, ie delays in critical activities.
- measure the progress of the project as a whole in relation to the planned cost and completion date.

Twiss illustrates his argument by showing the relationship for two projects between:

(a) Cumulative cost versus Time - Figure 7

(b) Progress versus Cost- Figure 8

(c) Progress versus Time - Figure 9

Project 1 is seen in Figure 7 to be absorbing costs at a greater rate than planned. This might be interpreted as a danger signal. Figure 8 however, shows that the high rate of expenditure was accompanied initially by a rate of technical progress commensurate with the cost. Later a technical problem was encountered which slowed progress and the costs increased beyond those planned for the progress achieved. In spite of this, Figure 8 suggests that the planned completion date might still be achieved provided the problem causing the current difficulty is overcome quickly. Thus it can be seen that if the profitability of this project is more sensitive to programme slippage than to development cost its future is not under immediate threat.

Project 2 shows a quite different pattern. It has progressed slowly

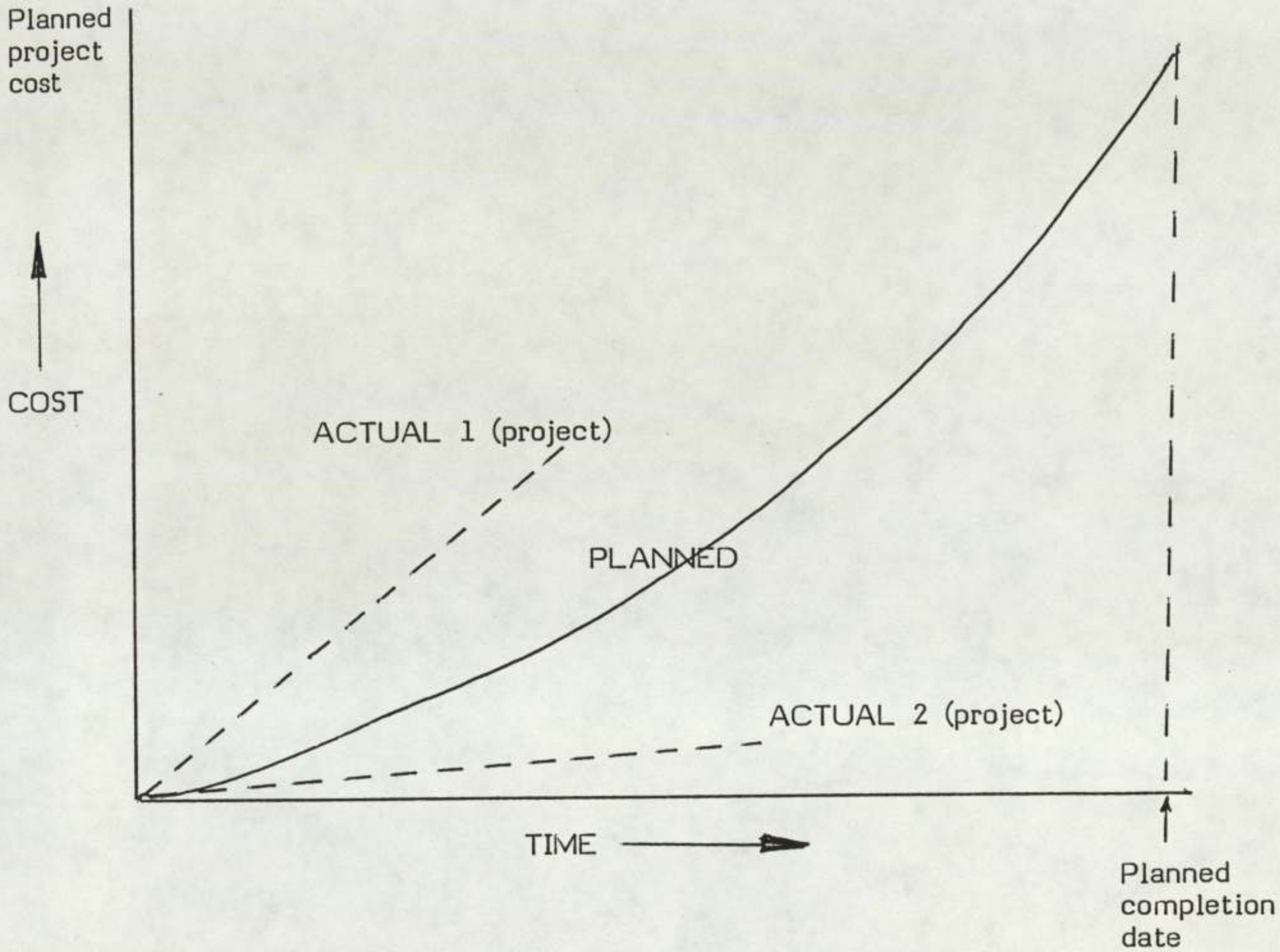

Figure 7 **Project control chart**
Cumulative Cost v Time

Adopted from Twiss B C (107)
'Managing Technological Innovation',
Longman, London, 1980

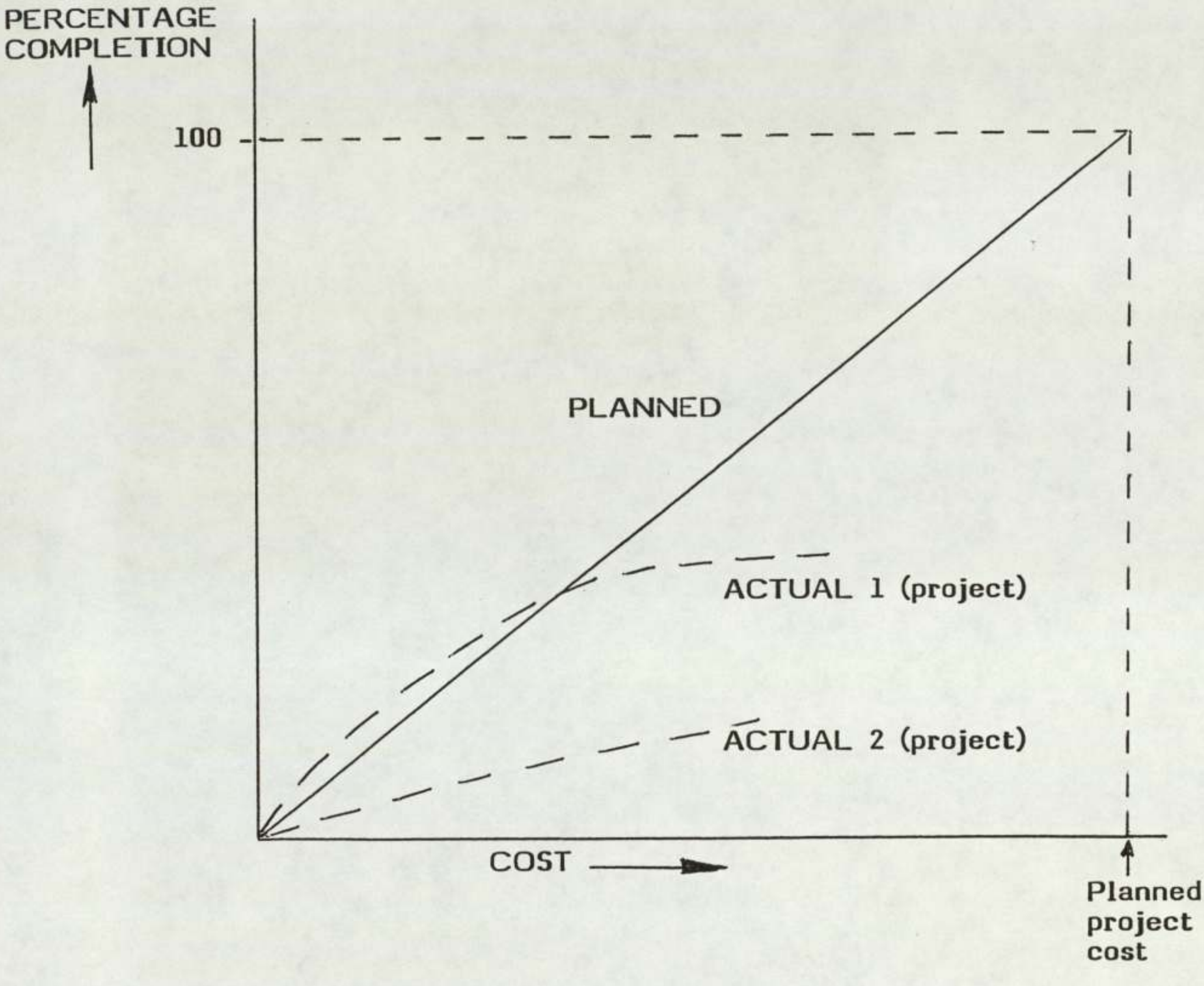

Figure 8 Project control chart
Progress v Cost

Adapted from Twiss B C[107],
'Managing Technical Innovation',
Longman, London, 1980.

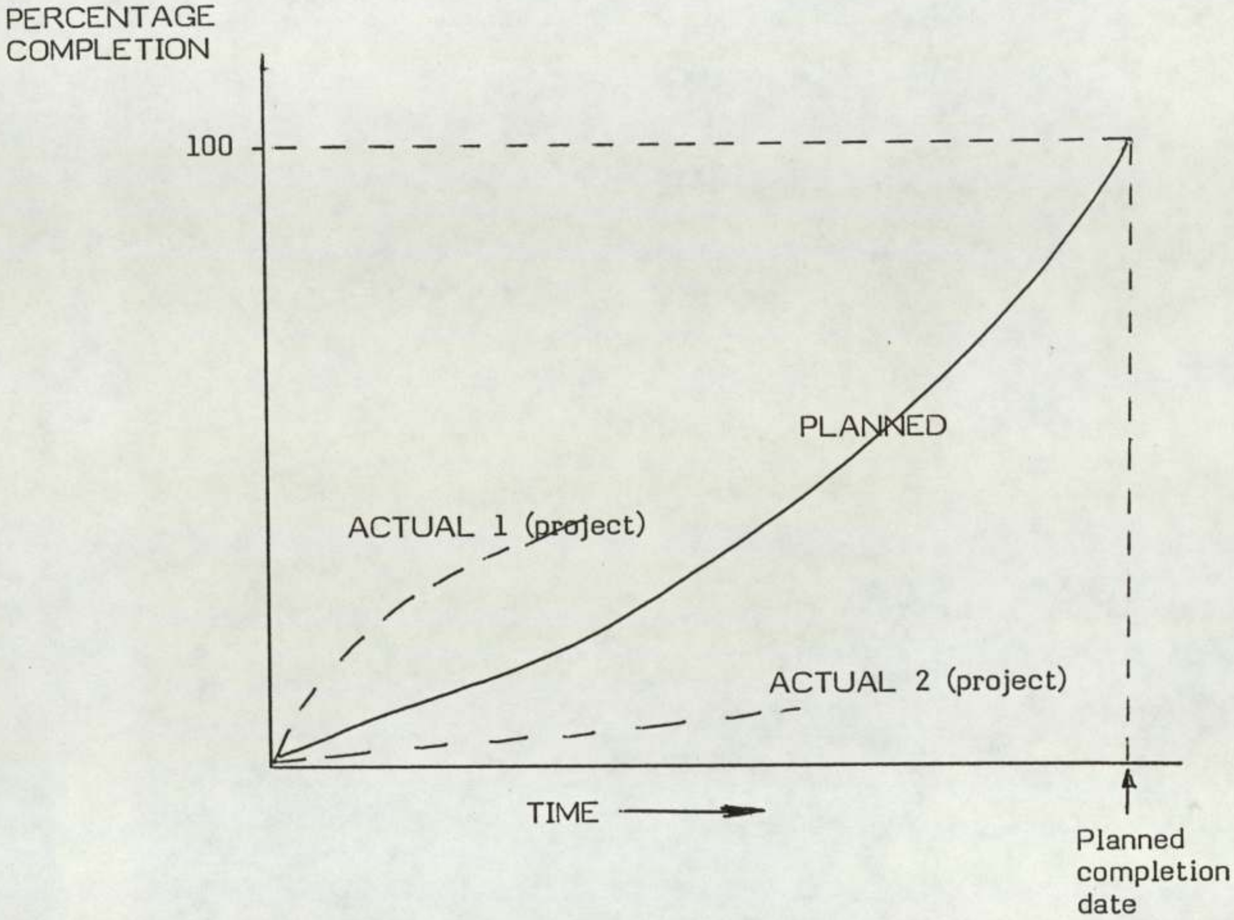

Figure 9 **Project control chart**
Progress v Time

Adapted from Twiss B C[107], 'Managing Technical Innovation', Longman, London, 1980

from the start. Although the expenditure against time is below that planned, technical progress has been slow, both in relation to cost and time. Whether the cause of this is poor management or technical difficulties, it appears to be a candidate for termination. The constant trend for all three graphs since initiation suggests that the problems associated with this project have been with it from the beginning and earlier corrective action could probably have been taken.

Twiss's diagrams conveniently summarise the importance of, and the relationships between the requirements which have to be satisfied. As reported earlier in this literature review, these requirements, ideally, should be laid down in a product specification and communicated to all relevant personnel in the firm. Failure to do this can lead to diversification from the main objectives of the project such as failure to satisfy the customer from the technical features point of view, or from the price or the delivery date aspects. All these can have adverse affects on the firm as a whole. Similarly, it is important to understand the shape of the cumulative cash flow curve during the project duration. So that these can all be kept under strict control, management needs to have in-depth knowledge of relevant control techniques and be able to design the organisational structure to achieve this.

(b) The need to satisfy the production criteria or requirements

The literature, frequently, refers to this as 'designing for production'. This, however, is a loose term and requires further clarification. For example, is one 'designing for production', when adequate consideration is given to existing production facilities or techniques?; or when new product designs are compatible with existing products or production control systems etc? The answer to these questions is unclear from a review of the literature, because most researchers tend to investigate only a specific aspect of production. In the context of this research project, designing for production is taken to mean that new product designs are compatible with different aspects of production such as:

- Production facilities and techniques
- Assembly techniques
- Labour skills
- Existing products and standardisation
- Control of production
- Others, such as material aspects (choice, handling and storage), transportation, and packing etc.

The extent of consideration given to each factor will, naturally, depend on the type of product to be designed and the company policy regards new product designs. It may be that the management of the company has decided to design a new product and purchase the necessary plant and machines etc, required to manufacture the new product. If this is the policy of the company it is important to convey this message to the designer in the early stages of the design process. On the other hand the company policy may be that the new product design has to be compatible with the existing production system. Once again this element of the policy has to be made known to the designer as early as possible so that he can channel his way of thinking in the right direction from the product inception stage.

Production facilities and techniques

As part designs are created, developed and detailed, the designer is actually selecting the process or processes by which the parts will be manufactured. Conversely too, he may be limiting the useable methods of those least desirable. Drawing details and specifications actually place wide limits or narrow restriction on practical processing. The design of a product often determines whether manufacture can be set up with relatively simple operations or will involve costly, unpredictable or even unnecessary steps in production.(90) By pre-planning and co-operating with manufacturing engineers, designers can more easily arrive at the most economical end product. The idea of close collaboration between design and production has been endorsed by numerous writers such as Leedham(101), Turner(119), Peat(120), Bronikowski(121), Betts(122), Buck(127) and others.

However none of these writers take this point further and elaborates on precise aspect of close collaboration. For instance, the stage, the frequency and the way this collaboration should take place is absent from their discussions.

Turner(119) suggests that if the design is right and it is communicated adequately, the manufacture should take care of itself. If the design is not right then no matter how good production facilities may be, an economical product will not be achieved. Peat(120) agrees and shows that a high percentage of scrap may be produced due to lack of production process consideration; his data indicates typical scrap levels at various stages of production so that action can be taken to reduce it. Leedham(101) takes the argument one step further and claims that co-operation, between design and production, saves time and money by eliminating uncertainties, and contributes directly to reduction of the time lag between the inception of a design and the commencement of actual production. Leedham recommends that:

- since designers and draughtsmen, in general, have a limited knowledge of production methods, they need to exploit these techniques to the maximum extent. Leedham, however, fails to indicate how should the designers and draughtsmen exploit production techniques.
- they should be encouraged to study production techniques and should be given the opportunity to observe production methods in actual operation. This point, however may be open to criticism from the practicing designers, that because they are continually working to very tight time schedules this it is not a practical solution.

Radcliffe(128) claims the answer lies in the area of comprehensiveness of the information available to the designer. He suggests that each designer should be issued with a document or a catalogue incorporating the maximum capacity dimensions on every type of machine or process in the firm. These should be in two classifications:

- absolute maximum
- productive maximum.

Every effort should be made to design within the productive maximum.

In order to ensure that production facilities and techniques are given detailed attention during the design stage, Bolz(90) proposes a committee plan. He suggests the following activities should be represented on the committee: Engineering, Tooling, Production Planning and Scheduling, Manufacturing, Service, Purchasing and Sales. He claims this way, everybody is involved in the product design process and thereby different aspects of the design can be rigoursly considered. Woudhuysen(129) agrees and gives an example from the aircraft industry where the shop floor personnel were involved in a product design resulting in a large number of suggestions. There is another aspect to the committee plan proposed by Bolz, that is concerning the time or project duration. It can be argued that greater the number of functions involved in the design process, the greater the number of factors the designer has to consider or satisfy - thus prolonging the project duration, which may be very crucial indeed as in an example illustrated by Leech(93). Although involving everybody in the project may be a good industrial relations practice, it can have serious repercussions on the progress of the project.

In general, it can be said that adequate consideration needs to be given to production facilities and techniques during the design stage. The majority of the writers claim this can only be achieved by either early involvement of staff responsible for production or by having an effective formal system where all aspects relating to production-capacities, availability, utilization times etc - are documented, so that the designer can refer to them during the course of the product design process. In either case, management needs to keep a careful balance between the extent of production involvement and the progress of the project.(130)

The advice offered by Wassell(114) perhaps points in the right direction. He suggests that when collaborating with production specialists, designers should:

(a) Try and understand some of their background and skills.

(b) Take time to ensure that production understands the product and equipment background.

(d) State the overall purpose of the design clearly and take the production specialists through all of them.

(d) Delay defining the "how" until the specialists have contributed their ideas.

Assembly Techniques

The last section was concerned with the design of components; these components have to be put together to form complete products or sub-assembles. Several experts (131,132,133,134,135) stress that assembly considerations during the design stage are just as important, if not more so, than the consideration given to component manufacture.

As Swift(132) points out, in mechanical and electrical industries about half of the workforce is employed in carrying out assembly activities, so correct 'design for assembly' is very important indeed. However, the literature makes no reference to the involvement of 'assembly experts' in the design process, other than 'production specialists', without elaboration of function. Should the term differentiate between assembly experts and process experts? Despite much emphasis in the literature on close collaboration between design and production functions little mention is made about assembly, although number of writers,(135,136,137,138,139) indicate the importance of factors like achieving:

- maximum degree of inter-changeability consistent with cost.
- maximum simplicity
- maximum reliability
- ease of assembly etc.

They all give specific product examples as to how to achieve these, but there appears to be no guidelines for design managers about how to achieve maximum benefits by for example, employing assembly specialists or by involving these specialists at certain stages rather than others.

Another point which seems to have been overlooked by many writers in this field is the aspect of ease of dismantling and re-assembly when a product is in service. Weinberg(140) mentions these aspects in passing emphasising their importance and also claiming that economic aspects during assembly are often ignored. This point is echoed by Swift(132), who shows that by using techniques proposed by Boothroyd(141) it is possible for the designer to predict the assembly cost of a product to within 10% of the measured cost. Swift cites examples of three companies in support of this practice.

Although the literature emphasises the need for adequate consideration to be given to design for production - it generally fails to segmentise production and explain precisely what the term 'production' implies. This term is used rather loosely, and it appears that inadequate consideration is given to 'design for assembly', despite the large proportion of the workforce involved in assembly tasks. Consequently, the literature fails to explore the need to have assembly specialists in firms how they might be involved in the design process, at what stage, and what effect their involvement or lack of it can have on the economics of product design.

Wassell(114) does offer some rather crude guidelines based on his experience:

(a) Get out on the assembly floor as much as possible to see what happens there. This can assist the designer enormously by seeing the environment in which his proposed designs will be assembled.

(b) Study the elemental assembly operations, establish their reliability characteristics and agree precise sub-routines with the production engineers.

(c) Establish a 3-D plan for the product or a mock up in wood or cardboard even for simple products. Get production engineers, the industrial designer and the test engineer involved.
Do not make assumptions about the physical form until the sub assembly philosopy has been worked out on value engineering lines.

(d) Maintain a good liaison with the shop-floor, even when the production is running.

Labour Skills

In the previous two sections the production facilities and assembly techniques have been considered; both of these require the availability of adequately skilled operators. When the designer is designing a product, as well as being fully conversant with production facilities and techniques, he also needs to consider the level of labour skill which is available in the company to carry out the proposed manufacturing operations.[142] Throughout the design process, the designer needs to be aware of the different types of skills available so that products can be designed to take the maximum advantage of human resources available within the company. Conversely too, he needs to consider how to avoid designers products which are unnecessarily complex and may require additional recruitment of skilled operators.

The best way to avoid unnecessarily complex product designs is to stress simplicity at all stages in the design process.[143] An attempt should be made to keep the design as simple as possible from a manufacturing point of view by maintaining close contact with production department from an early stage. Whitehead[100] advocates this and states that simplicity is always the source of economy - by keeping the manufacturing and assembly times to the minimum. Also it reduces the operator skill required to perform these operations. Leedham[101] argues that simplicity characterises all good designs but it cannot be achieved in haste. Too often, in the desire to 'get things started' this work is hurried with the result that many products are unduly complicated, thereby inflicting unnecessary and continuous strain on manufacturing facilities and operators. The important aspect here is the time involved in carrying out manufacturing and assembly operations and time costs money to the firm. The importance of this area seems to have been underestimated, since it contains vital advantages in designing economic products. Every designer and draughtsman should be capable of designing products that are practicable and convenient in manufacture.

Holland[144] points out that in batch manufacturing companies the physical design of a product largely determines economies relating to the processes by which it is made and the type of labour skill required. Product design can therefore determine the success or failure of a company, a view emphasised by Corfield[145] who claims that it is still not recognised by enough people in industry just how essential economic design is to the success of a business. His report demonstrates a clear connection between good design (especially in the sense of design that facilitates economic production) and higher productivity. Good design therefore increases the value added to the resources used in the business on which wealth creation and jobs depend.

In general the literature emphasises the importance of devoting adequate consideration to the labour skills, but gives little elaboration on what should be done in practice. It appears that too much responsibility is placed on the designer for ensuring that labour skills are sufficiently considered during the design process - the designer alone cannot be expected to be fully conversant with different levels of skills available in the firm. This information ought to be supplied to him by those who have this information available[146]. Usually, it is production management who will be familiar with the relevant workforce capabilities and limitations, and should therefore be involved throughout the design process. once again the literature fails to give sufficient guidance, as in the previous sections, about the precise stages at which production should be involved and in what manner; and about how all this affects the economics of production.

Existing Products and Standardisation

During the course of a product design process, the designer needs to consider any existing products, so that economies of scale in production may be achieved through standardisation and other methods of variety reduction. In doing this, the designer needs to appreciate that the basic requirements of production and marketing functions may be different and become a source of conflict.

On the one hand, production ideally seeks to make a single model so that standard processes and procedures can be adopted, such as flow-line production, which might be uneconomical with a greater range of products.(103) The single model also allows the production manager to have long production runs so that specialised equipment is used efficiently thereby reducing unit costs. Inventory costs will also be minimised because a lower aggregate of buffer stocks to meet a specified level will be required. The production manager may resent the manufacture of additional range of products simply because of the interruption to the smooth flow of work through the system.

On the other hand, the marketing manager needs to offer customers the widest possible choice of products, because, he may argue, in these days of increasing competition it is necessary to cater for a broad range of consumer tastes if a significant share of the market is to be retained.

The designer, therefore is in the midstream of these two functions and he needs to carefully consider the point of view of both sides.[119] In a sense he is the coordinator of these two functions and may, or may not, be assisted by senior management in ensuring that an appropriate product policy is devised. Product policy decisions are too vital for the future prosperity of the firm to be resolved by either marketing, production or design acting in isolation.[103] Top management should put emphasis on involvement by all these functions, because the product policy will also affect the corporate policy, which in turn may affect other functions such as purchasing, inspection, quality control, and production control etc. For instance, if the product policy is to keep the basic concept of a new design the same as existing products, then this is likely to require minimal changes to existing manufacturing and inspection techniques. However if the policy is to ignore existing products, perhaps in order to encourage innovative designs, then this may require purchases of new manufacturing tools, inspection and testing equipment, and functions such as purchasing and quality control will have to be fully involved if a conflict of aims is to be avoided.[147,148]

Once a product policy has been laid down, it has to be communicated to the relevant functions so that action is taken to ensure that everybody follows the prepared guidelines. The designer needs to be clear about the details of the product policy especially regarding existing products and standardisation. Also, in all cases, he needs to be fully conversant with the details of the existing products before starting on new designs, so that these existing designs can be carefully assessed and critically compared with those of the competitors. This will help determine which features should be retained and which features should be omitted.[149] These should be objectively compared and contrasted from both marketing and production points of view regards simplicity of design and optimum standardisation.[101,150] It is imperative that a balance is achieved to satisfy both marketing and production criteria.

The question of standardisation does not simply stop at achieving common parts with existing product and attempting to introduce interchangeability. Standardisation has to be looked at from different view points of the whole design process such as tolerances, clearances, limits and fits, measurement equipment, surface textures, drawing practice and standard forms (for example screw threads) etc.[100,151]

If the designer is expected to ensure that adequate attention is given to the existing products and standardisation a comprehensive system of coding and classification may be required.[152] Without a comprehensive system of coding and classification, of drawings, parts, materials and associated inspection and testing equipment a considerable degree of misunderstanding can arise, as well as the production of uneconomical products.[153]

Control of production

In this section, it is not intended to discuss in detail, the aspects of control systems used during manufacture of products but to give a outline of the types of consideration which the designer should be giving to the control features while designing new products.

When designing for production the designer needs to consider many aspects such as production control, quality control, inventory control, cost control etc. Usually it is production management who is responsible for the design and operation of these control systems so the designer needs to consult it continuously throughout the design process.(154) Twiss and Weinshall(154) argue that most production managers seek to manage the operation 'by exception' with the minimum of detailed supervision. There is no such a thing as a 'best' control system, only the 'right' system for a company at a given time, taking into account the type of product and the scale of production, etc. However, one important point is that as the company changes so will the parameters that determine the 'right' system. Production management must keep a system of control under constant review and decide the appropriate time to effect a change - which may be when a new product design is taking place. For this reason alone production management needs to actively participate in the design process.(155)

Hitomi(155) divided control systems into two categories:

(a) Control of logistics: This controls the flow from raw materials into the finished products and includes:

- production control - for controlling time (delivery date) and quantities to be produced;
- quality control - for assessing the desired quality and reliability for finished products;
- inventory control - control for excess storages and shortages of raw materials, parts and products; and others.

(b) Control of production resources: This is a control function for the factors of production, especially production facilities. The primary activity in this field is:

- productive maintenance for preventing the breakdown of production facilities and repairing breakdowns.

Hitomi's first category of control systems will be briefly discussed and the second category will not be discussed because this category deals with the maintenance of the production facilities which is beyond the scope of this thesis.

Production Control

Here the actual performances of the produced quantities and completion times are measured and compared with the planned standards.(156) This implies that before one can measure actual performance, it is necessary to devise production plans and schedules to gauge the actual against the standard and to allow deviations to be modified accordingly a part of the control process. This can be illustrated by the diagram in Figure 10 which shows a generalised feedback loop for production. With this control loop a means of 'management by exception' is provided by reporting unusual cases to management. The efficiency of the corrective action is usually dependent upon the speed with which information about any deviation can be monitored.(157)

The literature does not comment upon how the extent of production management's involvement in the design process may contribute to effective production control systems - suggesting that this may be an area requiring study.

Quality control

Quality control is a management tool for producing goods with satisfying quality characteristics by systematically establishing acceptable limits of variations in size, weight, finish, function and so forth, and then devising methods for maintaining the produced goods within these control limits. Once again, the designer needs to be aware of the quality control methods used and whether his designs will

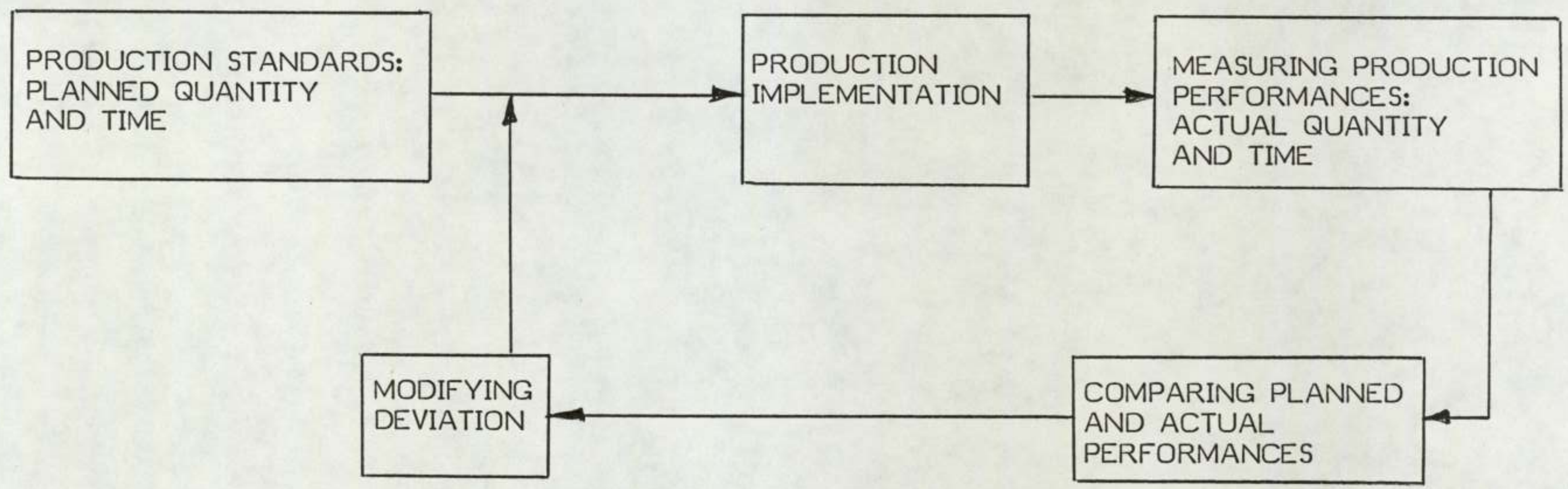

Figure 10 **The production control system works as a generalised feedlack loop: measuring production performances, comparing those with the planned standards, and modifying the deviation.**

Adapted from Hitomi K (155), **'Manufacturing Systems Engineering', Chapter 3, Taylor and Francis, London 1979.**

put unnecessary restrictions on the existing quality control procedures; the quality control department needs to be consulted during the design stage.

Inventory control

Inventory provides a buffer in the material flow from the acquisition of raw materials to the completion of products. Inventory control is made so as to reduce inventory costs, stablize production levels, and increase service levels by preventing product shortages to customers. Any inventory analysis, usually attempts to minimize the total costs incurred including acquisition or production cost, inventory-carrying cost, penalty associated with shortages, etc.

The designer needs to ensure that designs are compatible with these existing control systems and that they do not impose unnecessary restrictions on the systems. However the literature once again does not analyse how this is best done or at what stage of the design process it should be considered.

2.6 Concluding Summary

Three aspects of the literature have been examined in this chapter:

(i) the need to consider the market or customer requirements.

(ii) the compiling of specifications.

(iii) the management of the product design and development process.

For clarity, each of the above are summaried separately.

(i) The need to consider the market and customer requirements.

The majority of studies reviewed in this chapter examine the factors which is related to new product success or failures. The general indication is that there is no easy explanation for what makes a new product a success because success does not depend on one or a few variables. However, this is agreement amongst researchers that a large number of charactertistics determine the degree of new product success. The "success formula" is a complex one; and that success depends on several parameters, while failure can result from a single error.

Major success factors included:

- a recognition of a technical opportunity;
- proficient internal R&D management;
- well executed ventre decisions;
- ample development funds;
- the existence of a 'product champion';
- a need (market) recognition;
- effective internal and external communications;
- the existence of a technical entreprenuer;
- existence of open and flexible management structure;
- efficient development.

(ii) Compiling Specifications

There is little published literature in this area and that which does exist appears to be poorly researched. For example, little information is available to indicate what is the common practice in industry regarding procedures for compiling specifications. Apart from the participation of the designer and the customer (or representative) it seems to be largly a matter of circumstances as to who is or should be involved - or excluded. Perhaps more significantly, there seems to be poor understanding of the relationship between the extent of involvement by different functions and the final product outcome in terms of sales performance and the overall effectiveness of the design process.

Furthermore, there is a lack of published information, as to what product features needs to be considered and the degree of their consideration, when compiling product specification. What is the effect, the degree of consideration of features like development costs, performance levels and project duration etc on the final product outcome? Finally, the existing body of knowledge fails to provide guidance about the relationship between the format of the product specification and with the product outcome.

(iii) The management of product design and development process.

There were two strands to this aspect of the literature.

(a) The management of design and production functions.
A number of studies highlight the problems associated with the integration of design and production functions. These studies shed some light on why this interface is difficult to manage and what features should be considered in order to alleviate or avoid conflict between these functions.

(b) The factors affecting the management of product design and development process. In considering these aspects of the literature there appear to be a number of shortcomings. Much emphasis is placed upon the importance of 'design for production' but few details are given of current industrial practice and the main problem areas. Most references simply state, that it is imperative to give adequate attention to performance features of the product design and economic features of production but ignore aspects like, who should be involved in the design and their extent of involvement. What influence does this have on the product design performance from production point of view? Similarly what product design parameters need to be considered during the design stage that might have an effect upon production? These questions are reviewed in the literature but generally receive few answers.

This study sets out to investigate these issues and Chapter 3 transforms the existing studies into 'models' to be tested and enhanced by this research.

CHAPTER 3

RESEARCH DESIGN AND DATA

3.1 Introduction

In chapter two the literature relating to product design and development was examined. This was divided into three sections namely,

- the need to consider customer and market requirements.
- compiling specifications
- the management of the product design and development process.

Finally in the conclusions of chapter two, a number of important deficiencies of knowledge relating to the above three aspects were identified. The existing body of knowledge complete with the deficiences is transformed into 'models' in this chapter to serve as a basis for further investigation. Based on these models and on the general underlying assumptions to this whole study, a number of hypotheses are then devised.

Following a statement of hypotheses is the design of the field study programme. The remainder of the first part of the chapter is then devoted to a discussion of the methodology adopted in gaining access into firms in order to carry out field studies.

The second part of the chapter relates to the data which ~~has~~ have been collected from twenty firms participating in this resarch. The data ~~is~~ are presented in the form of case histories in Volume II of this thesis. However, list of case histories and codes used to represent each one are presented in this part of the chapter. This list also shows the method used to collect the data and the format used to describe the case studies.

3.2 The Design of Research Models

Of the three areas of the literature surveyed, the first, namely the need to consider customer or market requirements, may not appear to be strictly within the terms of reference of this thesis. However, certain features do have a direct bearing (eg market needs, selling price, delivery date, maintenance etc) upon the other two areas and these must be considered. Hence in this section two 'models' are proposed in order to highlight how the existing state of knowledge might be improved.

Model 1 - The factors involved in compiling product specifications.

The literature review in Chapter 2 underlines three factors relating to product specifications which have been poorly researched or are ignored in the existing published information. These are:

- the extent of involvement by different functions when compiling product specifications
- the format of product specifications.
- the comprehensiveness of product specifications.

Consequently, there is an absence of information about any correlation between these three factors and the eventual product outcome.

As a starting point from which to improve this state of knowledge, a model has been devised (Figure 11). This model as well as showing the

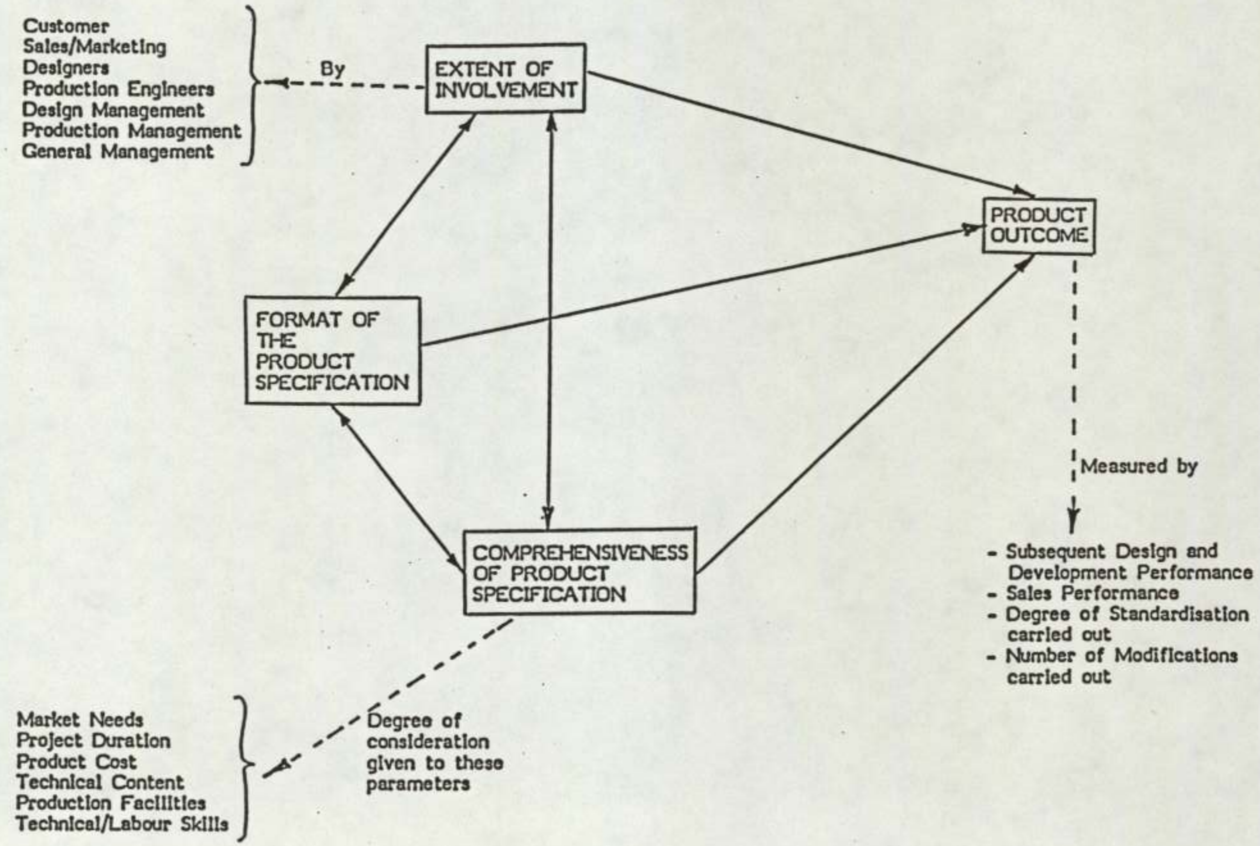

Figure 11 Model of the factors influencing Product Specification

main factors also indicates the measurement criteria used for them.

Model 2 - The factors involved during the design stage

The literature review points out that there are two factors relating to the design stage which have been poorly researched. These are:

- the extent of involvement by different functions during the design stage.
- the degree of consideration given to product design paramaters.

Also there is a lack of research regarding the relationship between these factors and the product design performance from production point of view.

In an attempt to improve upon these deficiences a model has been designed (Figure 12), which shows the main factors and the measurement criteria used.

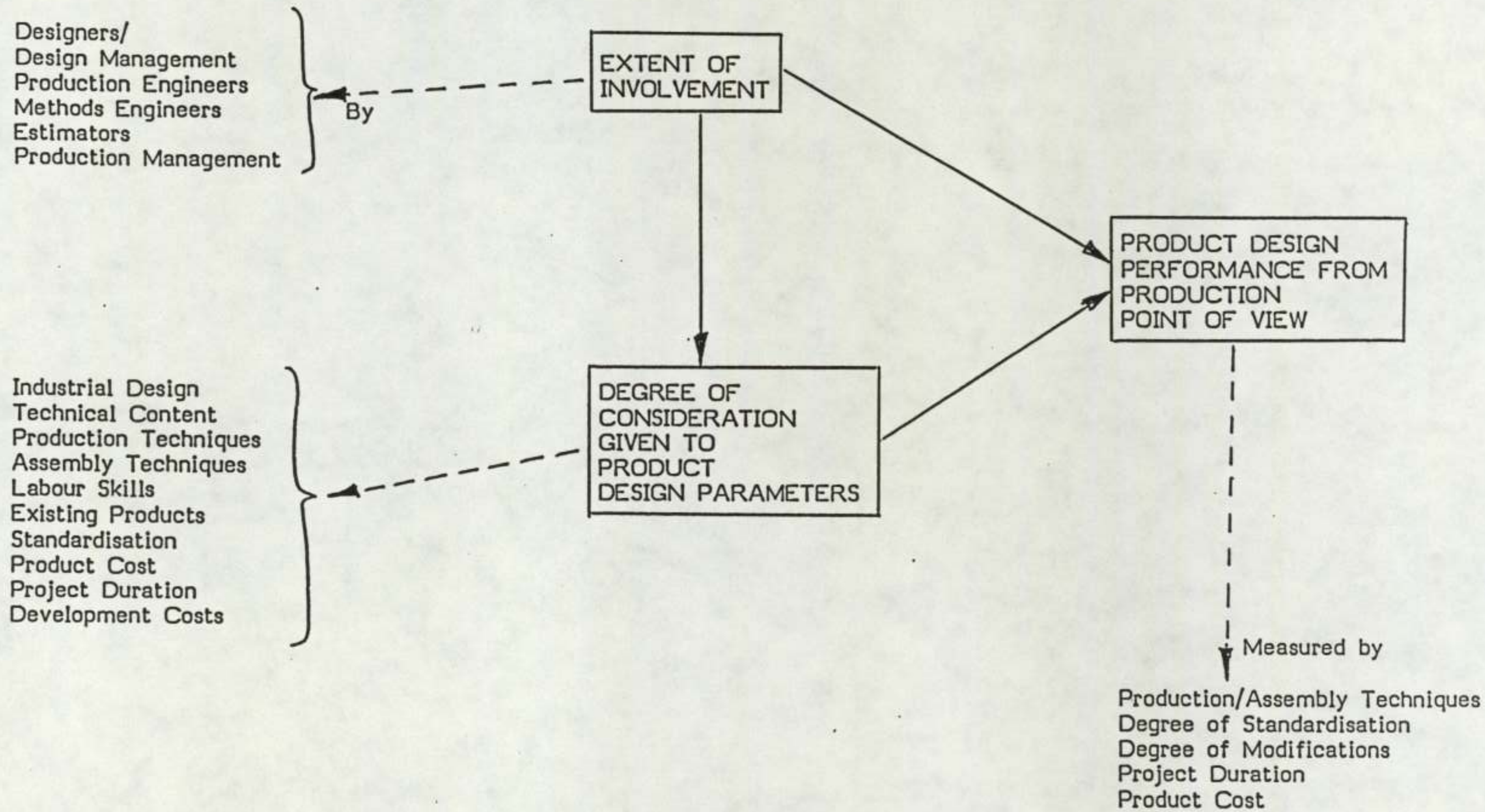

Figure 12 Model of the factors influencing the Design Stage

3.3 Hypotheses

The logical step after the design of the 'models' was to develop a set of working hypotheses. These hypotheses were subsequently translated into broad guidelines for collecting data. Simultaneously these hypotheses were used to test the data obtained.

The basic hypothesis was that the nature of the working relationshop between design and production functions in manufacturing firms directly influences product design performance.

The specific empirical hypothesis were:

1 The greater the degree of involvement by different functions, the more comprehensive is the product specificiation.

2 The greater is the comprehensiveness of the product specification, the better is the product outcome.

3 The greater the degree of involvement by different functions in preparing the product specification, the better is the product outcome.

4 The greater the degree of production involvement in the design process, the better is the product design performance from a production point of view.

5 The greater the degree of production involvement in the design process, the greater is the degree of consideration given to general product design parameters.

6 The greater the degree of consideration given to product design parameters, the better is the product design performance from production point of view.

3.4 Design of Field Study Programme

The field study was formulated to investigate the basic concern of the project:

> 'To identify and investigate the factors which influence the nature of working relationships between design and production functions in manufacturing firms.'

It was appreciated at the outset that this research project alone could not hope to collect sufficient data from which generally applicable guidelines could be drawn due to regional variations, and other environmental and economic factors. However it was considered that adequate information would be obtained to draw some valuable, although limited guidelines and highlight the benefits of alternative managerial approaches.

It was also recognised that an important aspect of the programme was to establish what types of empirical data were required and to explore techniques by which they could reasonably and reliably be obtained. In view of the fact that only limited research had been done in this particular area and that no relevant framework existed upon which to structure further research, it was decided that data collection should be done as follows:

(i) to conduct a series of interviews with key personnel in the design and production functions in firms which were reluctant to provide access to any other research activity, ie observation of product design process. Some of these interviews were recorded on tape.

(ii) to observe events and activities related to product design process and simultaneously interview those employees of the firm who were involved in the project at the time.*

The data collected by these techniques were presented in the firm case studies. Each case study also included background information to the project as well as a chronological account of the events.

During the course of the interviews the researcher attempted to obtain maximum information in the least time. Where possible, an attempt was made to interview members of <u>both</u> design and production departments to obtain their views on similar questions. On the basis of these semi-structured interviews, an analysis was made to assess the working relationship between design and production departments in the course of a new product design.

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* <u>Footnote</u>: This was done in firms which provided unrestricted access. The frequency of visits to these firms varied depending on level of product design activity. For instance in some cases it was four or five times a week, whilst in other cases it was once a month.

3.5 Gaining Access into Firms

Two approaches were taken in attempting to seek co-operation from firms prepared to participate in this research project.

(i) By Letter Names and addresses of potentially suitable companies, together with the name of a senior executive were obtained from trade directories. Standard letters were then sent to forty-six companies in the Midlands region. The letter explained the purpose of the research - "to identify the factors which determine the effectiveness of the relationsip between design and production departments", and gave examples of the areas of specific interest for investigation such as:

- how production is involved in the drawing up of product specifications;
- what consultation takes place between design and production before existing designs of products are changed;
- what is the commitment to standardisation etc.

A period of about two weeks was allowed for replies. If there was no reply within this period, these companies were then approached by telephone. In general the success rate was discouraging as only three companies agreed to co-operate initially. These companies were then followed up by personal visits whereby lengthy discussions/negotiations took place in order to secure their co-operation. As a result of these visits it was discovered that two companies, although very interested, were undergoing a fight for survival due to the recession. It was decided therefore not to carry out field work studies in these firms but simply conduct interviews with the key personnel in design and production functions. The third company was relevant to this research project and the researcher was able to proceed with field work studies in this firm. The main reasons for lack of co-operation is shown in Table 2 and Table 3 shows the number of firms contacted by letter in terms of number of employees.

In the light of this experience it was decided that companies with workforce of 100 or above should be approached since they were more likely to be designing and manufacturing products in-house. Taking these points into consideration a second approach using a questionnaire was attempted.

The lack of co-operation was mainly due to the following reasons:-

1 The companies contacted were relatively small in size (employees less than 100).

2 Companies did not have a separate design and production department.

3 They did not design their own products.

4 Reluctant to commit themselves to a project of this nature.

5 Fighting for survival, due to recession.

6 Short-time working, redundancies being enforced.

7 Not relevant to the research project.

Table 2 The main reasons why 45 out of 46 Companies contacted by letter failed to co-operate in this research project.

NUMBER OF EMPLOYEES	NUMBER OF FIRMS
⩽ 99	25
100-300	13
⩾ 301	8

Table 3 **Number of firms contacted by letter in terms of number of employees**

(ii) **By Questionnaire** Names and addresses of companies as well as the names of a senior executive were obtained from Kompass directory. These executives were approached by telephone to briefly explain the details of the research. They were then requested to complete a questionnaire, emphasising that it contained 9 questions and should take no longer than 10 minutes to complete. If the company was unsuitable, for instance it did not design and manufacture products in-house, or the executive did not wish to participate, then this was immediately apparent. Details of the questionnaire are shown in Appendix 1. A covering letter was sent with the questionnaire which briefly explained the details of the research and emphasised that the information obtained would remain strictly confidental. Table 4 shows the number of firms contacted by telephone in terms of number of employees and Table 5 shows the degree of co-operation received when conducting questionnaire survey.

NUMBER OF EMPLOYEES	NUMBER OF FIRMS
⩽ 99	16
100-300	36
⩾ 301	25

Table 4 **Number of firms contacted by telephone in terms of number of employees**

	NUMBER OF FIRMS
Total number of firms contacted by telephone	77
Questionnaire sent to	54
Completed Questionnaire returned by	34
Field work conducted in	20

Table 5 **Degree of co-operation received when conducting questionnaire survey**

Each company which returned a completed questionnaire was approached again by telephone, in order to arrange an appointment, to interview a senior executive. During the course of the interview as well as finding information about the nature of the working relationship which existed between design and production within the firm, an attempt was also made to develop the executive's interest in the project, to gain further access. Even where companies were unable to co-operate on a long-term basis, they were usually willing to allow the researcher to interview key members of design and production departments. The interviews were semi-structured, ie the interviewer had pre-prepared guidelines but when appropriate departure from these guidelines occured. See Appendix 2 for interview guidelines.

This second approach to seek co-operation with firms via a questionnaire was found to be more rewarding than the first approach by letter.

3.6 PREPARATION AND PRESENTATION OF DATA

The brief questionnaire is some cases provided basic information about firms size, type of activities, functional structure and nature of relationship between design/production functions.

Interview notes and transcripts were arranged in chronological order and by firms. During the process of arrangement the irrelevant information collected was excluded. The observation notes were composed similarly. These notes included information such as office and production layout, proximity between departments and researcher's personal impression of nature of the functional relationship between departments.

The interpretation of the collected data and material is presented in form of case studies. The case studies start with general background of the company and its product(s) or business. This is followed by details of the initiation of the specific product design or project, under the heading of product specification. The next part of the case study is devoted to the events which took place during the design and development of the product. Finally, each case study ends with general remarks relevant to the investigation. Table 6 shows the list of case studies and the method used to collect the data for each case. The details of the cases are presented in Volume II of the thesis.

The approach adopted for interpretation of the collected data was based on the working hypotheis and models (Figures 11 and 12). The main aim here was to establish the nature of the working relationship between product design and production functions.

APPENDIX	COMPANY CODE	BUSINESS/PRODUCT	DATA COLLECTION METHOD
3	HA	Heating appliances	O/I
4	WF	Wire fabricators	I
5	DHCA	Domestic heating and cooking appliances	O/I
6	FPM	Food preparation machines	O/I
7	MH	Materials Handling	I
8	GR	Generators	I
9	PIM	Plastic Injection moulders	I
10	PMT	Plastic moulder/toolmaker	I
11	GM	Gear Manaufacturers	O/I
12	AF	Architectral fittings	O/I
13	SPM	Special purpose machines	I
14	FCV	Fluid control valves	I
15	EE	Extraction equipment	O/I
16	MBC	Motorcycle/bicyle components	I
17	HPE	Hydraulic power equipment	I
18	LTT	Liquid transport tanks	I
19	APR	Air pistols and rifles	I
20	LA	Lifting appliances	I
21	SG	Switchgear	O/I
22	WA	Welding appliances	I

Key

I = Interviews
O = Observations

Table 6 List of case studies, company code and the method used to collect data.

CHAPTER 4

ANALYSIS AND DISCUSSION

4.1 Introduction

The first part of this chapter is concerned with the data analysis and discussion relating to product specifications in terms of the operational hypotheses derived in Chapter 3. This section is further sub-divided into four areas.

1. Extent of involvement by different functions when compiling product specifications.
2. Comprehensiveness of the product specification.
3. Format of the product specification.
4. Product outcome.

Under each of these sub-sections, the detailed factors shown in Figure 11 are critically analysed and discussed.

The second part of this chapter is concerned with the analysis and discussion relating to the design stage. This is done by sub-dividing this part into three sections:

1 Extent of involvement by different functions during the design stage.

2 Degree of consideration given to the product design parameters during the design stage.

3 Product design performance from production point of view.

Once again under these sub-sections, the factors relating to them, (as shown in Figure 12) are critically analysed and discussed.

4.2 The Factors influencing Product Specifications

4.2.1 Extent of involvement by different functions when compiling product specifications

In this part of the chapter the extent of involvement by various functions when compiling product specifications is individually analysed and discussed. The Table 7 shows the degree of inolvement by different functions in the process of constructing product specifications. An analysis of data has been attempted using a classification of three levels of involvement. These are considered to be sufficient as only significant or insignificant correlation is sought. The levels of involvement are:-

COMPANY CODE	DEGREE OF INVOLVEMENT IN COMPILING COMPILING PRODUCT SPECIFICATIONS							DEGREE OF CONSIDERATION GIVEN TO THE FOLLOWING PARAMETERS WHEN COMPILING PRODUCT SPECIFICATIONS						FORMAT SPECI -FICAT -ION	PRODUCT OUTCOME AND SALES PERFORMANCE	
	Custom -er	Sales/ Mtkg	Design -ers	Prodn Engrs	Design Mgt	Prodn Mgt	Gen Mgt	Mktg Needs	Project Dura- tion	Product Cost	Techni -cal content	Prodn Facili	Techni Labour skills		D+D Perf	Sales Perf
HA	0	++	0	0	++	+	+	++	0	++	+	++	0	V/W	V	U
WF	++	+	0	0	++	++	+	+	+	++	+	++	+	C	V	G
DHCA	0	+	0	0	++	++	++	0	++	+	+	++	+	V	G	P
FPM	0	0	0	0	++	+	++	0	0	0	0	+	0	V/W	P	V
MH	+	+	+	0	++	+	++	++	+	+	++	++	+	W	V	G
GR	+	+	+	0	++	+	+	++	+	++	++	++	+	W	V	G
PIM	0	++	0	0	++	++	++	+	+	+	++	++	+	W	G	V
PMT	++	++	+	0	++	++	++	+	+	++	+	++	+	W	V	G
GM	++	++	++	+	++	++	+	++	++	++	++	++	++	C	G	G
AF	0	0	+	+	++	+	+	0	0	0	0	+	0	V/W	P	P
SPM	++	+	+	0	++	+	+	++	+	++	++	++	+	W	V	G
FCV	0	0	0	0	++	+	++	0	0	0	0	+	0	W	P	V
EE	+	+	0	0	++	+	+	0	+	+	+	++	0	V/W	V	V
MBC	0	+	0	0	++	++	+	+	+	+	+	++	+	V	G	U
HPE	0	0	0	0	++	+	++	+	+	+	+	++	+	V/W	V	V
LTT	+	++	0	0	++	+	+	++	++	++	++	++	+	W	G	G
APR	0	0	0	0	++	+	+	+	0	+	+	++	+	W	V	V
LA	++	0	+	0	++	+	+	+	+	+	+	++	+	C	G	G
SG	+	+	0	0	++	+	+	0	0	++	++	+	+	W	V	V
WA	+	+	0	0	++	+	+	++	+	++	++	+	+	W	V	G
	++ = Extensive Involvement + = Limited Involvement 0 = Non-Involvement							++ = Extensive + = Limited 0 = None						V = Verbal W = Written C = Customer prepared or dictated	G = Good V = Variable P = Poor U = Unknown product not launched yet	

TABLE 7 **The degree of involvement, comprehensiveness and the format of the product specifications and their influence on the product outcome.**

- extensive involvement - where a department participates and significantly influences the contents of the product specification.
- limited involvement - where a department participates but does not significantly influence the contents of the product specification.
- non-involvement - where a department does not participate and therefore cannot directly influence the contents of the product specification.

Now each individual function will be considered and analysed and discussed using the above assessment criteria.

Customer

The analysis of the data in Table 7 shows that twenty-five percent of the companies investigated involved the customer extensively during the process of compiling the product specification. These were mainly those specifications dictated or strictly controlled by the customer, sometimes to the extent that the customer specified their needs almost precisely. An example is the case of SPM where customers usually had a considerable degree of knowledge and expertise themselves as to the precise type of machines which were required. As a result, each customer usually prepared a detailed commercial specification along with drawings and sketches and these were then submitted to SPM. Thereafter numerous discussions and negotiations took place prior to agreeing on the final format of the specification.

Similarly in the cases of WF, PMT, GM and LA, the customer had a significant influence over the content of the specification.

The remainder of the companies whilst considering the needs of the customer by other means, did not involve the customer extensively at this stage. For instance DHCA felt there was no need to involve consumers at this stage as consumers did not know what type of product was needed and FPM tended to follow their competitors who had already launched similar models.

Sales/Marketing

Table 7 indicates that in forty-five percent of the cases Sales/Marketing were involved in limited form and a further twenty-five percent had extensive involvement at the specification stage. The remaining thirty per cent made no use of these functions when compiling product specification. Examples of extensive involvement are typically illustrated by several cases. HA in particular was very strong in its marketing set-up and excellent use was made of it during the course of the product specification. Similarly in the case of other companies (PIM, PMT, GM and LTT), their sales/marketing functions were extensively involved during this stage.

Limited involvement of Sales/Marketing departments is illustrated by DHCA - this company was operating without a marketing specialist and this role was performed by other members of the management team. The Sales Director was usually otherwise occupied and information on market needs was provided by the Managing Director. When devising the product specification, they took decisions about the market needs and the Sales Director had limited involvement in this process.

Cases of non-involvement by these functions are illustrated by AF and FPM. AF was operating without a sales manager in the early stages of this project and there was no representation from the sales department during the initial meetings. The Technical Manager claimed to have a 'feel' for the market and said there was no need for the sales department to be involved. In the case of FPM, on the otherhand, the Sales Director did not take a keen interest in the project until a great deal of mis-directed effort had been wasted by the designer and others. For instance, at the beginning of the project when the Sales Director was asked by the designer for comments and approval, of an initial wooden model, he failed to provide any feedback for a period of three months. He only became involved in the project when he attended a meeting in Month 13.

Designers

There seems to be a universal absence of designers at this stage of the project; only one company made extensive use of its designer in preparing specifications. The remainder either made only limited or no use of the designers during the product specification stage.

Production Engineers

Production engineers were also generally excluded during the compiling of product specifications; only ten per cent of companies involved production engineers in limited manner and the remainder did not involve them at all. In fact ninety percent of the companies did not even inform production engineers that a product specification was being prepared.

Design Management

All the companies investigated indicated that design managers were extensively involved in compiling the product specification. In fact, the design management tended to dictate the specification and this is clearly demonstrated by the case AF, DHCA and SG. In the case of AF, the Technical Manager was the central figure in making all the decisions about content and comprehensiveness of the specification. This case was so extreme that even the Managing Director or the Production Director rarely influenced the content of the specification.

Production Management

Thirty percent of the companies made extensive use of their production management but the remainder more limited use of them at this stage. The companies which encouraged extensive involvement were generally very strong in this area and sometimes production management controlled the whole specification as in the case of FPM, PMT and WF. However production management in all the cases, knew of the existence of the product specification.

General Management

Under this heading are included other managerial staff who are not categorised in the previous sections, such as Managing Directors, Financial Specialists and General Managers.The data indicates that in thirty-five percent of the companies, general management was extensively involved when preparing a design brief. In these cases it was found that general management strongly influenced the content of the specification. In some companies (DHCA and FPM) its role became one of interference and 'dictatorship' to an extent that it strictly controlled details of the specification. In the case of FPM the Managing Director and the General Manager were frequently imposing their personal preferences onto the specification, which were not usually substantiated by any market research or technical data. The remainder of the companies involved general management in limited manner; general management either chose intentionally not to be involved actively or was not invited to participate. These reasons for limited involvement, however, are not true in all cases. In HA and AF, the Technical Managers tended to control the whole situation and the general management was 'powerless' to significantly influence the details of the specification.

4.2.2 Comprehensiveness of the Product Specification

Table 7 shows the factors which are involved in the specification; an analysis of these factors has been made using a classification of three levels of consideration. These are considered to be sufficient as only significant or insignificant correlation is sought. The levels of consideration are:

- extensive
- limited
- none

(i) Market Needs

The analysis shows that this factor was generally neglected by a majority of the firms, as only thirty-five percent extensively considered it, these usually being the firms with strong Sales/Marketing department. The rest of the firms either paid limited or no consideration to this parameter. Some of these firms failed to define customer needs precisely and subsequently this affected sales performance. This point is conveniently illustrated by considering the DHCA case. The company demonstrated excellence in all other areas except in the Marketing sector. This weakness was amplified when its new product was launched onto the market. Funds had been invested heavily during the course of the design, development and manufacturing operations but the company failed to invest even a small proportion of the total cost in attempting to define clearly the market needs. It failed to do this at the beginning of the project - ie prior to drawing up the product specification - and later when it had another opportunity, prior to commencing full production. At this stage, during the course of a management meeting, a 'market-survey' amongst the company employees was proposed to determine what the firm should produce. However even this was not done and no criteria were derived in order to arrive at a final choice between the proposed attractive models. Only a few months after the launch of the new product onto the market, it was withdrawn because the sales did not reach the hoped-for levels. This company had sufficient financial resources sales and revenue from other products to be able to withstand this product failure, but if it had been solely dependent on this new product the effect could have been catastrophic.

The fact that DHCA did not keep any formal written records of details of the design process means it is unable to go back and analyse the details to learn lessons for future. It can only rely on the memory of individuals to recall events which have taken place. The firm still does not feel a need to keep formal records, of events on projects, but it did recruit a Marketing

Director after this product had been unsuccessfully launched onto the market.

Similarly, AF and FPM also failed to define clearly market needs which led to numerous problems during the subsequent stages of the projects. For example, AF was unable to identify the optimum price that customers and markets would sustain for their products. In these companies various individuals claimed to have a 'feel' for the market and customer needs; this was in the absence of any data to substantiate their claim.

(ii) Duration of the Project

In general this factor was found to be ill-defined and many projects tended to 'plod along' without any clear aim or objective. Only fifteen percent of the companies investigated extensively considered and specified this factor, the remainder either considered it in limited manner or did not consider it at all. The observations revealed that companies which extensively considered this point, tended to set their target for the duration of a project and then strictly adhered to it. For example, in DHCA, additional costs were incurred as a result of modifications to tools rather than fall behind schedule. The management was adamant throughout the project that the launch date agreed upon at specification stage had to be achieved. It argued that it was better to launch the product at the initially agreed time and try to be one step ahead of competitors, rather than worry about costs which could be recouped through the additional sales revenue that would be generated by being in the market on time.

(iii) Product Cost

In general, product cost (cost to manufacturer) was either considered extensively or in limited manner at the product specification stage. The data shows that forty-five percent of companies extensively considered this factor, whilst forty percent gave limited consideration, but with no significantly adverse effects. However companies which failed to specify this feature, usually experienced problems at later stages of the project.

For example, in the case of AF a decision about the product cost was left to the discretion of the Technical Manager who was usually so occupied in attempting to satisfy the functional aspects and that product cost and selling price became a secondary factors. Once the product under study was manufactured and launched, the company's management realised that it was considerably overpriced and hence the selling price had to be reduced in order to stimulate higher sales. Earlier in the project it had been stipulated that as soon as the design and development work was completed and prior to introduction to production, a Value Analysis exercise would be carried out. The company did not carry out any such exercise and as a result the product was over-priced although, since no product cost had been set to work towards it is doubtful whether even VA would have retrieved this product.

In the case of FPM, product cost was not agreed upon initially - it was in Month 13 when the unit cost of the proto-type was calculated as £380 that there was any attempt to specify the product cost for the designer to work towards. It was at this stage of the project that the sales director decided to involve himself formally and the product cost of machine was set as no greater than £350. Even then the product cost of the other two sizes of machines were not considered. Upto this stage the designer had been allowed to proceed with the project without any cost constraint; it was left to his discretion and judgement to design the 'right' product at an unspecified 'right' price.

(iv) Technical Content

Only forty percent of the companies paid extensive attention to this parameter and fifteen percent did not consider this factor at all when devising a product specification.

The companies which paid extensive attention to this factor were found to be concerned with products which were technically complex and generally had strong engineering departments. They tended to consider this parameter to be very important - because customers usually demanded technically superior products. This was particularly true in the cases of GR, LTT, SPM, SG and WA - where the price of a 'basic' unit usually approached or exceeded five figure sum. Hence the customer was usually more concerned about the exact function of the product than small variations in its price.

However, many firms considered this element in limited manner, usually defining technical details broadly at the start of the project and then developing ideas as the project progressed. This was particularly true for DHCA, HA, MBC, PMT and EE. For example DHCA defined parameters very vaguely and the designers were allowed to develop them into practical propositions but under the strict control of the management.

The companies (FPM, AF and FCV) which did not give any consideration to this factor - experienced numerous obstacles at a later stage of the design process. At FPM, performance levels were not defined at the start of the project and even much later the exact requirements of the new machine were still only vaguely specified. The designer was allowed to proceed without clear objectives, the project did not achieve the 'anticipated' results and the designer's motivation suffered.

Similarly in the case of AF the specification was ill-defined and as a result all the major components of the product posed subsequent problems. For instance, one component was a pivot device; in the specification it was simply mentioned that a pivot is required but no details were given of the type of pivot, the force required to operate it, the material, the manufacturing processes needed to make it or the safety mechanism it should incorporate. The product specification was too broad to be useful and this led to numerous problems even after the product had been delivered to customers. A large number of complaints about premature failure of this pivot were received and the effect on the company's reputation may prove to be considerable. The company failed to ask a fundamental question prior to embarking on the new product design - do we have the right expertise in the company to design the required components? If the company had adequately examined its weaknesses and strengths regarding technical expertise (as well as other factors) it may have been able to follow a more successful course of action perhaps by using an outside design specialist.

(v) Production facilities

Out of all the companies investigated only two companies, DHCA and PIM, had ventured into radically new product designs. The remainder designed products which were familiar and compatible with the existing production facilities. DHCA as well as manufacturing gas fires, was simultaneously developing a new range of cooking appliances. New automated fabrication techniques were considered at the product specification stage and these were subsequently purchased. At this early stage of the product, the company paid detailed attention to the existing production set up and compared and contrasted this with the proposed new facilities. Similarly at PIM, preliminary investigations revealed the existing injection moulding facilities were inadequate to manufacture the proposed new product. Because of this problem the basic product design concept changed from moulding in one piece to that of modular units.

The data, although limited, does indicate that companies do generally pay attention to this feature at the product specification stage.

(vi) Technical/Labour Skills

It was difficult to establish whether this aspect was adequately considered at the design stage because, as mentioned in the previous section, only two companies were designing new products sufficiently radical to necessitate examining in-house strengths and weaknesses. The data suggests that these two firms gave adequate attention to 'in-house' technical and labour skills available.

Lack of inadequate consideration given to this factor is illustrated by AF. This firm as mentioned in the Technical Content section failed to identify internal strengths and weaknesses regarding technical experise. Subsequently this led to numerous problems which could have been avoided perhaps by engaging the services of external specialists.

4.2.3 Format of the Specification

The data in Table 7 shows that the presentation of specifications varied considerably. For example, 50% of the companies prepared written guidelines; 10% had non-written verbal specifications; 25% prepared partly verbal and partly written whilst the remainder had customer dictated specifications. The data reveals that a majority of the firms prepared some type of written design specification. It also suggests that the companies who prepared specifications either in a verbal or written manner had significantly less problems during the subsequent development process than those who prepared specifications partly verbally and partly in writing.

It was found that these latter companies were undecided in their precise definition of requirements. As a result, the points they were certain about were transformed into written format but unclear territory was verbally conveyed often causing a considerable degree of confusion during the subsequent design process. For example, in the cases of AF and FPM, not all the information was clearly defined in written form at the beginning of the project - hence numerous problems arose later such as confusion, misunderstanding, frustration, ill-feeling amongst staff, and general sub-optimisation in the design process.

Only ten percent of the companies prepared their specifications verbally and their subsequent design process was quite good; no conflict in personalities occured or any of the other problems mentioned earlier. However one major factor which the data suggests leads to successful execution of product design work is communication. Companies falling into this category were very strong in this area especially DHCA whose management had attempted to create a 'family' atmosphere and placed great emphasis on good communication and collaboration amongst employees. Information about the specification was conveyed through different channels to the designer - who in turn passed on the details to others as and when required. Similarly MBC being a small family owned business was very strong in communication which resulted in the successful execution of product design.

The companies which prepared written specifications were generally found to have technically complex products. For example SG, WA, LTT and MH, all designed products which needed utilisation of diverse specialisms; as a result they clearly defined their requirements and were generally found to be successful in conveying the necessary information to the designers.

4.2.4 Product Outcome

In this section an attempt is made to analyse and discuss the extent of association between three sets of variables:

(a) Extent of involvement and product outcome

(b) Comprehensiveness of specification and product outcome.

(c) Format of the specification and product outcome.

All these variables except product outcome have been analysed and discussed in the earlier sections. Product outcome as illustrated in the product specification model (Figure 11) is measured by the following parameters.

(i) Design and development performance

(ii) Sales performance

(iii) Degree of standardisation carried out.

(iv) Number of modifications carried out.

In order to analyse and discuss the data it is necessary to reitterate the key stages involved in a typical design project (Figure 13).

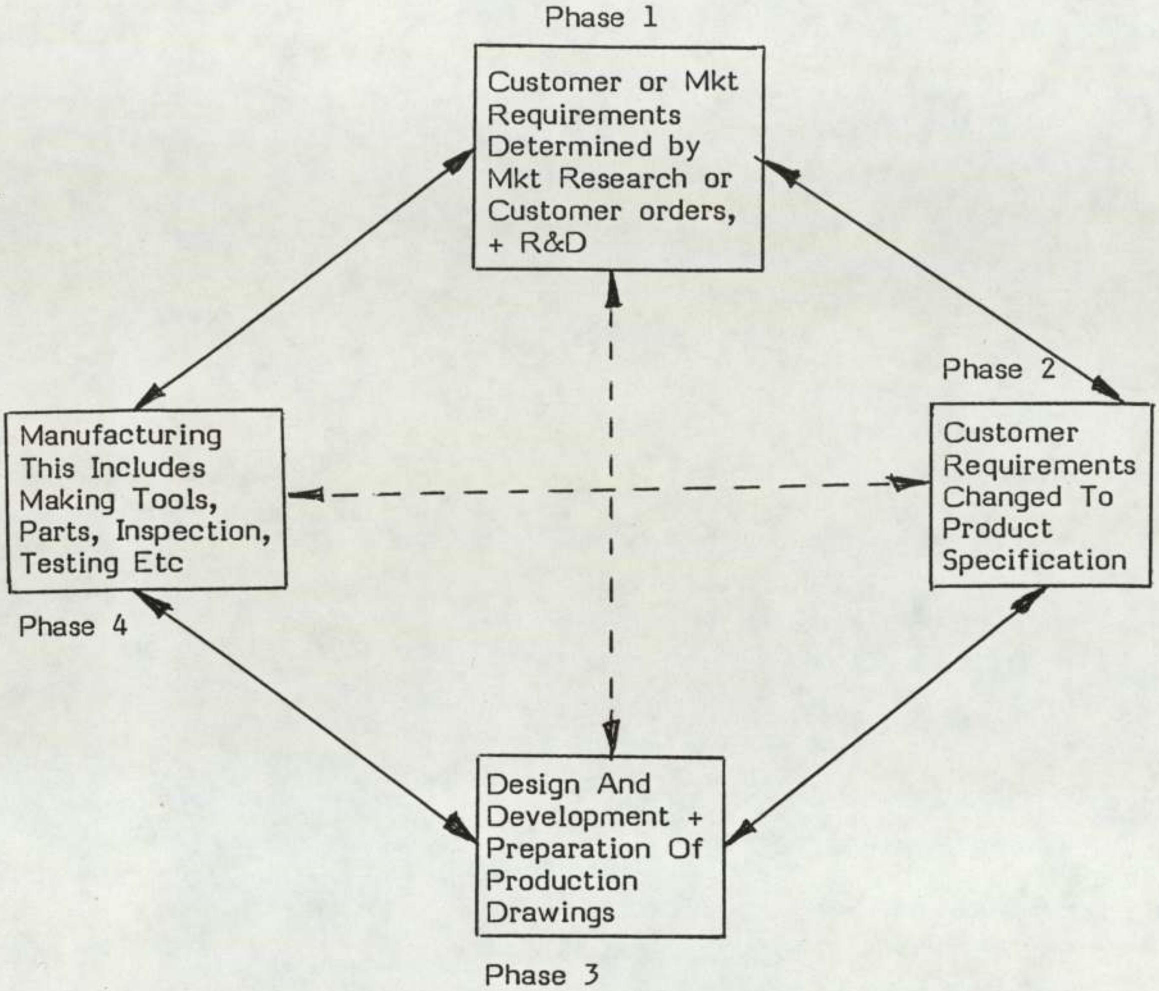

Figure 13 **A Diagrammatic representation of the key stages involved in a typical design project**

______ = Direct Link Between Phases

------ = Indirect Link Between Phases

Considering this diagram in the context of direct and indirect links between different phases, then there are:

Direct link between phases 1/2, 2/3, 3/4 and 4/1

Indirect link between phases 1/3 and 2/4.

In attempting to measure the degree of association between different phases in the cases of direct links and interfaces, this is relatively easy to do. However when attempting to measure the degree of association between phases with an indirect link this is more difficult because of the existence of an intermediate phase in between. For example, because of the existence of an intermediate phase 3, it is difficult to assess the influence of phase 2 on phase 4.

Hence, the four parameters need to be reviewed regarding the extent to which they can realistically be measured. When putting these four parameters (to measure the product outcome) into the model of typical design stages, it can be seen that for parameters (i) and (ii) there is a direct link between product specification (phase 2) and design and development (phase 3). Similarly there is a direct link between product specification (phase 2) and customer (phase 1). So these two parameters can be measured.

However, the other two paramaters namely the degree of standardisation carried out and the number of modifications carried out - these two can only be assessed in phase 4 (manufacturing) because until the product design process is complete the degree of standardisation achieved or the number of modifications are not known. As there is an intermediate phase between phases 2 and 4, the effect of phase 2 on phase 4 becomes interwoven with phase 3. Due to these restrictions the two parameters (iii) and (iv) cannot be reliably tested against the data available. However an attempt will be made to draw some general conclusions on parameters (iii) and (iv).

Influence of extent of involvement, comprehensiveness and format of the product specification on design and development performance.

Before proceeding with data analysis and discussion the criteria employed in measuring the design and development performance will be clarified. The prime concern is with measuring performance in terms of whether a company has achieved its design and development targets which were defined or laid down in the product specification. An analysis of data has been attempted using a classification consisting of three levels of performance, considered to be sufficient as only significant or insignificant correlation is sought between these variables. The levels of performance are:

good performance	- where all the pre-determined targets as laid down in the product specification were achieved.
variable performance	- where part of the pre-determined targets as laid down in the product specification were achieved.
poor performance	- where none of the pre-determined targets laid down in the product specification were achieved.

Using the above classification, the analysis indicates that only 30% of the companies investigated exhibited good design and development performance whilst 15% were poor and the remainder variable.

Good Performance

There is evidence from the data to suggest that there is a significant correlation between the successful execution of the design and development work and the following factors: communication amongst members of the company, strict management control of the project and extensive consideration given to the production facilities at the product specificiation preparation stage. All the companies in this category were very strong in these areas. For example in the case of DHCA - although specifications were verbal and the majority of parameters vaguely defined excellent communications existed between functions. Management maintained strict control over the project, both during the specification process and during subsequent design and development.

In addition, successful firms paid extensive attention to production facilities when devising product specification. However regarding other factors - extent of involvement and comprehensiveness of specification - there is a less clear association with good performance in design and development. Similarly the data suggests that there is little correlation between the format of the specification and the subsequent outcome of design and development work.

Poor Performance

It can be seen from the data that in these companies there was poor liaison amongst management and other members of the organisation. Management tended to dictate the product specification without paying adequate attention to parameters such as duration of the project, product cost, technical content and technical/labour skills.

Above all management failed to convey the relevant information in the specification to all those concerned with the subsequent product design and development. Further, during the design and development process management generally failed to maintain strict control of any parameters that were laid down in the specification. Usually, ill-defined parameters and lack of comprehensiveness of specifications led to considerable friction and confusion amongst project members, as illustrated by the cases and FPM, AF and FCV. These companies failed to pay adequate attention to the calibre and competence of technical expertise in the company resulting in poor functional designs. For example the pivot in the case of AF and the valve mechanism in the case of FCV . All these companies casually considered the production facilities at the specifiation stage whereas the companies with good performance gave extensive attention to this feature.

Variable Performance

More than half the firms were in this category. When analysing the data, the picture is rather blurred since the features exhibited by these firms are difficult to categorise. However an attempt is made to illustrate variable performance by considering a few firms which were classified in this category. HA for example had good communication channels between different functions of the organisation but due to lack of adequate control on project duration they suffered numerous setbacks during product development process. The technial complexity of the product was underestimated and inadequate guidelines in the product specification on project significantly contributed the postponement of the launch date by twelve months. Similarly GR and SPM gave inadequate consideration to project duration and labour skills but in contrast these firms had written specifications and good internal communication. However in the case of SPM detailed design work was sub-contracted which lengthened the design and development process. Inadequate control of design personnel in SG and WA lead to few unnecessary problems as designers were seeking technical excellence which it can argued was not always desired. However in these cases there was poor horizonal and vertical communications during the product specification stage.

Influence of extent of involvement, comprehensiveness and the format of the product specification on the sales performance

In this section an analysis of the data has been attempted using a classification consisting of four levels of performance. The levels of performance are:

Good performance - where the anticipated sales at the specification stage were fully achieved when the product was launched.

Variable performance - where the anticipated sales at the specification stage were not fully attained when the product was launched but sales were considered acceptable.

Poor performance - where the anticipated sales at the specification stage were not achieved when the product was launched and sales were considered unacceptable.

Unknown performance - where the product had not been launched yet.

Using these classifications, analysis indicated that 45% of the firms investigated exhibited good performance; 15% showed poor performance; the performance of 10% of firms was unknown and the remaining 30% were classified under the variable performance.

Good Performance

When analysing the data there was a consistent pattern that all the companies in this category clearly obtained and defined customer needs. This was either through extensive customer involvement or via sales/marketing departments. This, together with a comprehensively prepared specification, resulted in successful performance of products when launched on the market. The data therefore suggests that there is a direct correlation between the extent of involvement by the customer and sales/marketing personnel and good sales performance. However it is valuable to note that there also appears to be a correlation between the format of the specification and good sales performance. All had formal specifications in written form, including three firms where specifications were either prepared by the customer or customer dictated.

The evidence suggests, that providing market needs are clearly defined and formally translated into a written design brief then there is a greater likelihood that the product will achieve the anticipated sales performance.

Poor Performance

The firms in this category clearly exhibited the features which were opposite to that of good performance. For example all the companies failed to clearly define the customer needs. There was a lack of involvement by the customer and sales/marketing personnel etc. Specifications were generally vague and incomprehensive. There is however, an inconsistent picture regarding the format of the specification and the subsequent sales performance.

It is interesting to note, for example, one company (DHCA) had good design and development performance but failed to satisfactorily achieve anticipated sales levels. This company failed to define the market, so although it demonstrated excellence in all other areas, did not achieve the anticipated sales results. It is therefore paramount that market needs are precisely established prior to embarking on a project.

Variable Performance

Thirty percent of the firms were in this category. As in the case of influence of product specification on the design and development performance, it is again difficult to identify a consistant pattern of features which constitutes variable sales performance. Nevertheless it is possible to illustrate variable sales performance by considering firms classified in this category. FPM for instance, had poor design and development performance but was still able to launch its products. It is reasonable to postulate, however, that if a product speficiation had been prepared comprehensively at the outset their launch date could have been several months earlier. Similarly FCV, due to a non-comprehensive product specification, delayed its product launch date. At SG the search of technical excellence coupled with inadequate project control resulted in missed delivery targets some of which incurred penalties.

Influence of extent of involvement, comprehensiveness and format of product specification on degree of standardisation achieved.

As explained earlier in this section of chapter, influence of phase 2 on phase 4 is somewhat 'contaminated' by the intermediate phase 3, hence it is difficult to draw tangible conclusions. Nevertheless, an attempt is made to draw some tentative conclusions by citing specific examples.

The data suggests that with inconsistent involvement of different functions coupled with inadequate managerial control in the product specification compilatioon process leads to reduced standardisation. This phenomenon can be demonstrated by FPM where irregular involvement by different functions (ie Marketing, Production and General Manager) significantly contributed to low degree of standardisation achieved. The situation was further exacerbated by inappropriate format of specification. This argument can also be extended to AF, where designers ill-consideration to existing products lead to low degree of standardisation. In DHCA, a relatively higher degree of standardisation could have been achieved by formalising product specification preparation.

Influence of extent of involvement, comprehensiveness and formar of product specification on number of modifications carried out.

As explained in the previous section, it is difficult to draw specific conclusions on the correlation between extent of involvement, comprehensiveness and format of specification with number of modifications carried out. However an attempt is made to illustrate this phenomenon by citing few examples.

There is evidence to suggest lack of clear definition of factors like product cost, technical content, market needs and project duration leads to increased modifications. These factors coupled with poor communication and inadequate in-house technical expertise significantly increases the number of modifications carried out during the manufacturing stage. For example firms AF, FCV, and FPM are typical victims of these factors. FCV for instance had to abort the design a number of times and similarly AF designed pivot several times before seeking help from an external source.

Informal format of product specification can also lead to a relatively high number of modifications as in DHCA where 22% of the components had to be modified.

4.3 The Factors influencing the Design Stage

This section is concerned with the analysis and discussion of the data relating to the design stage. This is done by broadly spliting the section into three areas: (1) Extent of involvement by different functions of the organisations during the design stage, (2) Degree of consideration given to product parameters during the design stage, (3) Product Design performance from the production point of view.

These three areas and factors relating to them are conveniently illustrated by the model in Figure 12.

4.3.1 Extent of involvement by different functions of the organisation during the Design Stage

Table 8 shows the degree of involvement by different functions. An analysis of the data has been attempted using a classification of three levels of involvement. These are considered to be sufficient as only significant or insignificant correlation is sought. The levels of involvement are:-

- extensive involvement - where a department participates and significantly influences the product design performance.
- limited involvement - where a department participates but does not significantly influence the product design performance.
- non-involvement - where a department does not participate and cannot influence the product design performance.

These functions will be considered analysed and discussed using the above assessment criteria.

Designers and Design Management

The data analysis shown in Table 8 reveals that, as might be expected for all the firms investigated, designers and design managers were extensively involved throughout the design process.

Production Engineers, Production Management and the stage of their involvement.

It has been decided to discuss these two functions collectively because some of the firms investigated did not have production engineering specialists and this aspect of the organisation was performed by production management personnel. Another important variable closely connected with these functions, namely, the stage of production involvement is also discussed in this section.

Before proceeding with the data analysis and discussion, the terms production engineers(1) and production management(2) will be clarified.

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(1) Production engineers are those individuals or groups of individuals who are employed as specialists in manufacturing techniques. For a product design under consideration, they specify and plan the most suitable manufacturing processes. Their work includes:

(a) specifying materials required during manufacture;
(b) specifying of manufacturing methods;
(c) determining the sequence of operations;
(d) determining the work content of each operation;
(e) planning the overall time cycles within which all manufacturing activities are carried out;
(f) specifying the lead times which occur before the manufacturing activities take place;
(g) specifying the resources required in the form of labour, plant, tools and fixtures, raw materials and bought in (or out) parts;
(h) scheduling work to manufacturing departments; and
(i) monitoring and controlling production against the plan.

Production engineering activities and functions include jig and tool design, materials handling, method study, process planning, production control, production planning and value analysis.

(2) Production management, on the otherhand, deals with the management of all aspects concerned with transforming materials into finished products - including PE tasks - or a set of other, different tasks.

COMPANY	DESIGNERS/ DESIGN MGT	PRODN ENGRS	METHODS ENGRS	ESTIMATORS	PRODN MGT	STAGE OF PRODUCTION INVOLVEMENT
HA	++	DNE	DNE	DNE	+	H
WF	++	DNE	DNE	DNE	+	H
DHCA	++	++	++	+	++	T
FPM	++	0	DNE	+	+	H
MH	++	++	+	+	++	T
GR	++	0	0	0	+	H
PIM	++	DNE	0	+	++	T
PMT	++	DNE	DNE	0	++	T
GM	++	++	DNE	+	+	T
AF	++	+	DNE	+	+	H
SPM	++	0	0	+	+	H
FCV	++	0	DNE	+	+	H
EE	+	DNE	DNE	0	+	H
MBC	++	DNE	DNE	DNE	+	H
HPE	++	0	DNE	O	+	H
LTT	++	DNE	DNE	+	++	T
APR	++	++	+	+	++	T
LA	++	+	DNE	DNE	+	H
SG	++	0	0	+	+	H
WA	++	0	0	+	+	H

++	Extensive involvement
+	Limited involvement
0	None involvement
DNE	This function Does Not Exist
H	Handover of drawings from design to production
T	Throughout the design process

Table 8 **Degree of Involvement during the Design Stage**

The analysis of the data in Table 8 indicates that 20% of the production engineers were involved extensively, 10% were involved in limited manner and in the remainder of the firms this function either did not exist or these specialists did not participate during the design stage. From the data under the 'production management' column it can be seen that in 30% of the firms this function was extensively involved whilst in the remainder of the firms there was limited involvement by them. Under the 'stage of production involvement' column it can be seen that 35% of the firms investigated had their production functions involved throughout the design stage the remainder were involved only when the drawings were formally handed to them.

The companies in which the production function participated extensively throughout the design stage, were very concerned about the need to design their products for economic manufacture. As a result, production personnel actively participated early in the design process and attempted to ensure that products were designed with production in mind. For example, in DHCA, the Production Director and Production Engineering specialists were involved from the first project meeting and they always discussed in detail each component from the manufacturing point of view. It was observed that the design department usually 'over estimated' production capability and was thereby always a 'testing and stretching' of production personnel to the limit. Taking as an example the canopy of a gas fire, the design department specified that the forming tool should be able to produce this in three operations - when it knew that on previous similar items it had taken five. The Production personnel reacted by claiming that it would be impossible to achieve this but went away and considered the possibility and compromised by saying that it could be done in four operations. Each component was usually considered in this sort of detail and the agreement on various items between the design and production functions usually took the form of 'hard-bargaining'. The Technical Director claimed that this method of operation was deliberately instigated and controlled by him to ensure that products are always designed with economic manufacture in mind.

Similarly in the case of MH and APR the production engineering specialists and production management personnel were involved throughout the design process and considered each component in detail to ensure that products were designed for economic manufacture.

In the companies which did not have production engineering specialists, this function was usually performed by production management personnel. These firms (PIM, PMT and LTT) had competent and experienced production management staff who closely liaised in the design process and thereby ensured that production features were considered in the product design. However the Works Manager of LTT was critical of the situation which existed in his company. Although production management did attempt to get involved in product design, time limitations and other managerial responsibilities meant that detailed and serious attention to all aspects of the design could not be given. Similarly, because the design engineers were working on 5 or 6 projects simultaneously, they tended to overlook details. This usually resulted in uneconomical product design from the manufacturing point of view. He strongly felt a real need for Production engineering specialists who would be able to consider each component in detail and thereby eliminate, at the drawing board stage, the majority of the production problems.

Hence, in many of these cases, although production management seemed to be extensively involved throughout the design process this did not necessarily result in economic product design. This was mainly due to two reasons:

(i) production management did not have sufficient time to consider components in detail because of other managerial commitments.

(ii) production management perhaps due to lack of expertise or training and time, did not have the capability to investigate new production techniques or new ways of manufacturing components.

Considering firms whose production engineering function were involved in limited manner (AF and LA) it was found that the production engineers basically knew what was going on but did not influence the product design process. For example in the case of AF, the design department usually approached the production engineering department to carry out a specific task, production responded to the request but they did not have significant influence in changing the designer's line of thought. In these cases the information flow was in one direction only in the form of instructions or 'command'. In fact, in AF production engineering personnel did not extensively get involved until drawings were formally handed-over and only then could they commence planning and appraising each component to facilitate manufacturing operations.

Finally, under this heading come those companies where production engineering functions either did not exist or did not participate and so could not influence the product design process. This constituted the majority (70%) of the firms investigated in this study. The problems of non-involvement are clearly illustrated by FPM Limited. In this company the Chief Production Engineer was involved in a number of meetings with the design department, but his role was limited to that of a materials specialist and very rarely was any reference made to production engineering aspects of the product design. His involvement gave little warning to the production engineering department about the commencement of manufacturing operations or other vital information. Hence, only one week was allowed to start a pre-production run after the hand-over of drawings although the design department had spent 28 months on the project. The newly appointed Manufacturing Manager was very critical about this, stressing the importance of the hand-over stage. He wished to see production engineers actively participating in the project at the design stage so that the majority of the problems were resolved before the drawings were handed-over to production, thus avoiding or minimising problems such as modifications, late deliveries, frustration and ill-feelings amongst members of the two departments.

The effects of non-involvement is further illustrated by the companies SG, WA and SPM. In these firms, the managements claimed that due to technically complex products, functional design tended to overshadow the economical manufacturing features. As a result their design departments, tended to dominate the whole design process and the production departments played an insignificant role. The production departments only got involved after the completed drawings were handed-over to them. The production management of these firms were very critical about the situation claiming that products in general are frequently over-designed which usually resulted in numerous changes to the drawings at the commencement of manufacturing operations.

This point was illustrated by the Manufacturing Manager of SG who claimed the design department tended to be 'traditional and reluctant to change'. For instance the designers continued to specify silver plating of machined aluminium surfaces in order to increase electrical conductivity, when production had suggested that these surfaces could be copper sprayed and still give similar conductivity results. However, production was not consulted at an early stage and when the drawings were issued these components had to be reviewed and later amended. Since production was rarely involved in the design process these over-designs of products were usually carried through to customers.

Similarly in the case of WA, the primary objective of the design function was to satisfy the functional aspects and very rarely was there any reference made to production features. Since the price of the product was agreed upon at the initial stages of the project, providing the project was within these guidelines, the designers rarely became concerned with economical manufacturing features. Again an active participation of the production personnel during the design stage was needed in order to eliminate excess costs.

In the case of the companies where production engineering functions did not exist, occasional use was made of production management personnel but their input tended to be insignificant as in the cases of HA and EE etc.

Methods Engineers

Methods engineers perform a similar function to production engineers except they specialise in assembly methods as opposed to manufacturing techniques. Table 8 shows that only 5% of the firms made extensive use of this function and only 10% had limited involvement during the design process. The remainder either did not employ specialist methods engineers or if they did, they were not involved during the design stage.

One company which extensively involved methods engineers, namely DCHA, was very aware of the need for 'designing for assembly' as well as 'designing for manufacture'. Hence assembly techniques were always discussed throughout the project. (The methods engineers and the production coordinator were considered to be specialists in this area). Also when the new product was undergoing type-approval trials by a regulatory body various ways of assembling the product were attempted, until satisfactory methods were agreed upon between the design and the methods engineering departments which satisfied the trials.

The non-involvement found in 30% of the firms indicates that these companies failed to make use of the expertise available in-house. For instance, in firms such as SG, WA and SPM assembly techniques were completely disregarded because products were being made as one-off's or only in small quantities and it was felt that detailed attention to assembly methods was unnecessary.

A majority of the companies did not employ methods engineers. In some firms there was no need for these specialists, but in others, (companies such as AF, FPM, EE, MBC and LTT) this function was completely overlooked, even though extensive assembly operations were involved. Some of these companies paid adequate attention to manufacturing techniques but completely overlooked assembly methods despite the greater importance of assembly compared with component manufacturing. Especially in the case of AF, observations showed that the majority of the problems existed in the assembly area.

Estimators

The role played by estimators, if this function existed, was that of either simply limited or non-participation during the design process. This function was usually limited to providing estimated prices for the designs under consideration; in other organisations these duties were performed by the designers themselves.

Others

This includes functions such as Sales, Marketing, Finance, After-sales service and Buying. The observation found a universal absence of participation by these functions during the design process. Only PIM extensively engaged its Marketing and Financial specialists during the course of the project. The remainder of the firms tended to use these functions as providers of 'service' as and when required by the design department. For example Buying generally worked to the instructions of Design, in order to obtain information on the bought out components regarding availability, prices and delivery etc. Other than this buying departments rarely influenced the product design process.

4.3.2 The degree of consideration given to the Product Design parameters

In this section an attempt is made to analyse and discuss the data relating to the type and level of consideration given to the product design parameters. Table 9 shows the factors which are considered during the design stage. An analysis of these factors has been attempted using a classification of four levels:

extensively considered	- when a feature is deliberately taken into account during the course of product design process.
limited consideration	- when a feature is taken into account by chance during the course of the product design process.
not considered	- when a feature is not taken into account during the course of the product design process.
no data available (N)	

COMPANY	INDUSTRIAL DESIGN	TECHNICAL CONTENT	PRODN TECHNIQUES	ASSEMBLY TECHNIQUES	PRODUCTION CONTROL	LABOUR SKILLS	EXISTING PRODUCTS	STANDARD -ISATION	PRODUCT COST	PROJECT DURATION	DEVELOP -MENT COSTS
HA	+	++	+	+	+	+	+	+	++	+	+
WF	O	+	+	+	N	+	+	+	++	+	++
DHCA	++	++	++	++	++	++	++	++	+	++	+
FPM	+	+	+	+	+	+	+	+	+	+	+
MH	+	++	++	++	++	++	++	+	+	+	+
GR	+	++	++	++	+	+	++	+	++	+	+
PIM	++	++	++	++	++	++	NA	++	+	+	+
PMT	O	+	++	++	+	+	++	++	++	+	++
GM	O	++	++	++	++	+	++	++	++	++	++
AF	O	+	+	+	+	+	+	+	+	+	+
SPM	+	++	+	+	++	++	+	+	++	++	++
FCV	+	+	+	+	+	+	+	+	+	+	+
EE	O	+	+	+	+	+	+	+	+	+	+
MBC	++	++	++	++	+	+	+	++	++	+	+
HPE	+	++	++	++	++	+	++	++	++	+	++
LTT	++	++	+	+	++	++	++	++	++	++	+
APR	++	++	++	++	N	+	++	++	++	+	+
LA	+	++	++	++	N	+	++	++	++	+	++
SG	O	++	+	+	+	+	++	+	+	+	+
WA	+	++	+	+	+	++	++	++	+	+	++

++ = Extensively considered
+ = Limited consideration
O = Not considered
N = No data available
NA = Not applicable

Table 9 The extent of consideration given to the Product Design parameters

Industrial Design

The analysis of the data summarised in Table 9 shows that 25% of the firms extensively considered aesthetic aspects during the design stage, whilst 45% gave limited consideration and the remainder did not consider this feature at all.

Companies which extensively considered industrial design aspects when designing new products included DHCA, PIM, MBC, LTT and APR. These firms placed high importance upon industrial design inputs to their products. DHCA for instance employed a full-time industrial designer who was responsible for initiating the product design process after the specification has been devised and he worked very closely with the detail design team throughout the project. Management continually look to this industrial designer to come up with original and creative ideas regarding the product appearance and considered this function to be 'core' of the organisation if the company was to maintain its 'edge' over the competitors. Other companies such as PIM, MBC, LTT and APR also considered industrial design input to be an essential selling characteristic of their products and gave extensive attention to this during the design process, usually by engaging the services of a consultant industrial designer.

Some companies, like HA and FPM also engaged the services of a consultant industrial designer but the ideas proposed were given inadequate attention and dismissed without consideration of detailed implications. These companies attempted to satisfy the industrial design features by 'ad-hoc methods', whereby various individuals gave an opinion of the appearance aspect only; on no occasion was any consideration given to other aspects of industrial design such as ergonomics, colour, appeal or perception.

Of the companies which failed to give any attention to this feature (such as WF, GM and EE) it could be argued that the decision was justified because of the nature of the products whose industrial design features were not essential requirements. However in other cases such as AF, SG and PMT, decision not to consider aesthetic aspects of the design is highly debatable. For instance, in the case of AF which produced windows for office buildings, some industrial design features should have been very important indeed.

Technical Content

Before proceeding with the data analysis and discussion it is important to clarify the meaning of the term 'technical content'. In this study it is taken to mean the degree of consideration given to the functional characteristics of the product design such as performance, quality and reliability.

Table 9 shows that 70% of the companies gave extensive consideration to this feature while the remainder only considered it in limited manner during the course of the design stage.

In the cases of the extensive consideration, at the extreme end of the spectrum there were MH, SPM, LTT, SG and WA. These companies considered their products to be technically highly complex and as a result the technical features tended to dominate the design stage. This argument is supported by the fact that these companies placed utmost emphasis on the quality and calibre of design engineers and gave a significantly higher status to them. These firms, in fact, placed a high degree of emphasis on the technical content of the product from the specification stage until it was delivered to the customer. This is particularly true when comparing and contrasting this with economic manufacturability of the product design, as pointed out by the Manufacturing Manager in SG, who said that products in this firm were frequently 'over-designed'. The designers were continually concerned with the performance, quality and reliability when perhaps they should have put equal amounts of emphasis on manufacturability.

Other companies where extensive consideration was given to this feature, for example DHCA - had products which were not as technically complex as SG or WA's but still regarded this parameter as very important. DHCA did not have a comprehensively laid down product specification but the whole design team appeared to 'operate on the same wavelength' because there was excellent communication between management and the other members of the organisation. Any ideas during the design stage which the design staff wanted to pursue were informally discussed and if all those concerned with the project argeed, then these ideas were developed into working models. The whole design process progressed in this manner until a product considered to be of 'superior performance' was developed. Nobody actually specified what was a 'superior performance product'; the new product design was compared against existing models and competitors products. If the new product was considered to be better then these it represented 'superior performance'. Design management very strictly controlled the technical performance attainable in the time available for the project. The time available for the project was a very important feature for this firm because the market for the product is seasonal. Often only marginal improvements could be achieved in order to meet the product launch deadlines. Given more time further improvements to the product would be possible, but the technical content had to be carefully balanced with the other features of the project.

Several firms only considered this aspect in limited manner during the design stage. Although still considering the technical content of the product to be very important, these firms were relatively vague and imprecise about technical aspects when designing new products. For example AF in the initial specification for a new window, specified feature such as frame bars, pivot, handle, cleat, rubber seal and a locking mechanism, but did not define other design parameters such as material, size and shape etc. Consequently these were major problems in attempting to satisfy the functional requirements because nobody in the company knew precisely what they were; both management and design team appeared to 'drift along' aimlessly from one idea to another.

Like AF, DHCA did not clearly define the technical content of new products, but unlike AF, the management knew precisely what was required. In AF neither the management nor the design team knew about the technical content of the window. Similarly, in the case of FPM, there appeared to be vagueness and a lack of understanding about the technical content of the products being designed. Nobody was certain as to what was required - there were always 'feelings' or 'rumours' or 'opinions' about what the technical content should be; design projects tended to go in 'circles'.

Perhaps the worst example in this study was FCV, which more than any of the other firms investigated in this study failed to clarify the technical content. The project was abandoned twice before, finally, a functional design was bought in from an outside firm. This company did not have sufficient technical expertise to enable it to clearly define the functional features of the product.

Production Facilities/Techniques

Under this heading it is intended to include consideration given to the production facilities available in the firm as well as the consideration given to the manufacturing techniques. The data analysis in Table 9 shows that 50% of the firms investigated in this study extensively considered this feature. The remainder considered this aspect in limited manner when designing new products.

DHCA appeared to be at the top of the league in area of 'designing for production'. The management of this company ensured that there was active participation by the production personnel and as a result a detailed attention was given to the production features. The company's management continually emphasised throughout the project that new product designs must be compatible with existing production facilities and techniques, although there were no written guidelines available to the designer regarding the type of plant and machines and their capacities and capabilities. However this management claims that due to the 'good communication' system amongst various functions in the organisation any formal guidelines for the designers were unnecessary.

The advantages of extensive consideration given to production aspects is further illustrated by PIM - who from the initial conceptual stage were concerned with and aware of the need to ensure that their new product design is compatible with the existing production facilities.

An example of 'limited' consideration given to production facilities and techniques is sounded by FPM where the production department was rarely involved during the design stage. Lack of any written guidelines on the production facilities meant that production features were generally inadequately considered. Similarly in the cases of SPM and SG the production aspects were always considered to be of secondary importance. In SPM the detail design was sub contracted out so it could be argued that no outsider can be totally familar with the details of production facilities and techniques. In SG there were no formal written guidelines available to the designer about the production facilities nor was there any active participation by the production personnel during the design stage. Enquiries revealed that design staff did not even know about the type of machines available let alone about their capabilities or limitations.

Assembly Techniques

Table 9 shows that 50% of the firms extensively considered assembly methods during the design stage and the remainder gave limited consideration to this aspect.

Extensive consideration is again illustrated by the case of DHCA, where the production coordinator was involved throughout the design activity and Methods Engineers (experts in assembly techniques) were actively involved from the pre-production run stage. When this company was compared and contrasted with HA which was in a similar business, it was found that HA did not have Methods or Production Engineers, so this work was performed by the Works Manager who was only involved in limited manner in the project and had little expertise in assembly matters. Similar problems arose in AF.

Production Control

In 35% of the firms investigated, extensive consideration was given to production control during the design stage, whilst 50% gave limited consideration to this feature and in the remainder of the cases no data was available to make an assessment. Most companies were designing products which were, by their nature compatible with existing production control systems, but they still considered this feature during the design stage. An exception was PIM, where existing production control aspects did not suit the new product design and extra attention was required during the course of the design process.

Labour Skills

This includes the personnel who were involved with the subsequent manufacture of the products under design.

Table 9 indicates that only 30% of the firms extensively considered the labour skills during the course of the design stage and the remainder gave limited consideration to this feature.

For example, company PIM was the only one which was diversifying from its present range of products and consciously considered the labour skills currently available and the labour skills required for new products. Similarly MH always was concerned and aware of the need to consider the labour skills. Not only from manufacturing point of view but also from servicing and maintenance angles as well, because a large proportion of its products are hired, which frequently involves servicing and maintainance. This also entails re-training both production and their hire-fleet maintenance personnel.

Existing Products

Table 9 indicates that the majority (55%) of the companies extensively considered existing products when designing new products. The remainder of the firms, with the exception of PIM paid, limited consideration to the existing products.

PIM were considered to be diversifying their product range into kitchenware to complement their existing range of plastic bathware. In this case the degree of attention paid to existing range of products was not applicable.

Of the companies which extensively considered the existing product in the process of designing new products, DHCA is typical example their new range of gas fires were based on the basic concept of existing models. In fact as one would expect this led to a high degree of standardisation. Similarly GM, LTT and SG etc were also considered strong in this area. For instance GM and SG had basic standard products and these were 'modified' to suit the needs of each individual customer.

Standardisation

As can be deduced from Table 9 half the companies gave limited consideration to existing products, the other 50% extensively considered standardisation during the design stage.

The extensive consideration is typically illustrated by DHCA. In this company 45% of the components on GF3 and 41% of the components on GF4 gas fire models are common to the existing range of fires. There are no formal guidelines for the designers to follow vis a vis standardisation during the course of the product design process. The design team attempts to standardise as many components as possible through informal methods. For example during the course of the design process, several meetings are held where components are individually considered and discussed in detail regards various aspects such as standardisation, manufacurability and price.

It was the basic concept of standardisation which PIM were concerned with when the firm eventually decided to adopt a modular design appraoch for their kitchen sink. Similarly standardisation was the central issue in companies like GM, HPE and LA, whereby they had developed systems to ensure optimum numbers of components when designing new products.

Certain of the companies (SG, EE and LTT) although they had developed a basic standard design concept for their products, had failed to take full advantage of standardisation when producing detailed drawings. In these companies there were flaws in the system vis a vis current stock availability of items such as sizes of drills, reamers, milling cutters, nuts and bolts and gauges of sheet metal. Therefore designers frequently, for example, specified hole sizes (SG) and gauge of material without any reference to currently held stocks (EE). In a number of cases, these were specifically purchased in an attempt to manufacture a product as specified on the detailed drawings. These occurances were quite common, unless subsequently picked up by the production personnel (when planning for manufacture) and pointed out to the designer.

Product Cost

The data analysis shows that the majority (55%) of firms adequately considered product cost during the design stage while the remainder gave limited consideration to this aspect.

Certain firms (HA and GM for instance) were strict about this throughout the design process, where the price of the product was borne in mind. At different stages of the project the price was estimated to ensure that the initially agreed price at the product specification stage was maintained. This usually necessitated a detailed and careful selection of the various parts of the product.

On the otherhand some firms were very casual about the product cost, as in the cases of DHCA, FPM and AF. In FPM, for instance, the designer proceeded with the product design aimlessly, for 13 months, when it was realised that product under consideration would cost £380. It was at this stage when the importance of the product cost 'dawned on' everyone. Similarly in AF the product price was never initially agreed upon and it was only when the window was launched and the sales were not as anticipated, that there was any realisation of the importance of the product cost.

Project Duration

This feature was inadequately considered, the data analysis shows that only 20% of the firms investigated in this study realised the importance of time. The remaining 80% only considered project duration in limited manner.

Companies like DHCA, PMT, SPM and LTT were found to be strong on this point. For instance, the management of DHCA specified a target and strictly adhered to this, although there is strong evidence to suggest this lead to substantial additional costs (due to modifications to tools). The launch date of their products essentially determined the project duration because product sales were seasonal. Unless the management had allowed sufficient time for design and development at the planning stage of the project, the designers were constantly put under pressure to ensure that deadlines were met. Company HA for example in a similar business to DHCA, due to a weakness in this area, their product launch dates had to be postponed by 12 months.

The majority of the companies casually 'plodded-along' with their product designs in the absence of strict deadlines as illustrated by the cases of AF, FPM and FCV.

Development Costs

The analysis of the data shown in Table 9 indicates that 35% firms extensively considered development costs during the design stage whilst the remainder paid only limited attention to this cost.

The implication being that 35% of the firms which had estimated the development cost for the project had made allowances in the budget and, continuously monitored these costs while attempting to work within the allocated amounts. The remaining firms did not have strict control on the development process and made funds available for the project as and when necessary.

Some companies such as DHCA, FPM, AF and FCV appeared to be generous with their development costs either intentionally or unintentionally. Due to insufficient available data it is difficult to discern the reasons for this. However it can be posited in the case of DHCA, that management were far more concerned with the project duration than with development costs. As the Technical Director stated the concern was not with exceeding the budgted costs, but with the need to launch the product on time.

In FPM and AF there was lack of strict control on various aspects of the project such as technical content, product cost , project duration and development costs, hence resulting in under-estimation of development costs.

FCV on the otherhand had numerous technical problems (mainly due to lack of technical expertise within the company) which resulted in overspent on budgeted development costs.

4.3.3 Product Design Performance from Production Viewpoint

The product design performance from the production viewpoint (phase 4 in Figure 13) is analysed in this section. This is when the product under considation has progressed through all four phases of the design cycle. Hence the events in phase 3 will be analysed in terms of their impact upon phase 4.

Before proceeding with an assessment of the 'product design performance' it is necessary to clarify the term and the criteria used to measure it. The question as to what determines the level of product design performance from the production point of view escapes strict definition. The area is an extremely complex one because of a vast number of factors which influence product design performance. Some of these are quantifiable but others are not; some are external to the firm while others are internal and to some extent managerial. It is the internal factors which are the primary concern of this study.

It can be argued that it is unreasonable to isolate internal factors from external ones because of the extent to which they are interdependent. Whilst investigating the effectiveness of the design process from this point of view, it is assumed that an adequate marketing input exists in the product specification, which should give clear and concise guidelines to the design function. The focus is on the internal design process, external factors are minimised. Under these circumstances the following factors are used as a means of assessing the product design performance from the production point of view. They are:

- manufacturing techniques including production and assembly
- degree of standardisation carried out
- number of modifications
- project duration
- product cost
- achievement of technical performance.

The degree of association between the following variables will be examined in this section.

(i) The relationship between the extent of production involvement in the design process, and the degree of consideration given to the product design parameters.

(ii) The influence of the extent of production involvement on the product design performance from production point of view.

(iii) Degree of consideration given to product design paramaters on the product design performance from a production point of view.

4.3.3.1 The relationship between the extent of production involvement in the Design Process and the Degree of consideration given to the Product Design parameters

In this section the analysis will attempt to establish whether there is a significant association between the extent to which a production function participates in the design process and the degree to which product design parameters are considered. It is basically a critical comparison between the factors analysed in Table 8 and 9 and an attempt to establish whether any kind of relationship exists between them.

If the production involvement in the design process is considered, as in Table 8, it can be seen that effectively there are 'three' functions which are related to production, namely, production engineers, methods engineers and production management. As discussed earlier some firms do not employ specialist production engineers or methods engineers and in these cases input with regard to production came from production management staff. The term production or production specialists encompasses production engineering and methods engineers and/or production management or both.

When the product design parameters (Table 9), are considered it can be seen that for parameters such as industrial design, technical content and development costs, production had insignificant influence. This can be attributed to the fact that these were outside the usual experience of production specialists, due to their background, training and the fact that expertise in these areas came from other sources. It can argued that the degree of contribution made by production to these paramaters depends on each individual case or person, the type of problem at hand and the competence of the production personnel. In this study production personnel were not found to be specialists in these areas and as a result had an insignificant input in product design paramaters.

The remainder of this section is devoted to examining the relationships between the extent of production involvement and assembly techniques, production facilities/techniques, production control, labour skills, existing products, product cost and project duration.

The relationship between extent of production involvement and the degree of consideration given to assembly and production techniques

When considering the assembly techniques, there is insufficient evidence to suggest a correlation between the extent of involvement by the methods engineers and the degree of consideration given to assembly techniques; the majority of the companies did not have specialist methods engineers. However when considering production management personnel, the data indicates that there is a strong likelihood of a relationship. The data suggests that adequate awareness existed amongst designers and production personnel to enable them to extensively consider assembly techniques during the design stage. On the otherhand, it is important to remember that this does not mean that assembly techniques as a whole were extensively considered because the data indicates that only 50% of the companies were under this category.

Similarly there also appears to be an association between the limited involvement of production specialists and limited consideration given to assembly techniques during the design process. It is difficult to predict whether this type of approach was intentional or unintentional, but in some cases (HA, FPM and AF) it is reasonable to deduce that there was a lack of appreciation, knowledge and relevant technical expertise when considering assembly techniques.

Considering the extent of production involvement and the degree of consideration given to production techniques, Table 8 and 9, there appears to be an association between them. As would be expected, the greater the participation by production personnel in the design process, the greater was the degree of consideration given to production facilities and techniques.

However in certain cases there is no correlation, for example, GR, MBC, HPE, LA and LTT. These cases were considered to be exceptional. In GR the functional aspect was of primary importance and the designer knew that new production facilities would not be required so production only needed to be involved during the handover stage. MBC was mainly involved with the design and assembly of components and the majority of their parts were bought from outside.

Other companies (HPE and LA) had well established standard products and they mainly produced scaled-up or scaled-down versions of these standard models. Thus detailed attention to production facilities and techniques was not needed. Finally in the case of LTT, production management was generally involved in major design problems but relatively minor details were left to the discretion of the designers.

The relationship between extent of production involvement and the degree of consideration given to production control and labour skills

In general production control and labour skills did not warrant detailed attention because the products under design by all the firms, except for PIM, were compatible with their existing range. PIM considered these aspects throughout the design process and the operators were re-trained and production control adjusted accordingly. This however does not mean that production control was not revised and updated. In some (WA, MH, LTT and GR) companies significant changes were taking place due to introduction of micro-computers. These were mainly due to efficiency improvement in general, rather than the design of new products.

The relationship between the extent of production involvement and the degree of consideration given to existing products and standardisation

When considering existing products, there are indications there is a direct correlation in all the cases, except PIM, where production was extensively involved throughout the design process this resulted in extensive attention being given to existing products. Hence leading to a high degree of standardisation of components. Similarly if production participated in limited manner in the project this usually lead to poor attention being paid to existing products and standardisation.

Of course, there are certain exceptions (HPE, LA, SG and WA) to these generalisations. HPE and LA as mentioned earlier had developed standard products and in these companies production did not participate actively.

In SG and WA, although their basic concept was standard the only variation was in the application, hence each detailed product design had to be engineered specifically to meet the individual customer needs. One can argue here that although extensive consideration was given to the existing products, this necessarily did not lead to high degree of standardisation.

The relationship between the extent of production involvement and the degree of consideration given to product cost and project duration

From the data, there appears to be a lack of significant correlation between these variables. It is arguable that these factors are primarily of interest to project management, because it is they who usually specify these parameters when compiling product specifications. Project management plays a far more important and significant role in controlling these variables than any other functions in the organisation, as clearly illustrated by DHCA, GM and LTT.

On the otherhand, considering project duration, the greater the production involvement, the greater the time it would take to reach a final decision with regard to detailed product design. This is because production normally tried to ensure that it was right before committing itself - requiring a greater lead time. Where production is only involved in limited manner and drawings are not handed over to production for detailed appraisal or plan for manufacture - delay might be caused because the drawings may require amendment later after the hand-over stage. The drawings would have to be returned to the designer and it is possible this would take longer than if production were involved at the drawing board stage. Hence management has to decide at what stage to involve production and its subsequent affect on the project duration.

4.3.3.2 and 4.3.3.3 The influence of the extent of Production involvement and the degree of consideration given to Product Design parameters ON the Product Design peformance from production point of view

It was found extremely difficult to measure individually the influence of the extent of production involvement and the degree of consideration given to product design parameters on the product design performance from the production point of view. This is because it is the combined effect of these two variables which influences the product design performance and these two variables are interwoven. It is therefore extremely difficult to separate them. Hence the data relating to these variables is analysed and discussed collectively.

An analysis of the data (Table 10) has been attempted using a classification consisting of the following levels of the product design performance.

For the paramaters production facilities/techniques assembly techniques, project duration and product cost three levels of classification have been used, namely

++ = when the original plan or intention has been completely fulfilled without any significant problems.

\+ = when the original plan or intention has been partly fulfilled.

u = when the product design process has not yet been completed and therefore no

COMPANY CODE	PRODUCTION TECHNIQUES	ASSEMBLY TECHNIQUES	DEGREE OF STANDARD--ISATION	DEGREE OF MODIFIC--ATION	PROJECT DURATION	PRODUCT COST
HA	U	U	U	U	U	U
WF	++	++	H	L	+	++
DHCA	+	+	H	H	++	+
FPM	+	+	L	H	+	+
MH	+	+	A	A	+	+
GR	+	+	Not Applicable	A	+	+
PIM	+	+	"	A	+	U
PMT	+	+	A	A	+	++
GM	++	++	H	L	++	++
AF	+	+	L	H	+	+
SPM	+	+	L	H	+	+
FCV	+	+	L	H	+	+
EE	+	+	L	H	+	+
MBC	+	+	H	A	+	+
HPE	++	++	H	L	++	++
LTT	+	+	A	A	+	+
APR	+	+	H	A	+	++
LA	++	++	H	L	++	++
SG	+	+	A	H	+	+
WA	+	+	A	H	+	+

++ = when the original plan or intention has been completely fulfilled without any significant problems.

\+ = when the original plan or intention has been partly fulfilled.

U = when the product design process has not yet been completed and therefore no analysis was attempted.

H = High
A = Average
L = Low

Table 10: Product Design Performance from Production Point of View

analysis was attempted.

For the paramaters, the degree of standardisation and the degree of modifications carried out during the course of the product design process, four levels of classification have been used; they are

H = High

A = Average

L = Low

U = Unknown when the product design process has not been completed yet and therefore no analysis was attempted.

Manufacturing facilities and techniques

This includes both production and assembly facilities and techniques.

The analysis of the data is shown in Table 10.

First, companies which completely fulfilled their plans or intentions (which were either devised at the product specification stage or during the course of the design stage) are considered. The data shows that these companies carefully examined the details of the customer requirements before they accepted an order to manufacture a product. In addition these firms were found to be fully conversant with their internal stengths and weaknesses of the shop-floor facilities and manufacturing techniques. This situation was further strengthened because these firms maintained a two-way communications with customers. It is however, arguable that their products were usually familiar types (WF, GM, HPE and LA), based on a basic design concept with just some minor variation. Thus providing, the upper and lower limits of the manufacturing capability are known, it was difficult to make an error. Nevertheless in GM, a large amount of design work was undertaken to adapt one of the standard gearboxes to the hedgetrimmer tractor. This necessitated careful and detailed attention to the manufacturing techniques, as some new tools were required. Here the designer took the initiative by involving the production engineer during the early stages of the design process thus ensuring adequate attention was given to manufacturing techniques.

Companies who only partly fulfilled their original plan or intention - accounted for the majority (75%) of the firms. It was difficult to determine the factors which were common to all the firms for a number of reasons, such as, type of business, size of the company in terms of number of employees, type of technical and managerial staff and their competence levels and complexity of the product. However, there are a number of discernable reasons as to why these firms did not achieve their plans or intentions with regard to manufacturing facilities and techniques. It was found that some of these firms (HA, EE, MBC and LTT) did not have specialist production engineers or assembly engineers and that this role was inadequately performed by member of production management who were not professionally trained in manufacturing techniques. Also, these management personnel had usually to deal with other managerial duties and as a result, they rarely gave detailed attention to the product under consideration. This combined with the fact that some designers (especially in HA, EE, AF, SPM and FCV), lacked appreciation of the importance of manufacturing techniques, did not assist the product design performance.

There is sufficient evidence to suggest that designers in general failed to take the initiative to involve production functions at an early stage of the design process. There appeared to be one way communication from the design to production in the form of instructions or command. Hence production was often only involved at the hand over stage. Frequently this led to conflict (AF, FPM, EE and SG) and usually resulted in a high degree of modifications when the product was at the manufacturing stage. In fact there was a universal lack of appreciation of the importance of production amongst designers and design managers, as well as a lack of project management expertise. It is arguable that it is a project management responsibility to ensure that adequate consideration is given to all the product design paramaters such as production, marketing and costs. If for example there is a lack of relevant expertise in-house (for example the lack of methods engineers in HA, FPM, AF, EE and LTT) then the designer is left in an impossible situation and it is up to management to make provision for these deficiencies.

On the otherhand the companies who did have relevant manufacturing specialists (SG and WA) sometimes failed to utilise them extensively, so once again management has to ensure that designers are made aware of the need to consult the relevant production specialists as and when necessary during the design process and not to leave problems until the hand-over stage. It was evident in the study that when drawings were formally handed-over, there was usually insufficient time for production specialists to give detailed attention to each component to achieve economic manufacturability (SG, WA, FPM and AF).

Furthermore, there were some firms whose products were technically complex (SPM, LTT, SG and WA) and in order to satisfy their customers, they tended to 'over-design'. These firms frequently over-looked production techniques and facilities and always tended to design products which were technically superior to their competitors. It is debatable whether firms can either maintain or increase their existing market share by producing technically excellent products or by offering the customer a product of an 'acceptable performance level' combined with lower cost. It however appears that these firms were inclined to continue to improve the technical performance of their products as opposed to reducing manufacturing costs.

Degree of Standardisation

Discussion in this section is based on the degree of standardisation which was carried out during the course of the product design process as a result of the extent of production involvement and due to the degree of consideration given to the product design parameters.

The analysis of the data in Table 10 shows that there was a considerable variation in the degree of standardisation which was carried out, 35% of the firms carried out high degree of standardisation, 25% were in the average category and the remaining 40% were in the lowest category.

If the companies under the high standardisation classification are considered. A variety of reasons can be given as to why these firms were able to carry out a high degree of standarisation. Some firms, as mentioned earlier, had developed basic standard products (WF, GM, HPE, and LA) the only variation being in the application of their products. Very rarely were they asked to design 'specials', in fact, in the majority of the cases they could modify and adapt their existing range of products to meet the customers needs. Thus standardisation was always at the top of their list.

Other firms (DHCA and APR) for instance were also able to achieve a high degree of standardisation. For their range of products, many functional parts remained unaltered and they simply carried out 'cosmetic surgery' to their products in order to offer updated versions regularly. These were relatively minor changes because they had developed standard functional parts of wide applicability. As a result a high degree of standardisation was achieved. But in addition they carefully looked at each component in detail from a standardisation point of view during the design process. This was done by holding regular meetings as well as through constant informal dialogue amongst various functions in the organisation. This was reinforced by management continually advocating, the advantages of standardisation. In one small family business (BMC) the product range was so limited, that the Managing Director (Designer) had such thorough knowledge of the existing range of products that he was able to push for a very high degree of standardisation.

For firms within the average classification, there were a variety of reasons why they were not able to carry out a high degree of standardisation. All the firms in this category, with the exception of PMT, had developed a standard basic product which included the main functional components. But they failed to adopt a similar approach to other components, due to attempts to take full advantage of equipment already available (such as drills, reamers, milling cutters, jigs and fixtures). Sometimes this was due to an absence of specialist manufacturing personnel (LTT), in other cases it was due to lack of active involvement by these specialists during the design process (SG and WA). Also these firms were engaged in producing technically complex products and designers engrossed themselves in an attempt to improve the functional performance and quality and to a large extent disregarded the advantages to be gained through standardisation. In these firms although some fairly detailed formalised procedures existed, (for example computerised information on current stock availability), management failure to enforce standardisation resulted in poor performance in this respect.

Finally, firms in the low degree of standardisation category, (with the exception of SPM) were generally very weak in project management expertise. Either they did not have (FCV and EE) anyone in charge of product design or if they did (FPM and AF) these were ill-equipped to manage effectively. Typically there was a lack of competent design and production personnel as well as an absence of any formalised standardisation proceedure. Thus these firms were unable to appreciate the importance of standardisation, reflected in company policies in this area which were very vague and unclearly defined, especially in FPM, AF, EE, FCV and SPM.

Degree of Modifications

This section discusses the relationship between the extent of involvement by production and the degree of consideration given to product design parameters with the degree of modification carried to the product design. The analysis of the data in Table 10 indicates that there exists a large variation. For instance 40% of the firms carried out a high degree of modifications, whilst 35% were considered to be average and the remainder, with the exception of HA, were in the low category.

The high degree of modifications are considered here with an analysis of the reasons as to why these companies were placed in this category. The data reveals that there were a number of reasons, for instance in some firms (DHCA, FPM, AF and FCV) the product specification was very unclearly constructed, hence the marketing needs as well as other product design paramaters were inadequately defined or considered. This together with poor communication between designer and marketing functions did not assist the situation. Also the fact that in some firms (FPM, AF, FCV and EE) there was a lack of project management expertise and a lack of clearly defined product design policy, designers tended to go around in circles. There was also evidence of an 'enforcement of personal opinions and feelings' during the course of the design process, which meant numerous changes resulted as the project progressed. These opinions or feelings were not always supported by any type of factual data, which usually lead to conflicts and a clash of personalities. These firms usually failed to clearly and precisely analyse and define the problem at hand and frequently embarked upon new product designs without realising the full implications of the work involved. Furthermore, these firms did not appraise their internal weaknesses and strengths with regard to technical competence and expertise available in order that contingency plans could be made, if problems arose. There is sufficient evidence to indicate that these firms undertook new product designs without carrying out adequate planning.

All the firms in this category considered production techniques adequately but in some, major problems existed in the area of assembly methods (AF and EE). Here, neither the design nor the production personnel were fully conversant with assembly techniques. Design departments produced engineering drawings when 3D isometric drawings may have been more appropriate. Thus during assembly numerous problems arose. The designers, due to their lack of experience and knowledge, failed to pay adequate attention to this area. Also the lack of production involvement and an appreciation of their problems during subsequent assembly operations did not assist the situation.

In a number of companies (FPM, AF, EE, SG and WA) design departments considered themselves to be superior and well equipped with regard to production expertise; they did not consider it necessary to involve production during the design process. Perhaps this was not solely due to the attitude of the designers but also of the design managers, communication at this stage was usually in one direction, ie from design to production in the form of commands or instructions. Production was formally involved after the drawings were handed-over to them to commence preparations for the manufacture.

Thus resulting in a large number of modifications when the drawings were appraised from the economic manufacturing point of view.

There is an indication that if a firm is operating to a very tight schedule with regard to product launch date (designing and developing as well as simultaneously, preparing for manufacturing operations) a high degree of modifications can result (DHCA).

Another important factor which can lead to a high degree of modification is when the detail work is done outside the firm (SPM). This may be because outside contractors are not fully conversant with the company's manufacturing facilities or becausee of lack of active production involvement coupled with communication problems.

Of the companies who carried out an average degree of modification, the main feature common to all, was the fact that they had good project management expertise and clearly defined product design policies. These firms in general were considered to have good systems of communication and liaison among the various functions of the organisation during the course of the design process.

All the firms, although good at carrying out initial feasibility studies and appraising their own strengths and weaknesses failed to achieve a low degree of modifications for different reasons. For instance due to a lack of existence of production specialists (PIM, PMT, MBC and LTT). Others (MH, GR, PIM and APR) were keen to satisfy the market needs and hence changes were necessary in order to ensure that the marketing requirements were adequately considered. Similarly the sheer pressure of time as well as the handling of a number of projects simultaneoulsy (LTT) also led to higher than expected modifications.

For the firms in the low degree of modification category, it was usually found that they had clearly developed standard product designs and the only variation was in the new application of the product. Hence before accepting an order they knew precisely the product design parameters and other customer needs could 'modify' existing standard products. This combined with the fact that people in these firms were good at communicating their ideas with each other, usually led to a significantly low number of modifications during the design process.

Project Duration

In this section an analysis and discussion of the influence of the extent of production involvement and the degree of consideration given to product design paramaters on the project duration will be undertaken. It can be seen from the data analysis carried out in Table 10, that 25% of the firms completed the project in the planned intended time allowed for its completion, whilst the remainder only partly fulfilled this criteria.

Of the firms who completed the project at the anticipated or planned time, it is difficult to find features which are common to all of them. However in firms, WF, GM, HPE and LA, their delivery dates were strictly controlled by the customer, whereas in DHCA the launch date was determined by the winter season. Hence they were all working to strict deadlines it was imperative that projects were completed on time. For some there was the fear of penalty clauses due to contractual agreements whilst for others, 'fear of being beaten to the market' by a competitor was the motivating force. Managerial control played an essential and critical role in achieving these deadlines.

In some firms (GM and DHCA) active participation by production during the design stage was encouraged through an emphasis of the team work approach as well as good communication amongst various functions in the organisation. It can be seen, however, that in order to keep within these strict time deadlines a high degree of modification to various components sometimes resulted (DHCA). Here the management argued that additional costs incurred due to the modifications could be easily recovered through extra sales revenue generated by launching the product on time.

In other firms such as WF, HPE and LA, emphasis on the development of standard products assisted in the achievement of project delivery dates.

Firms who partly succeeded in meeting the anticipated or planned dates for a project, as mentioned earlier, accounted for the majority of the cases. The most important weaknesses in this area were to non-comprehensive product specifications and poor managerial control. Without strict deadlines in the product specification, then in the majority of cases (FPM, GR, PIM, AF, FCV and EE) it was seen that the project would 'plod-along' unless management had strict control of the project (DHCA). Otherwise the project was conrolled by the designers (AF, GR, FCV, SG and WA) who made 'marginal improvements' with little regard for the time constraints.

In a number of cases the technical content of the product was perhaps too vaguely defined (FPM, AF and FCV) which lead to confusion, personality clashes and generally greater than anticipated duration. Added to this was a lack of relevant in-house technical expertise which did not improve the situation.

Project Duration was further prolonged if, for example, the detail design work was done outside (SPM). This led to problems of control, communication and difficulties during subsequent modifications when production was planning for manufacture. The problem of poor liaison was quite common, even amongst the firms who had design and production personnel on single site (SG, WA, FPM, AF and EE).

Furthermore if the product design parameters are not clearly defined at the start of the design process, it can be argued that the greater the involvement by different functions the greater the likelihood of differing opinions (FPM and PIM) the longer will be the project duration. So this approach can either hinder (FPM) due to frequent changes (of mind) or assist due to the team-work approach (DHCA).

Product Cost

In this section an attempt is made to analyse the influence of the extent of production involvement and the degree of consideration given to the product design paramaters on the product cost. The data analysis in Table 10 shows that 30% of the firms were within the planned or anticipated price of the product whilst the remainder, with the exception of (HA), only partly fulfilled this criteria.

As one would expect that the product cost needs to be laid down in the initial product specification so that the designers can work within these guidelines. In fact all the firms who achieved their product cost did this (with the exception of WF, PMT, GM, HPE and LA). Their costs were initially agreed with the customer and attempts were made to work within the agreed parameters. However in the case of APR the market was very competitive and an emphasis was placed on a teamwork approach in order to reduce costs where possible. As a result the design derpartment in conjunction with production personnel carefully examined each component to cut costs. This is one reason why management placed emphasis on standardisation.

Of the firms who fulfilled their planned or intended product cost - the data shows these accounted for the majority of the cases.

First, the most common yet very important fault, was the fact that some firms (DHCA, FPM, GR and AF) did not specify product cost in the initial stages of the project. This lead to a considerable amount of misdirected effort by all those involved in the design process. This point was especially highlighted by (FPM) and (AF). In FPM some 13 months elapsed before any figure was specified, even then, this was based on 'guess-work' rather than on any kind of market research data. Similarly in AF the importance of product cost was not realised until the product was launched and the sales did not reach the anticipated levels.

Another important aspect common amongst a number of firms (MH, SPM, LTT, SG and WA) was the complexity of the products. Their products were sophisticated in design and it was difficult for them to strictly adhere to the initial product cost because of unexpected events, and a high degree of modifications (SPM, SG and WA). In others this was due to prolonged field trial tests which resulted in the need to change technical features of the product (MH and BMC).

Another reason why these firms did not achieve the intially perceived costs was that a high degree of modifications (DHCA and EE) sometimes had to be completed within very strict time schedules. There is also evidence to show a lack of in-house technical expertise which resulted in a failure to achieve desired functional requirements (FCV).

CHAPTER 5

CONCLUSIONS

5.1 Introduction

The aim of this study has been to investigate the nature of the working relationship between design and production functions in manufacturing firms. The basic assumption upon which the research has been developed is that the nature of the working relationship directly influences the product design performance. In order to examine this assumption some specific operational hypothesis were developed (see Chapter Three). The findings of this study, in this chapter, are related to these hypotheses, which in summary are:-

Hypothesis

1 The greater the degree of involvement by different functions the more comprehensive is the product specification.

2 The greater the comprehensiveness of the product specification, the better is the product outcome.

3 The greater the degree of involvement by different functions in preparing the product specification, the better is the product outcome.

4 The greater the degree of production involvement in the design process, the better is the product design performance from a production point of view.

5 The greater the degree of production involvement in the design process, the greater is the degree of consideration given to product design parameters.

6 The greater the degree of consideration given to product design parameters, the better is the product design performance from production point of view.

In order to present these findings clearly, this chapter is divided into two parts:

Part One deals with the operational hypotheses related to the factors affecting the preparation of the product specification and the influences of these factors on the product outcome. These factors and the criteria used to measure product outcome are shown in Figure 11.

In part two the operational hypotheses related to the factors affecting the design stage and the influences of these factors on the product design performance from the production point of view will be examined. Figure 12 shows these factors and the criteria used for the assessment of the product design performance from production point of view.

5.2 Part I

The factors affecting the preparation of the product specification and the influences of these factors on the product outcome.

In this section the operational hypotheses related to the preparation of the product specification are examined in relation to the findings of this research programme (and with the other studies in Chapter Two).

Hypothesis 1: the greater the degree of involvement by different functions, the more comprehensive is the product specification

There was insufficient evidence in the literature as to who should be (or is) involved in the product specification, the extent of their involvement and at what stage. Much of the literature emphasises the importance of a multi-disciplinary input when preparing specifications but fails to provide any indication of the effect of this on the comprehensiveness of the product specification. Any contribution in this area is an exception rather than a rule. These earlier studies only provide tentative guidelines and require further research to substantiate their claims. The findings of this study will form a context for further research into this under investigated area.

This study has demonstrated that there is relative absence of financial specialists, production engineers, buyers, estimators and, perhaps more remarkably, designers in the process of preparing a product specification. The findings support the argument that involvement of the designers in the product specification tends to be on a limited basis. Yet the literature emphasises the importance of the extensive involvement of the designers at this critical stage. For example, Burns and Stalker [(42)] have shown that in successful firms the designers were even involved in carrying out market research prior to compiling the product specification.

The findings also indicate that marketing and sales personnel were only extensively involved in a minority of the cases. The major contributors to the product specification were the design managers and other senior managers such as production, finance and general managers. The data also shows that the comprehensiveness of the product specification can be significantly important in determining the final product outcome. However the need to give adequate consideration to the comprehensiveness of the specification was frequently overlooked. Factors like market needs, project duration, product costs, development costs and technical features of the product were commonly inadequately considered. There is evidence of continual imposition of individual (usually managers) perceptions, feelings, opinions and intuition usually not supported by any empirical evidence.

For example with regard to the degree of consideration given to the market or customer needs, this has frequently been referred to as the most common reason for failure of the new product designs.[19, 24, 28, 40] The results of this study indicate that a number of firms continue to embark on design projects without adequate consideration being given to the market features in the product specification. Lock [45] points out some of the drawbacks of this practice. The marketing needs were usually based on individual (usually management) feelings, perception, notion and intuition and opinions. In contrast to this, however, some companies extensively considered the customers requirements but this practice was quite uncommon and rare. In these cases the firms were very much market orientated. In general, customers requirements were sufficiently considered only when a firm was designing products for customers specific orders.

Similarly factors like product cost , project duration and development costs were vaguely defined. These were frequently left to the discretion of the designers without any specific guidance or instructions. The study shows that projects usually 'plodded-along' aimlessly without any kind of monitoring or control. This often led to greater than the anticipated (not planned) project duration as well as causing the anticipated budgets to exceed the desired limits. This as the literature points out [107] is often the cause for new product design failures.

The product cost of the product was only specified in the product specification when designing products to customers orders. Otherwise some firms simply stated that the value engineering concept would be employed during the course of the design process to keep costs to the minimum, or value analysis techniques would be used prior to commencement of production in an attempt to reduce the product costs. However the study provides sufficient evidence that no such exercises were actively encouraged or adopted by these firms.

Furthermore, it is an accepted fact that the technical content of the product has utmost priority during the preparation of the specification (44, 46, 93, 94, 95, 96) and it has been argued that this is the exclusive responsibility of the designers or the design managers. [8] This point of view holds true in the "technically complex" products when technical personnel extensively contribute to the specification. This is because as this research indicates that these firms employ engineers and designers who are relatively (to the firms whose products were not classified as technically complex) more experienced, highly qualified and given a significantly higher status. Thus these engineers, designers and their heads of departments ensure that extensive consideration is given to the technical features of the product. In firms whose products were not considered to be technically complex, the technical features were vaguely considered and usually left to the discretion of the designers to develop during subsequent design and development process. This as the data shows lead to a number of problems.

Finally the degree of consideration given to the production facilities during the product specification stage, was found to be difficult to judge as the majority of the firms were designing new products which were compatible with the existing production facilities. However, there were a few exceptional cases, in these the data shows sufficient attention was given to production facilities at the product specification stage, where the basic design concept changed due to the restrictions imposed by the existing production facilities. The study shows the impact on production facilities of the involvement of senior production managers. This argument is also applicable to the degree of consideration given to the existing available labour skills. The data shows that in these firms re-training of operatives was considered and carried out when appropriate.

The firms whose product specification was prepared either verbally or in written manner were found to have fewer problems during the subsequent design and development process than those whose specification was prepared partly verbally and partly in writing. However this did not mean that these firms were successful in their sales performance. There is insufficient evidence to identify a relationship between the format of the specification and the sales performance.

Where specifications were written and had comprehensively laid down parameters such as technical content, product cost , project duration and development cost, these were widely circulated throughout the company. Also the fact that these firms usually embarked on a project after the receipt of a firm order tended to lead to a satisfactory execution of design and development activities.

The firms which had verbal specifications were often found to be very strong on inter-personal and inter-departmental communication and co-ordination greatly assiting successful design work.

When product specifications were partly written and partly verbal, the firms were found to have a significantly higher number of problems during the subsequent design and development process. This was mainly due to the number of unspecified and vaguely defined parameters such as project duration, details of technical content, product costs and development costs.

Hypothesis 2: **The greater the comprehensiveness of the product specification, the better is the product outcome.**

Hypothesis 3: **The greater the degree of involvement by different functions in preparing the product specification, the better is the product outcome.**

Finally, the operational hypotheses related to the product outcome are dealt with. It was found difficult to assess the relationship between the extent of involvement, comprehensiveness and format of of the specification with the product outcome on an individual basis (the reasons for this are described in the analysis and discussion in Chapter Four). Thus the influence of these three factors (extent of involvement, comprehensiveness and format of the product specification) on the product outcome is measured collectively. Three levels are used (see Chapter Four for details of measurement criteria) to assess the performance.

There is no evidence in the existing studies on the relationship between the method of product specification compilation and the product outcome. The findings of this study cannot be compared with an existing body of knowledge.

Extent of involvement, comprehensiveness of the specification, and the format of the specification	versus	Design and development performance.

There are several factors which determine the type of product performance. The study has shown that the factors which resulted in good and poor performance of the design and development activity were as follows:

<u>Good performance</u> was due to

- good internal communication
- good coordination of internal activities
- good managerial control of the project
- extensive consideration given to production facilities
- extensive consideration given to technical features of the product
- written or verbal format of product specification.

<u>Poor performance</u> was due to

- poor internal communication
- poor consideration given to project duration
- inadequate consideration given to product cost
- inadequate consideration given to technical features of a product
- inadequate consideration given to technical expertise (in-house)
- inadequate consideration given to existing production facilities
- lack of in-house project management expertise
- inadequate project planning
- inadequate project control
- general existence of conflict, confusion and ill-feelings amongst employees
- partly written and partly verbal product specification
- lack of appraisal by the firm of its in-house strengths and with regard to technical expertise.

Extent of involvement, comprehensiveness of product specification and format of product specification	Vs	Sales performance

The factors which were found to relate to good and poor performance of the sales performance were:

Good performance was due to:

- clearly defined and obtained customer needs (through extensive involvement of customer, and sales/marketing functions).
- comprehensively prepared product specifications.
- product specifications prepared in written manner.

Poor performance was due to:

- lack of definition and determination of customer needs
- lack of involvement by customer and sales/marketing functions
- non-comprehensive product specification.

5.3 Part II

The factors affecting the product design stage and influence of these factors on the product design performance from the production point of view

In this section the operational hypotheses related to the product design stage are examined and the findings of this research and other studies (Chapter 2) are also considered. It is a comparison between the variables listed in Figure 12 and other studies (Chapter 2).

Hypothesis 4: **The greater the degree of production involvement in the design process, the greater is the degree of consideration given to product design parameters.**

In order to test this hypothesis, ideally, one needs to consider production related functions (such as production engineering and production management) and examine in terms of the degree of consideration given to each product design parameter. In practice, it is difficult, if not impossible, due to the combined effect of these functions (as discussed in Chapter 4) which affects the degree of consideration given to product design parameters. Due to this difficulty, detailed association between the extent of production involvement and the degree of consideration given to product design parameter is not attempted. However an attempt is made to draw some general conclusions.

Before attempting to do this, it is necessary to comment briefly on the current industrial practice regards the degree of contribution made by production personnel during the design process. Also it is necessary to clarify the meaning of the general term 'production'. Production is intended to mean the engineering staff related to a manufacturing department and the production management who control the production activities(such as production managers, supervisors and superintendents).

The study shows that there were three levels of involvement namely extensive, limited and non-involvement.

This research points to a number of features related to extensive involvement. There was the existence of a strong two way internal communication between design and production during the design process. This was usually brought about by senior management co-ordinating these two activities by means of regular formal meetings and by encouraging informal dialogue amongst the design and production personnel. There is evidence that members of both design and production departments were prepared to debate, and discuss in detail, product design at the drawing board stage. Also the members of these functions were continually 'testing and stretching' each other to the limit and final agreements usually took place as a result of 'hard-bargaining'. However this was done in a professional manner without undermining opposing functions ability or knowledge. So that during this course personal differences , conflict and ill-feelings were clearly avoided. During this process the management played a key role in managing the interface. This type of situation was apparent in the companies who had production engineering specialists.

Furthermore, in this extensive involvement classification, there was another category - that is when the firms in this study, did not have production engineering specialists and this input came from production management. In these firms extensive production management involvement existed during the basic design concept but not during the detail design process. This type of involvement however, did not necessarily lead to economic product design. The reasons for this were:

- lack of time on the production management side who were unable to devote sufficient attention to detailed product design.

- lack of appreciation by the production management of production engineering principles due to their background, training and experience.

- absence of two-way channels of communication during the detail design process. There was usually the existence of one-way communication, from design to production.

Considering features related to the limited involvement by production in these firms there was an existence of one-way communication in the form of instructions or command, ie information flow from design to production with little feed-back. If there was any feed-back it did not significantly influence the product design. Changes to the product design usually occured after the drawings were formally handed-over to the production department rather than during the design process.

In terms of the features related to non-involvement of production personnel during the design stage there is a strong evidence that they were only involved at the hand-over stage. The production department was usually unaware of the design activities and given insufficient time to design jigs and fixtures and plan for manufacture. Also under this classification were the firms whose products were considered to be technically complex. In these firms the functional design tended to over-shadow the 'economical manufacture' concept. As a result production input came after the drawings were formally handed over to them.

The findings of this research also indicates the absence of a general awareness and of a lack of appreciation by the firms in terms of the need for the assembly specialists' input to the product design process. Firstly the existence of these types of specialists was uncommon and even rare. Secondly, on the otherhand the firms which did employ these specialists did not utilise them to the full during the design process. In general, however, assembly experts did not exist, yet the majority of the problems were related to assembly techniques. Other studies point out the importance of an input by assembly experts. [141]

Input from other functions such as marketing, finance and servicing were absent during the design process, while estimating and buying departments were used as a 'service' to the design department.

In considering the <u>relationship between the extent of production involvement and the degree of consideration given to the product design parameters</u>. It was found that the degree of consideration given to industrial design and technical content was not related to the extent of production involvement but that it was associated with the type of staff available within the design department. There was a general absence of appreciation and awareness of the characteristics related to the aesthetics, and ergonomics of product design. Only a minority of the firms intentionally considered these features while in the remaining companies this type of input was absent. Usually the firms did not employ specialist industrial designers but a number of firms utilised the services of consultant industrial designers. The others attempted to consider aesthetic features by trial and error methods.

Similarly the degree of consideration given to technical content was dependent upon the nature of the product, the calibre of designers/engineers and the comprehensiveness of the product specification. The firms with technically complex products usually employed highly qualified and experienced designers. These firms tended to 'over-design' their products and frequently economic product manufacture was sacrificed in the drive to achieve technical perfection. There were a number of reasons for this:

- orders were usually won due to technically superior products
- designers in these firms were significantly of higher status in relation to production
- lack of importance attached to economic product manufacture by designers and by management
- production facilities and techniques devised after product had been designed
- product specification comprehensively prepared with regard to technical content but not with regard to production.

In the other firms if the technical parameters were extensively considered this was due to good management control systems and the existence of good communication channels between management and the design department. In these cases the firms were attempting to achieve the desired product design in an informal manner. The majority of them failing due to imprecise product specification via a vis the required technical features. This usually resulted in several detours before finalising the technical characteristics of the product.

There were also a number of other features present for example:

- lack of thorough understanding of what was required from the product
- lack of clear guidelines in the product specification
- poor communication
- poor coordination of internal activities
- existence of friction, conflict and confusion between management, design and production.
- lack of in-house technical expertise
- unclear or non-comprehensive product specification relating to technical details.

The production facilities and assembly techniques and their association with the extent of production involvement were next considered. There is evidence of a direct correlation. This does not imply that production personnel were always extensively involved throughout the design process - in fact this situation existed only in the minority of the cases. If production was involved extensively it was due to the top management's initative in the form of coordinating both design and production activities during the design process. If management failed to coordinate these activities then inadequate consideration was given to production facilities and assembly techniques. There is sufficient evidence to support the argument if the that production function is actively involved then the basic design concept changes significantly. Also this study shows that there was a general lack of awareness and/or absence of knowledge amongst designers regards availability of in-house production facilities. When detail design work was sub-contracted out, production features were frequently inadequately considered.

Assembly techniques in general were neglected during the design process and there appeared to be a general absence of knowledge and/or lack of appreciation of the importance of assembly features in the product design. With few exceptions, assembly specialists did not exist in the firms; those which did employ assembly experts, failed to utilise them extensively. In the remainder of the firms, input in terms of assembly methods came from production managers who were usually ill-equipped (because of expertise, training, experience, background etc) to significantly assist in the design process.

The majority of firms were found to be designing products which were compatible with the existing production facilities control systems and labour skills, so these did not neccesitate detailed attention during the design process. A small number of firms whose products were not compatible, the data shows that they, did give sufficient attention to these features.

Standardisation of components used in new designs was usually left to the discretion of the designer - this was in the absence of formalised procedures or guidelines. There is strong evidence to suggest that adequate standardisation was carried out on the basic design concept but this approach or philosophy was not always adopted during the subsequent detail designs. This was particularly true when production was involved in limited manner in the design process.

When considering product cost, development costs and project duration, the study shows these were usually not planned prior to embarking on the project. There is sufficient evidence to suggest a lack of appreciation and/or lack of knowledge regards the importance of these features. Frequently project duration and the product cost was left to the discretion of the designers which subsequently lead to problems such as higher than anticipated (not planned) product cost and late deliveries. These further led to lower than anticipated sales and other problems such as conflict, confusion and ill-feeling amongst the members of the design and the managerial staff.

Product design performance from production point of view

Hypothesis 5: **The greater the degree of production involvement in the design process, the greater is the degree of consideration given to general product design parameters.**

Hypothesis 6: **The greater the degree of consideration given to product design parameters, the better is the product design performance from production point of view.**

In this section the relationship between the extent of production involvement and the degree of consideration given to product design parameters with the product design performance from production point of view is examined The last two hypotheses related to the design stage are considered. As mentioned in Chapter 5, because of the difficulties involved in testing these two hypotheses separately, they have been tested collectively. As the model in Figure 12 shows, the product design performance from the production point of view is measured by the following variables:

- Production/assembly techniques used
- Degree of standardisation carried out
- Degree of modifications carried out
- Project duration
- Product Cost

The most convenient way to present the findings of this research is to take each variable and list the factors which were found to be associated with either the achievement or failure of the anticipated, or planned outcome.

PRODUCTION/ASSEMBLY FACILITIES AND TECHNIQUES

The factors which were found to be associated with either the COMPLETE ACHIEVEMENT OR PART ACHIEVEMENT of the anticipated or planned outcome of production/assembly facilities and techniques.

FACTORS ASSOCIATED WITH COMPLETE ACHIEVEMENT

- Existence of standard range of products - this meant very little variation was required to the existing facilities and techniques. Usually the designers knew the production capabilities and capacities.
- Existence of basic standard design concept the only variation was the application.
- Existence of two way communication between design and production.
- Existence of thorough knowledge of in-house production strengths and weaknesses prior to acceptance of a firm order.

FACTORS ASSOCIATED WITH PART ACHIEVEMENT

- Lack of in-house production expertise, especially in the area of assembly techniques.
- Inadequate attention given to detail design during the design stage.
- Lack of production involvement at the design stage.
- Lack of two-way communication between design and production. Usually the communication was in one direction only (design to production in the form of instructions at the handover of drawings stage).
- Lack of appreciation of production by the design personnel, this frequently led to over-design
- Lack of awareness of importance of design for assembly concept.
- Inadequate managerial control of the project.
- Lack of appreciation of importance of design to production hand-over stage, especially regards the time required by production to prepare and plan for manufacture, as well as the time required by production to appraise the product from economical manufacturing point of view.

DEGREE OF STANDARDISATION CARRIED OUT

The factors which were found to be associated with the achievement of HIGH, AVERAGE and LOW degree of standardisation.

FACTORS ASSOCIATED WITH HIGH DEGREE OF STANDARDISATION	FACTORS ASSOCIATED WITH AVERAGE DEGREE OF STANDARDISATION	FACTORS ASSOCIATED WITH LOW DEGREE OF STANDARDISATION
- Existence of standard range of products the only variation was the application.	- Firms which had developed a standard range of basic product concepts, but failed to apply the same approach to detailed components.	- Firms where designers think production relatively unimportant.
- Firms which produced standard functional products and varied the aesthetic features in order to revitalise the interest in their products.	- Firms which did not have production engineering specialists, especially assembly specialists.	- Firms where designers lack appreciation and knowledge of standardisation.
		- Firms where there are no guidelines for the designers in terms of standardisation.
- Firms which appreciated the advantages of high standardisation and took relevant steps to achieve this.	- Firms which were attempting to produce technically superior products and frequently over-looked standardisation.	- Firms where the management failed to coordinate the activities of design with production functions during the design process.
- Firms where other functions (besides design) extensively contributed to the design process - such that number of suggestions were made regard standardisation.	- Firms where designers working in isolation with production not actively involved in the design process.	- Firms where the management are unable to maintain adequate control over the design process.
- Firms where the activities of different functions were well coordinated.	- Firms where a lack of awareness and appreciation of the importance of standardisation.	

DEGREE OF MODIFICATION CARRIED OUT

The factors which were found to be associated with HIGH, AVERAGE AND LOW degree of modifications carried out

FACTORS ASSOCIATED WITH HIGH DEGREE OF MODIFICATIONS

- When firms designed and developed products in parallel with designing and manufacturing jigs and fixtures.
- Non-comprehensive product specification vis a vis features like performance, market needs, product cost, project duration and development costs.
- Product design policy unclear or vague resulting in frequent changes in-decisions of designers and managers. They imposed their personal opinions or feelings which were not usually coordinated for the best interest of the project.
- Lack of communication between marketing, design and production during the design process management were unable to coordinate their activities.
- Lack of in-house project management expertise.
- Lack of clear problem definition before embarking on a project.
- Lack of appraisal in company's weaknesses and strengths in terms of in-house technical and assembly expertise.
- Lack of production involvement at the design stage.
- Existence of differential status between design and production as a result designers reluctant to consult production during the design process.
- Lack of guidance by the management.
- Lack of appreication and knowledge by the designers of production facilities and assembly techniques.
- Imprecise or inappropriate assembly drawings (ie firms frequently produced conventional engineering drawings when 3-D isometric drawings would have been more appropriate.
- Lack of appreication of the importance of design for economical assembly.
- Information flow in one-direction only (ie design to production).
- Detail design work sub-contracted out.

DEGREE OF MODIFICATION CARRIED OUT

The factors which were found to be associated with HIGH, AVERAGE AND LOW degree of modifications carried out

FACTORS ASSOCIATED WITH AVERAGE DEGREE OF MODIFICATIONS

- When firms gave adequate attention to functional features of the product but inadequate attention to other aspects (such as aesthetic, project duration, product cost) during the design process. Number of components were over-designed due to lack of production involvement at the design stage. These were usually drawings handed over to production.
- Good project management in terms of importance of market needs and technical content but failed to follow the same approach on design for assembly or production.
- Existence of specialist production engineers and assembly specialists.
- Good internal communication.
- Due to time constraints the designers unable to devote adequate attention to detail design.
- Designers not always fully conversant with production facilities and techniques, this combined with lack of in-house production engineering expertise, often resulted in modifications.

DEGREE OF MODIFICATION CARRIED OUT

The factors which were found to be associated with HIGH, AVERAGE AND LOW degree of modifications carried out

FACTORS ASSOCIATED WITH LOW DEGREE OF MODIFICATIONS

- Standard range of products the only variation being in the application.
- Comprehensive product specification especially in terms of clear identification of customers needs.
- Existence of effective two-way communication between design and production and emphasis on teamwork approach.
- Existence of good project management who were able to coordinate effectively the activities of marketing, design and production from inception of a project until launch.
- Relatively small companies (in terms of employees) and existence of effective liaison amongst different functions.

PROJECT DURATION

The factors which were found to be associated with the COMPLETE OR PART ACHIEVEMENT OF PROJECT DURATION expected or planned project duration.

FACTORS ASSOCIATED WITH COMPLETE ACHIEVEMENT OF PROJECT DURATION

- Firms where delivery dates of the products strictly agreed with the customer prior to starting the project.
- Firms where the launch date of the product was dependent on seasons (eg winter or summer).
- Firms where the product design concepts were standard and only Variation was the application, as a
- Firms where an existence of a good in-house project management expertise. Hence management was able to co-ordinate effectively, the activities of marketing, design and production
- Firms where there was a good team work approach complemented by effective communication amongst employees and the management.

FACTORS ASSOCIATED WITH PART ACHIEVEMENT OF PROJECT DURATION

- Non-comprehensive product specification where market needs, technical features, target price, and project duration (or launch date) were vaguely or unclearly defined. Due to these uncertainities, conflict, confusion and ill-feelings amongst employees and between functions existed.
- Lack of in-house project management expertise - who were unable to effectively coordinate the design, marketing and production activities.
- Lack of marketing involvement during the early stages to the project concepts were standard and only which lead to inadequate information vis a vis customer needs. result very little design and development work.
- Lengthy field trials because attempting to test the market was required prior to commencement of full production.
- Lack of in-house technical expertise when attempting to satisfy the performance requirements.
- Project duration over-estimated due to inadequate planning at the early stages.
- Lack of in-house expertise in assembly techniques.
- Lack of appraisal by firms of its weaknesses and strengths prior to start of the project.
- When detail design work sub-contracted out.
- Existence of non-communication (ie design to production) which usually lead to conflict between the functions.
- Lack of awareness or appreciation of importance of production by designers.
- Problems of design/production interface management, particularly during handover stage. Usually insufficient time allowed for production to plan and prepare for manufacture.

PRODUCT COST

The factors which were found to be associated with the COMPLETE OR PART ACHIEVEMENT of the anticipated, or planned product cost.

FACTORS ASSOCIATED WITH COMPLETE ACHIEVEMENT OF PRODUCT COST

- When the selling price of the product was agreed with the customer before accepting an order.
- When products were standard the only variation was the application.
- When in order to remain competitive the product cost calculated to minute detail and strictly adhered to. These prices were realistically specified at the start of the project

FACTORS ASSOCIATED WITH PART ACHIEVEMENT OF PRODUCT COST

- Due to high degree of modifications on product designs therefore unable to comply with the intended cost.
- Due to strict deadlines regards project duration therefore unable to carry out the intended cost reduction exercises.
- Due to lack of clear guidelines regards the product cost at the product specification stage, the designers continuing with design projects aimlessly.
- Due to the complexity of the product, therefore unable to determine, accurately, the product cost at beginning of the design project.
- When firms had difficulty in satisfactying the functional requirements of the product design.
- Due to indecision by the customer for a long period therefore unable to produce the product design within the existing product cost limits.

5.4 Relevance of the Results of this Study for other Firms

The results of this study are primarily of interest to designers, design managers, production engineers, production managers, marketing personnel and other managerial staff who are directly or indirectly concerned with the management of product design. This study is also very useful to those personnel who are concerned with coordinating the activities of marketing, design and production functions. The case history approach adopted in this research gives an opportunity to industrial practitioners and academics an insight to events in design projects. Although there are distinct dissamilarities between products and firms, still there are important parallels concerning the management of design projects.

The case studies can be used to illustrate typical product design process, for designers and managers, on a number of business management and engineering related courses.

Although the sample of firms in this study was confined to the Midlands and Staffordshire regions, there is no reason to believe why it should not be applicable to other parts of the country because the study is concerned with the management of the design process as opposed to problems associated with detail design. Furthermore if adequate consideration to features like culture, economic and environment are given the results of the study would serve broad guidelines overseas as well.

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