Engineering Design and Product Development in a Company Context

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Abstract

Engineering design and product development are sources of competitive advantage for companies faced with increasing competitive pressures in home and overseas markets. A fundamental requirement for this is the ability to identify market opportunities and to effectively and efficiently translate these into successful products. Product development is a complex and difficult task which involves both intra- and inter-firm processes, and requires many pressures and considerations to be considered. There is a considerable literature on the subject which provides guidance to companies. However, this makes generalisations concerning the nature of the competitive environment and it tends to be general in scope and prescriptive in nature. As a result, companies find that a considerable onus is placed on them to interpret the literature's recommendations.

This research concentrates on the processes of product development and, in particular, the role of the engineering design function and its relationship with other aspects of the manufacturing operation. It contributes to our understanding of the influence of the company context on the processes of engineering design and product development. The relevant literature has been examined and a model of best practice factors has been derived. A research methodology based on empirical study and a contextual framework for comparative analysis has been developed that provides a way of distinguishing between generic and company specific features of engineering design and product development and identifying which elements of best practice are appropriate and achievable for the companies studied. Empirical investigations and analysis have been based on twelve in-depth case studies and interview survey data for a further seventeen establishments from the mechanical and electrical engineering sectors of UK manufacturing industry.

The empirical results suggested that the literature's recommendations on best practice have a number of shortcomings. Some aspects of best practice were found not to be generally applicable. It was also revealed to focus narrowly on certain types of project and, because it deals with general requirements, it often does not indicate how best practice should be implemented. The investigation identified that, although a considerable amount of good practice was been implemented by companies, several important strategic and managerial activities were associated with less good practices. The research also suggested that, as a result of the complex and diverse nature of companies and their projects, good practice for any one company is dependent on its unique attributes. Against this background it has been concluded that a framework that enables the engineering design and product development processes to be interpreted in the context of a particular company is preferable to prescribing generalised models, which may result in attempts to implement inappropriate approaches.

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Chapter 1

Introduction

1.1 Problem Area

In order to maintain or improve their competitive position in increasingly challenging markets manufacturing companies need to innovate. Innovation can take many different forms (see, for example, Birmingham et al (1996)). One source of competitive advantage, however, is through technological innovation. A fundamental pre-requisite for technological innovation is the ability to identify product development opportunities and to translate these into successful products. It is also important that the processes involved in product development, including the important process of engineering design, are effectively and efficiently managed.

The business environment for the 1990s has changed, and continues to change, in response to a number of economic, demographic, environmental, market, technological and competitive drivers. These have been cited widely as creating several imperatives for product development. These are to meet the market and business demands for higher quality and higher performing products, in shorter and more predictable development lead-times, and at lower cost. This requires the ability to identify opportunities, instigate the necessary development effort, and to undertake projects in a quick and timely manner. Despite an increasing number of product and process technologies, and reducing product life cycles, this must be performed by the same or fewer resources, whilst still meeting the market's stringent requirements for value, quality, reliability and distinctive performance. Such changes in the nature of the competitive environment means that the development of products increasingly has to be managed as a concurrent, multi-disciplinary process.

With so many and diverse pressures and considerations to be considered the task of managing and undertaking the development of products is complex and difficult. In recognition of this, however, a considerable literature on product development has emerged. Moreover, a number of private (e.g. consultancies) and public (e.g. Department of Trade and Industry, Business Links, TECs) initiatives in the UK have sought to disseminate 'best practice' to, and encourage its adoption by, industry. There has also been considerable academic research undertaken over a number of years into the development of engineering design methodologies and enabling technologies. Moreover, a wider recognition of the potential for design to positively impact on companies' performance has resulted in a number of research initiatives. The creation of the Engineering Design Centres by the Science and Engineering Research Council is a notable example. Public organisations (e.g. Design Council) and professional bodies (e.g. Institution of Engineering Designers) have sought to encourage a greater awareness of good design practice.

There is no doubt that many companies have benefited from the various research and support initiatives. The numerous case studies reported in the literature are testimony to this. However, concerns may be raised about the characteristics of the models of engineering design and product development which have been proposed in the literature, as well as the generalised assumptions on which the models are predicated. Firstly, the models tend to be general in scope. Consequently, a considerable onus is placed on companies when interpreting the models and developing their own procedures. Secondly, the nature of the competitive environment, and the resulting requirements for product development, inevitably have consequences for the management and nature of the process. The models of product development are predicated on the type of competitive environment described above. However, it would be reasonable to suppose that the different competitive pressures will influence different industries and firms or establishments to greater or lesser degrees and that these variations will give rise to varying responses from individual firms, which in turn will have implications for their product development practices. The engineering design models generally assume ideal or conducive circumstances in which there are no constraints on time, resources, design skills, and so on. They therefore take no account of the design context. Thirdly, much of the guidance to companies on product development is based on research into the activities of large firms, often multinational, and often associated with the consumer electronics or automotive industries. Doubts can be raised about the universal usefulness of these recommendations in all industries, firms or establishments. It may be argued that variations in the relative significance of the different competitive drivers, and the characteristics of companies, will give rise to different requirements for product development, thereby requiring alternative approaches to those which have been prescribed. It may be unreasonable, therefore, to expect the existing set of prescribed ways of generating new products to be universally acceptable or appropriate. Moreover, with the characteristics of companies and their competitive environments, and their range of strategic and operational choices, being both complex and diverse, companies may find that interpreting these models, and understanding and managing the development function, represents a significant challenge.

Consideration of the competitive environment, the characteristics of companies, and current best practice models, as outlined above, raise a number of key questions. Firstly, given the apparent complexity and variability in the characteristics of companies and their business environments, and their responses to these, how well do the engineering design and product development models cope with this? To what extent are they sufficiently comprehensive and flexible to meet the needs of industry in practice? Secondly, to what extent are companies adopting the models' recommendations? Thirdly, are there constraints to adopting the models' recommendations for certain types of company and, if so, what practices are appropriate?

The main argument of this thesis, therefore, is that the processes of engineering design and product development need to be understood in a company context. Moreover, relating factors which characterise the company and project context to engineering design and product development practices will lead to an improved understanding of the requirements for the product delivery process and the appropriate methods to adopt.

1.2 Research Aims

The research was concerned with the need to develop improved models of the processes of engineering design and product development in a company and project context. The research therefore had the following objectives:

- To identify the generic and company specific features of the engineering design and product development process in a company and project context.

- To identify the extent to which recommended practices are implemented by companies and the constraints that may impede their adoption.

The research was to focus on the mechanical engineering related sectors of UK manufacturing industry and primarily firms engaged in intermediate product markets. These were to include a balanced representation of small (over 50 employees), medium and large establishments, and both independent and corporate establishments.

In addressing such concerns, there was a need to capture the important discriminatory factors relating to the company and project contexts, and to ascertain their relationship to the various elements of engineering design and product development practice. In understanding these causal relationships and to carry out systematic research, it was important to recognise firstly, that the critical features that define a company, its strategic policies and the projects it undertakes, needed to be captured within a suitable contextual typology, and, secondly, that a structured framework was required in order systematically to research the various features of companies' development processes. This required a comprehensive and flexible approach to capture and explain the complexities of companies and their product development projects. An important aim of the research, therefore, was to develop an appropriate research methodology and frameworks for undertaking this type of investigation.

1.3 Structure of the Thesis

The remainder of this thesis is structured as follows. Chapter 2 and Chapter 3 examine the existing literature relating to engineering design and product development respectively. A broad review of the scope and characteristics of the models which are proposed in, and the recommendations of, the literature is provided. In particular, the literature is critically examined to determine the extent to which factors relating to the company context are accommodated. The review also identifies important issues in engineering design and product development and, therefore, bounds the focus of the research and acts as a prelude to the development of a model of best practice factors.

Chapter 4 describes the methodological background to the research analysis and findings presented in Chapters 5, 6, and 7. The choice of research method, and the execution of the case studies, the interview survey and the analytical work, are discussed in some detail. Particular attention is given to the development of the conceptual frameworks which provided a theoretical and operational structure to the research. These include the proposed contextual typology for the classification of companies, their strategic policies and key project variables, and the thematic framework which was used to compare and contrast companies practices. The development of a model of best practice factors from the literature is also described.

In Chapter 5 the appropriateness of the recommendation on best practice derived from the literature is examined. The findings of a comparison of the case study projects against the model of best practice factors are presented. This involved a comparison of companies actual practices against the different elements of the model and, also, an assessment of what was appropriate and achievable for each company. Where relevant data from the interview survey is also introduced.

Chapter 6 is concerned with the identification of those features of good engineering design and product development practice which are generic and those which are company specific. It uses a thematic analysis in which the factors used to characterise the company and project contexts are systematically related to a number of themes associated with companies' practices. The chapter describes in some detail a series of hypotheses, established by comparing and contrasting the case study projects, and their testing using interview survey data. The best practice evaluations described in Chapter 5 are also used to inform this part of the analysis so that aspects of less good practices are highlighted and accounted for.

A synthesis of the research findings discussed in Chapter 5 and Chapter 6 is provided in Chapter 7. Using similar themes for the section headings as the previous chapters, the main aspects of best practice relating to these are outlined and this is discussed in terms of its applicability to the case study and survey establishments. Those aspects of companies' development practices which where found to be determined by the context of companies and their projects are also discussed.

The main conclusions of the research are discussed in Chapter 8. These relate to shortcomings of the literature's recommendations on best practice which are indicated not to be generally applicable, and to focus narrowly on certain types of project. Also, because it deals with general requirements, it often does not indicate how best practice should be implemented. Although a considerable amount of good practice is being implemented by companies, several important strategic and managerial activities are found to be associated with less good practices. It also suggests that, as a result of the complex and diverse nature of companies and their projects, good practice for any one company is dependent on its unique attributes. Against this background it is concluded that a framework that enables the engineering design and product development processes to be interpreted in the context of a particular company is preferable to prescribing generalised models, which, may result in attempts to implement inappropriate approaches. The chapter also discusses the need for future research to adopt a more holistic approach which takes account of, and reflects on, the context in which engineering design and product development takes place. This raises important issues for research methods and skills. Finally, Chapter 9 concludes the thesis with a discussion on areas for further research.

Chapter 2

Engineering Design Literature

2.1 Introduction

Design methodology has been defined by Cross (1984) as "the study of the principles, practices and procedures of design in a rather broad and general sense. Its central concern is with how designing both 'is' and 'might be' conducted. This concern therefore includes the study of how designers work and think; the establishment of appropriate structures for the design process; the development and application of new design methods, techniques, and procedures; and reflection on the nature and extent of design knowledge and its application to design problems". This concern is complementary to the objective of this thesis, that is to identify improved models of the processes of engineering design and product development. Therefore, the literature on engineering design methodology which has emerged over the last thirty years will be the focus of this chapter. In particular, the review will be concerned with the extent to which existing engineering design models incorporate influences from the intra- and extra company environments. The review will mainly be constrained to characteristics of the process-based models that cover the entire design process, since these have the most relevance in a product development context. There are of course, other considerations, the fundamental nature of problem solving, for example. These are only explored where they have some relevance to the main discussion.

2.2 Prescriptive and Descriptive Models

A number of models of the engineering design process have been proposed dating from the early 1960s (Asimow, 1962; Jones, 1963) and during the 1980s and 1990s (Cross, 1989; French, 1985; Hubka, 1982; Pahl and Beitz, 1984; Pugh, 1990; Ullman, 1992). These models are typically categorised as being either prescriptive or descriptive in nature. The aim of prescriptive design methodology is to prescribe "a better or more appropriate pattern of activities" (Cross, 1994). In contrast, the descriptive design methodology draws on experience or empirical study and seeks to "describe the sequence of activities that typically occur in designing" (Cross, 1994). This distinction may however be somewhat arbitrary, since it is often difficult to distinguish between what Asimow (1962) identifies as statements or principles with a factual content and those with an ethical content. Generally, prescriptive models not only contain an ethical content, but also incorporate some experience of design activity; and similarly, not all descriptive models are explicitly based on empirical studies, some also incorporate an ethical content. Consequently, many design models are hybrids, having both prescriptive and descriptive characteristics, in that they express a prescriptive opinion based on descriptive studies or experience.

Descriptive models of the design process usually emphasise the importance of initial conjecture to generate a solution concept, which is then subject to analysis, evaluation, refinement and development. This process is heuristic in nature, drawing on previous experience, general guidelines and rules of thumb. By way of example, Cross (1994) has developed a simple four-stage model of the design process comprising:

1. *exploration* of the ill-defined problem space;
2. *generation* of a concept;
3. *evaluation* of the design proposal against the goals, constraints and criteria of the design brief, which may lead to the need to revise or generate an alternative concept; and
4. *communication* of the design for manufacture.

A more detailed model, which encapsulates a similar pattern of activities is that of French (1985). Again, having established a statement of the problem, "broad solutions in the form of schemes are generated ... it [conceptual design] is the stage where engineering science, practical knowledge, production methods, and commercial aspects need to be brought together".

Prescriptive models usually attempt to engender the adoption of a more systematic, sometimes algorithmic, procedure. As such, they are often regarded as providing a particular design methodology. So that the design problem, as presented, is fully understood, these models tend to emphasise the need for more analytical activity prior to the generation of alternative solution concepts and making a rational choice between them. In its most basic form this prescriptive structure may therefore be represented simply as a process comprising three stages: analysis, synthesis and evaluation (Jones, 1963). A number of models develop this approach in more detail. Of these, Pahl and Beitz (1984) is one of the most prominent (see Figure 2.1). It is a comprehensive model which retains the main aspects of the prescriptive models.

The prescriptive models typically exhibit a number of common basic features, such as their breakdown of the design process into conceptually distinct stages or activities, leading to certain intermediate results (specification, functional structure, working principle, preliminary layout, detailed documentation, etc.), and their implied notion of linearity, albeit with varying emphasis on iteration, interaction and feedback loops at various points. In attempting to bring rational procedures into the design process, the prescriptive literature also recommends or even demands certain methods for specific steps in the design process. The combination of a more systematic approach and methods to support specific stages or activities is intended to improve the effectiveness and efficiency of the design process.

2.2.1 Scope of the Models

The main differences between the models can be assigned to the way in which they discern divisions of the stages and activities. Some models limit the distinction to the main stages (French, 1985; Pugh, 1990); others extend this to include intermediate steps (Archer, 1984; Asimow, 1962; Hubka, 1982; Pahl & Beitz, 1984; VDI, 1987); and some incorporate activities explicitly in combination with the stage division to describe how to proceed during a specific stage (Ullman, 1992).

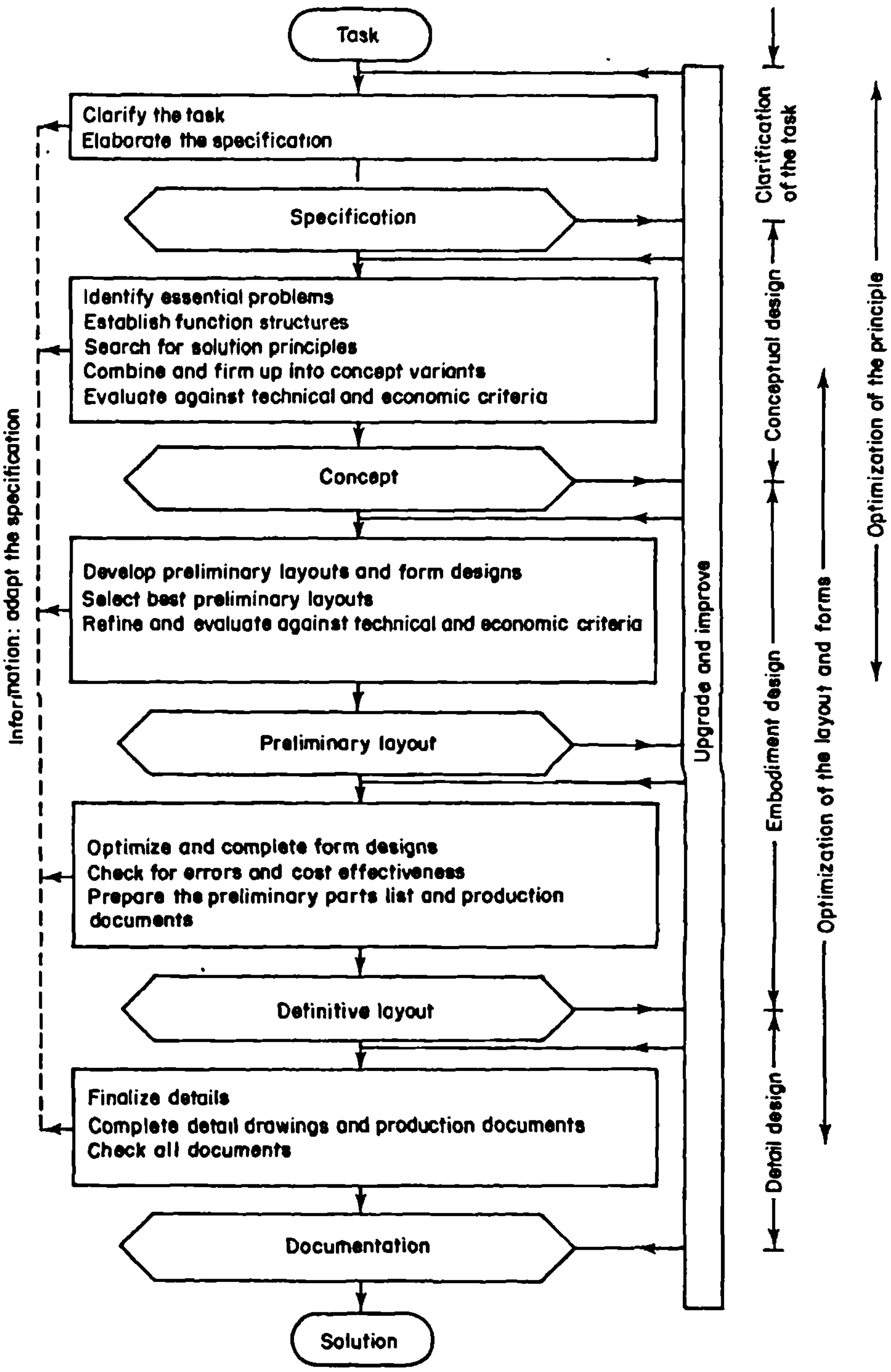


Figure 2.1: Model of the design process by Pahl and Beitz

(Source: *Engineering Design* by G. Pahl & W. Beitz

c The Design Council 1984)

Design methodologists distinguish between the breakdown of the main design stages where embodiment issues are concerned. Some regard the embodiment activities as a separate stage which follows conceptual design and precedes detail design (BSI, 1989; French, 1985; Hubka, 1982; and Pahl and Beitz; 1984). Others do not include an embodiment stage (Pugh, 1990; and Ullman, 1992). Pugh and Morley (1989) suggest that the reasoning for this is two fold. The first is somewhat pragmatic in that practitioners usually only distinguish between conceptual and detail design. Secondly, embodiment issues are often addressed very early in the design process, and embodiment is therefore a subset of conceptual design.

In terms of the overall product cycle, most of the models focus on the process from the initial problem formulation through to completion of the detailed product definition: all influencing factors being assumed to be captured by the given problem brief. Other models are extended in various ways by the inclusion of stages relating to marketing and product policy (Pugh, 1990) through to the ultimate disposal of the product (Asimow, 1962; Archer, 1984; BSI, 1989), and some include the activities of disciplines working in parallel (Andreasen and Hein, 1987).

Clearly, to develop improved models from the perspective of the processes of engineering design and product development, a more holistic view is required, which considers these relevant upstream, downstream, and simultaneous influences. Pugh (1990) captures the sentiment of this when defining total design as "the systematic activity necessary, from the identification of the market/user need, to the selling of the successful product to satisfy that need - an activity that encompasses product, process, people and organisation". Indeed, as Pugh also points out, a product is made up of many technological and non-technological components that impinge on product design. Achieving the necessary balance of these factors requires the coordinated partial inputs from many specialisms, both engineering and non-engineering, namely a total design effort.

2.3 Design Methods

A method is the systematic way in which a number of activities are performed, and the practical means for executing a method is referred to as technique (Blessing, 1994). According to Pugh (1990), there are techniques of analysis, synthesis, decision making, modelling, etc., applicable to any product or technology. These are independent of the domain of application. There are also techniques and areas of knowledge - stress analysis, thermodynamic analysis, electronics, etc. - which are discipline dependent.

Methods have also been categorised as being either creative (or intuitive) or rational (or formal or discursive) in nature. Creative methods seek to externalise design thinking, whereas rational methods aim to formalise certain procedures of design (Cross, 1994). Nevertheless, rational methods will often have similar aims to the creative methods, such as increasing the flow of ideas, widening the search space, or facilitating team work and group decision making (Cross, 1994).

In attempting to introduce rational procedures into the design process, many of the proposed methodologies place much emphasis on the methods and techniques viewed as being best suited to specific stages and activities. Some methods require specific inputs and therefore can only be used in a few specific situations, whereas other methods are more generally applicable. A summary of the relationship between the most commonly prescribed rational methods and the product design stages are shown in Table 2.1.

The choice of method depends on the skills and background of the designer and the nature of the problem. An inevitable question which arises, therefore, is to what extent these methods are applied in industry and whether the best use of specific methods and techniques are contextually related.

Design Stage	Method
Market	Literature searches
	Patents; Reports, proceedings, and reference books; Market data publications; Statistical data; Product data for competitive and analogous products
	Parametric analysis
	Matrix analysis
	Competition analysis
	Literature, sales reports, trade fairs & exhibitions
	SWOT analysis
	Reverse engineering
	Market research analysis
	Sales data; Economic; Political; Legal; Technological innovation; Demographics; Market trends
	Need analysis (Customer requirements)
	Market feedback mechanisms
	Customer complaints; Field (service) reports; Sales reports.
	Customer interviews & customer questionnaires
	Competition benckmarking
	Quality function deployment (QFD) matrices
Specification	QFD matrices
	Engineering requirements
	Competition benchmarking
	Engineering targets
	Performance specification method
	Specification checklists & questionnaires
Concept	Concept Generation
	Objectives tree & functional decomposition
	Principle of division of tasks
	Design catalogues
	Literature and patent search results
	Function-concept mapping (Morphological charts)
	Concept Evaluation
	Feasibility judgement (Gut feel)
	Technology readiness assessment
	Go/no-go screening (customer requirements)
	Evaluation matrix (relative or weighted objective)
	Graphical or physical mockups
	Design review
	QFD matrices
Detail	Product Generation
	Component design specification
	Engineering design standards
	Producibility engineering (Mat'ls, form, process)
	Product Evaluation
	Evaluation matrix (engineering requirements)
	Evaluating performance
	Analytical, physical & graphical model development
	Evaluating costs
	Design review
	Design for manufacture and assembly (DFMA)
	Taguchi/Robust design
	Failure mode effect analysis (FMEA)
	Value engineering
	Functional cost analysis
	QFD matrices
	Prototyping and testing
	Manufacturing process design
	QFD matrices
	Process capability studies

Table 2.1: Summary of the most commonly prescribed formal methods in relation to the product design stages.

2.4 Strategies for Design

A design strategy represents the particular design approach adopted on a design project or part of a project and may be characterised by the sequence in which the design stages, activities, methods and techniques are planned or executed (Cross, 1994). According to Blessing (1994), a stage is a subdivision of the design process based on the state of the product under development (e.g. problem definition, concept design, and so on), and a design activity is a subdivision of the design process that relates to the individual problem solving process, and typically re-occurs, either in part or in full, during the design process. Activities may be referred to generally by a number of terms: generating, evaluating and selecting, modifying, documenting, and collecting and using information. It is this fundamental combination of stages and activities which Asimow (1962) refers to respectively as the morphology (vertical structure of a design project) and the design process (horizontal structure to each stage).

Notwithstanding the earlier discussion on the scope of the models, a fundamental distinguishing feature between them concerns their methodologies for the transformation from problem statement into product definition. The prescriptive models on the whole are *problem-focused*, and concentrate initially on analysing the problem (i.e. characterised by abstraction steps), followed by a systematic concretisation process. The descriptive models (Cross, 1994; French 1985), and some of the prescriptive models (Archer, 1984; Asimow, 1962), are initially *product-focused*. Such an approach emphasises analysis of the product idea or concept (i.e. characterised by the use of solution conjectures to generate a solution concept and so to gain further insights and an improved definition of the problem) and promotes the notion of solution and specification being developed simultaneously. This process is characteristically heuristic in nature, drawing on previous experience, general guidelines and rules of thumb. This is then followed by further analysis and evaluation steps to refine and develop the solution.

Design methodology can be viewed in terms of a hierarchy (Asimow, 1962). At the highest level are design philosophies. A philosophy deals with underlying principles, concepts and methods which are generic in application to whole classes of problem. Disciplines of design derive from philosophy, and represent a more detailed scheme of action, dealing with particular classes of problem, mechanical engineering or software engineering, for example. When dealing with a particular problem, a designer must develop from his knowledge of discipline a particular tactic to suit the unique nature of the problem.

It is evident from the discussions so far that in presenting an overall strategy in the form of a general combination of stages, activities and methods, most of the models are dealing with the discipline of design. It follows, that in prescribing a strategy that is applicable to a group of design problems, it is assumed that the designer is able to elaborate the specific details required by a particular problem. Indeed, the designers first task at the outset of any project, is to develop a general plan or strategy for the design process (Cross, 1994).

Moreover, in attempting to prescribe improved ways of working, some of the models are deliberately constrained to a particular strategy which limits the flexibility of approach open to the designer. In response to this, Cross (1994) expressed that what is needed is a more flexible, strategic approach to designing, which identifies the right kind of thinking at the right time, and within the context of the particular design project. Indeed, a discerning feature of recent models is their more 'balanced' view, and the greater flexibility of approach they accommodate (e.g. Cross, 1994; Pugh, 1990; Ullman, 1992). These models differ in their details, but they are not contradictory, and in many regards a consensus now exists. Through the evolutionary process there has been a convergence to what might be regarded as a general consensus model in that, as outlined earlier, many of these models exhibit common basic features (Cross and Roozenburg, 1992; Pugh, 1986b). This holistic view of design, which is more flexible to the demands of different design problems, is an important consideration. It does place a greater emphasis on the designer, however, to identify a suitable design strategy for a particular design problem. This assumes an understanding of what may be appropriate for different types of design problem and, significantly, this is where the models do not provide adequate advice. This is an aspect which any contextual development of the models should address.

So far the discussion has dealt with strategies for resolving overall design problems. In order to review design methodology thoroughly, it is necessary to address the hierarchical nature of design problems.

2.5 The Hierarchical Nature of Design

The complex nature of many design problems means that it is simply not feasible to tackle the whole problem at once. In order to make the problem more manageable it is often necessary to decompose the overall problem down into its sub problems. Ideally, this should be done in such a way as to make the problem easier to solve.

Newell (1969) categorised problems as being either well-structured or ill-structured in nature, and Simon (1984) identified their characteristic properties. Expressed simply, well-structured problems have clear goals, often a single correct or optimal answer, and rules or known ways of proceeding to the solution. Such problems according to Simon (1969) are fully-decomposable or nearly-decomposable into branches of sub problems and sub-sub problems, for which there is little interaction between the sub problems and sub-sub problems of the respective branches. It is possible therefore to solve each sub problem independently and then to synthesise these to arrive at a solution to the overall problem (Levin, 1984).

In contrast to well-structured problems, many design problems are recognised as being ill-structured (or ill-defined) in nature. Cross (1994) summarised ill-structured design problems as having the following features:

- there is no definitive formulation of the problem;
- any problem formulation may embody inconsistencies;
- formulations of the problem are solution dependent;
- proposing solutions is a means to understand the problem; and
- there is no definitive solution to the problem.

Ill-structured problems characteristically exhibit interdependencies between sub solutions to sub problems, so that a sub solution which resolves a particular sub problem, may create unreconcilable conflicts with solutions to other sub problems. This pernicious feature means that it is necessary to iterate selectively around the problem hierarchy, using solution conjectures, in order to realise an overall solution.

Simon (1984) has argued that the distinction between ill-structured and well-structured problems is not a clear one. With a thorough analysis and problem formulation, some ill-structured problems may be formulated as well-structured problems. Yet there is no guarantee that optimal sub solutions will combine into an overall optimal solution (Luckman, 1984).

However, descriptive studies of design, for example Lawson (1984), suggest that designers in practice will usually adopt a product-focused approach, by using solution conjectures as a way to gain further insights and an improved definition of the problem. That is, conjecture and problem specification are developed simultaneously (Hillier et al, 1984). Moreover, Cross (1994) has suggested that these product focused strategies are perhaps the best way of resolving design problems: "in most design situations, it is not possible or relevant, to attempt to analyse 'the problem' *ab initio* and in abstract isolation from solution concepts". He argues that although there may be a logical progression from problem to sub problem and from sub solution to solution, there is a symmetrical, commutative relationship between problem and solution and between sub problems and sub solutions, involving iteration between problem and solution, as illustrated in Figure 2.2.

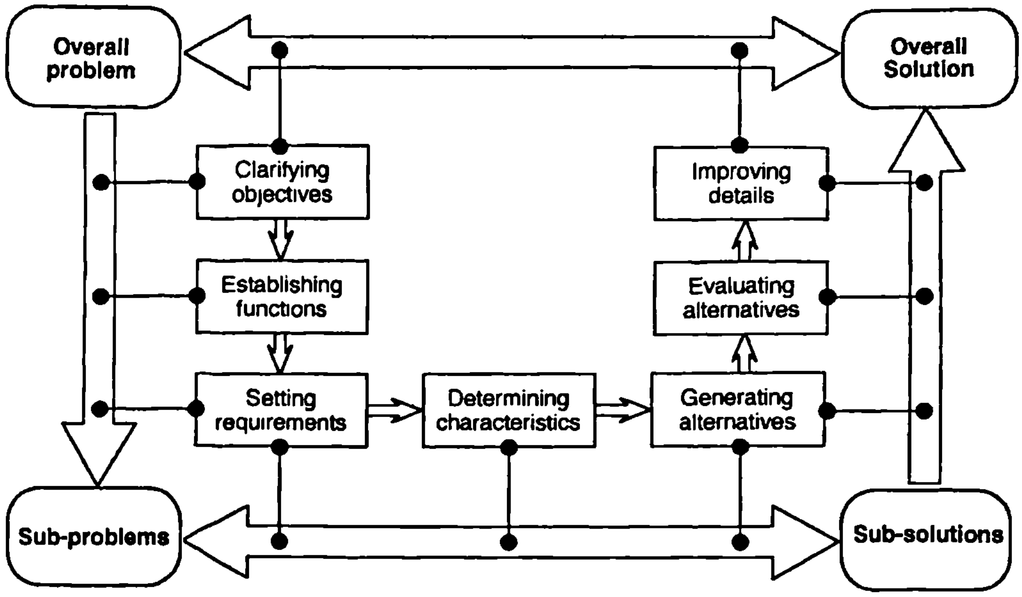


Figure 2.2: Model of the design process by Cross

(Source: *Engineering Design Methods* by N. Cross
c John Wiley & Sons 1994)

The notion of decomposing a design problem into sub problems is consistent with the subdivision of the project into its system, sub system and component levels as applicable. The design activity at these overall system, sub system, and component levels will typically vary in originality across the design activity spectrum. Indeed, Pugh (1990) suggests that in all probability, while many overall concepts are relatively static, there are often opportunities for innovation at the sub system and component levels. Important implications for managing the subsets of design projects arise out of this. It is necessary to recognise where differences occur and to be able to accommodate for them. In particular, different design strategies may be required to resolve differences in problem characteristics within the problem hierarchy. It follows, therefore, that the subsets of design projects must be managed carefully, as aspects of both the problem-focused and product-focused approaches may be required. The hierarchical aspects of design activity are clearly contextually related and, therefore, there is a need for these to be considered.

2.6 Contextual Characteristics

This research is in part aiming to address the contextual aspects of engineering design methodology. It is therefore appropriate to review the extent to which existing models accommodate influences from the context of design projects.

Beyond the initial problem definition stages, any notion of contextual influences are rarely integrated into the models. Only in the models of Hales (1993) and Wallace and Hales (1987) and to a lesser degree Pugh (1990) and Hollins and Pugh (1990) have contextual influences been illustrated. Elsewhere, some authors make passing references to influencing factors, but their consequences are rarely elaborated.

The model of Hales (1993) explicitly accommodates contextual influences (Figure 2.3). These are represented at macroeconomic, microeconomic, corporate, project and personal scales. Hales (1993) develops this into a framework in the form of checklists, broken down according to area of influence and contributory factor. Table 2.2 summarises the factor groups. This provides the basis to interpret the relative status for the key influences impinging on a project and, to decide whether to try to control, compensate or monitor the influence. Hales' framework is comprehensive and insightful in capturing a spectrum of influences within a logical structure. However, it does not deal explicitly with their causal relationships with features of a design project.

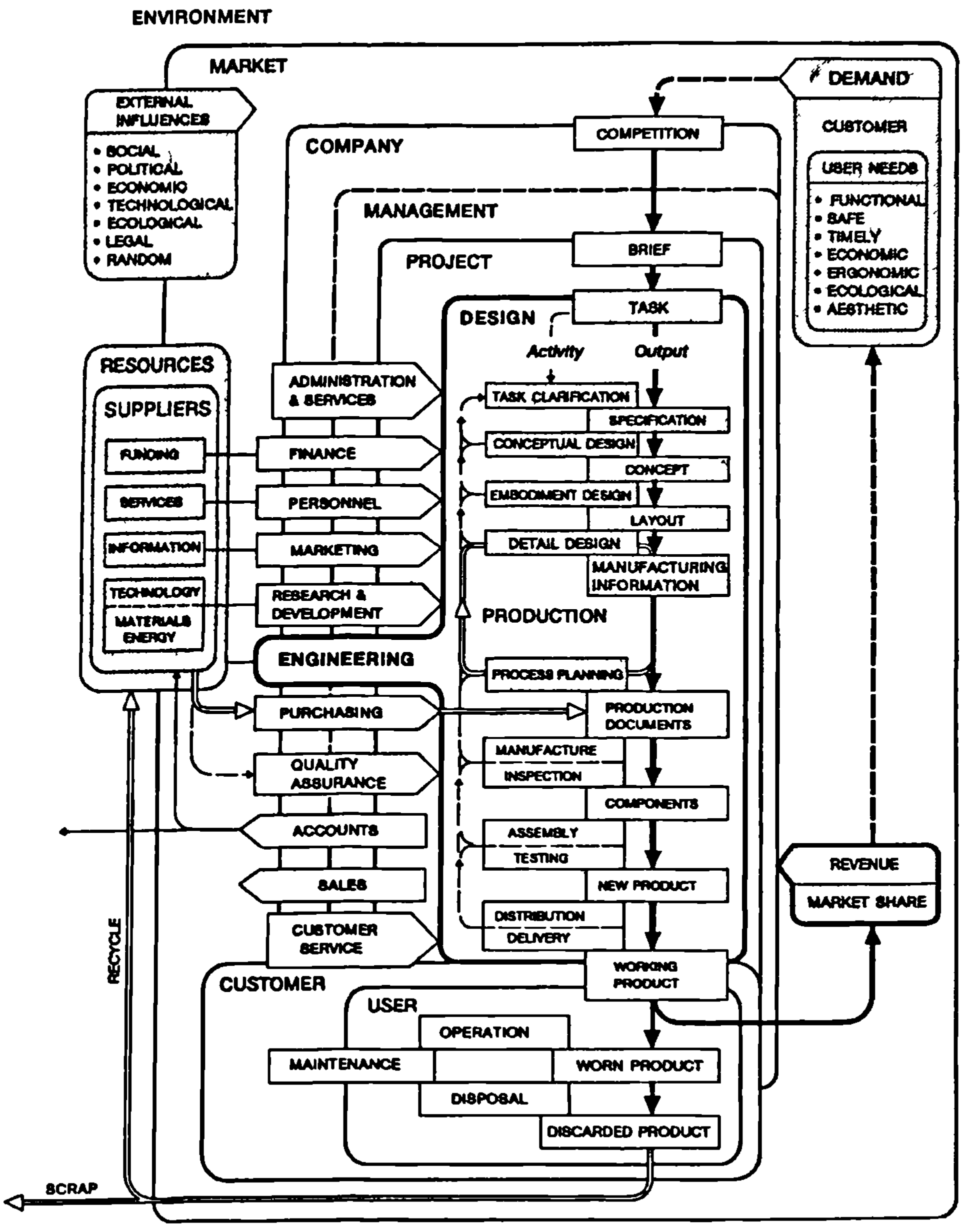


Figure 2.3: Model of engineering design process by Hales

(Source: *Managing Engineering Design* by C. Hales

c Longman Scientific & Technical 1993)

Contextual Scale	Influences	Contributing Factors	
Macroeconomic	Cultural Scientific Random	Social issues Political climate Economic situation Legal requirements	Technological advances Ecological concerns Luck / chance
Microeconomic	Market	Demand Competition	Financial risk
	Resource availability	Human services Capital finance Information for design	Appropriate technology Appropriate material Appropriate energy
	Customer	Understanding of need Urgency of need	Expectations Involvement
Corporate	Corporate structure	Span of company Size of company	Type of project control
	Corporate systems	Help getting information Quality of work environment	Pay scales and benefits
	Corporate strategy	Clarity of objectives	Level of risk taking / innovation
	Shared values	Degree of commitment Degree of involvement	Degree of project enthusiasm
	Management style	Degree of staff freedom	Degree of staff participation
	Management skill	Quality of planning/coordination Quality of communication	Effectiveness of project support Effectiveness of resource use
	Management staff	Number of staff involved Quality of judgement	Degree of motivation / morale Degree of confidence
Project	Design task	Magnitude Complexity Novelty	Production quality Technical risk Delivery time constraints
	Design team	Expertise Experience Role balance Cooperation Commitment	Motivation Morale Negotiating ability Negotiating power User involvement
	Design tools	Systematic approach Formal design methods Intuitive design methods Communication	Project control Computer design methods Computer aids Codes and standards
	Team output	Productivity	Quality of work
Personnel	Knowledge	Knowledge base	Knowledge applicability
	Skills	Perception Use of knowledge Communication	Creativity Versatility Negotiation
	Attitude	Work standards Self-discipline	Integrity
	Motivation	Enthusiasm Involvement Tenacity	Frustration / Anxiety Humour
	Relationships	Team role compatibility Relationships with company	Relationships outside company
	Output	Productivity	Quality of work

Table 2.2: Contextual influences on design projects (after Hales (1993)).

Hollins and Pugh (1990) incorporate influencing factors through their concept of product status. It is used to describe whether the overall conceptual design of a product is likely to change or need changing. A product can be positioned along a design spectrum ranging from static product status (i.e. incremental or non-existent design changes) through to dynamic product status (i.e. innovative design changes). Clearly, in the context of the design hierarchy, similar assessments could be made for the sub systems and components. Their methodology mainly focuses at the front-end of the design process, allowing product status to be ascertained and, by knowing whether it is necessary for the design process to be incremental or innovative, to emphasise the appropriate design disciplines. A criticism of this concept is that although it draws on a number of influencing factors (Table 2.3), these are reduced to a single dimension, namely product status. Consequently, any causal relationships relating to specific influencing factors, or interactions between them, may not be captured and related individually to the design disciplines required.

Design time
Customers willingness to change
Market infrastructure
Stability of environment (legislation, economic, resources)
Market share
Technical advancement
Stability of product design specification
Restrictions in PDS (extent of use of existing sales and distribution channels)
Conformance standards
Number and size of competitors
Degree of market research
Relative importance of process design
Dedicated vs flexible machinery
Use of CAD
Parts commonality and/or rationalisation
Interfacing to supply
Length of product's availability in present form
Design / financial resources and management commitment
Nature of design guidelines.

Table 2.3: Influences on product status (after Hollins and Pugh (1990))

An improved methodology capable of dealing with these relationships in a more subtle manner, would be to relate directly the causal influences, both individually and collectively, to the design disciplines. The research method developed in this thesis will seek to accommodate a similar approach.

Pugh (1990) further relates product status to characteristics of the design process. Pugh's models, as illustrated in Figure 2.4, is representative of the design process for innovative (dynamic) products. In the case of more conventional (static) products, where incremental design at the sub system and component levels may dominate, for example, the specification and concept stages are reversed. Hence, from the market need the concept is taken as being relatively fixed, and the product design specification written around this. This approach is more characteristic of the product-focused strategy discussed earlier.

Most of the models infer a rather linear representation of the design process, implying a step-by-step process with varying degrees of iteration and interaction, both within and between stages. Indeed, as expressed by Pahl and Beitz (1984), "at every step, a decision has to be made as to whether the next step can be undertaken or whether the previous steps have first to be repeated". In practice, simultaneous activities may occur within and between disciplines, may involve interactions between the disciplines, and may be performed at disparate locations.

The model of Andreasen and Hein (1987) deals explicitly with the simultaneous processes of marketing, design and production. Similarly, to enable the values of simultaneous engineering, Pugh (1990) develops the concept of a process design core. He suggests that the 'lag' between product design core and process design core is a function of product status. More generally, Pugh emphasises the need for all facets of the business to be involved in, and interact with, the design core (team).

It is evident that simultaneous engineering principles are not dealt with by most engineering design texts. This is a surprising truism of even the most recent models. Even amongst those which do address simultaneous engineering, a superficial account is often given (e.g. Ullman, 1992). Hence, there is a need for these simultaneous activities to be more fully incorporated into engineering design methodologies.

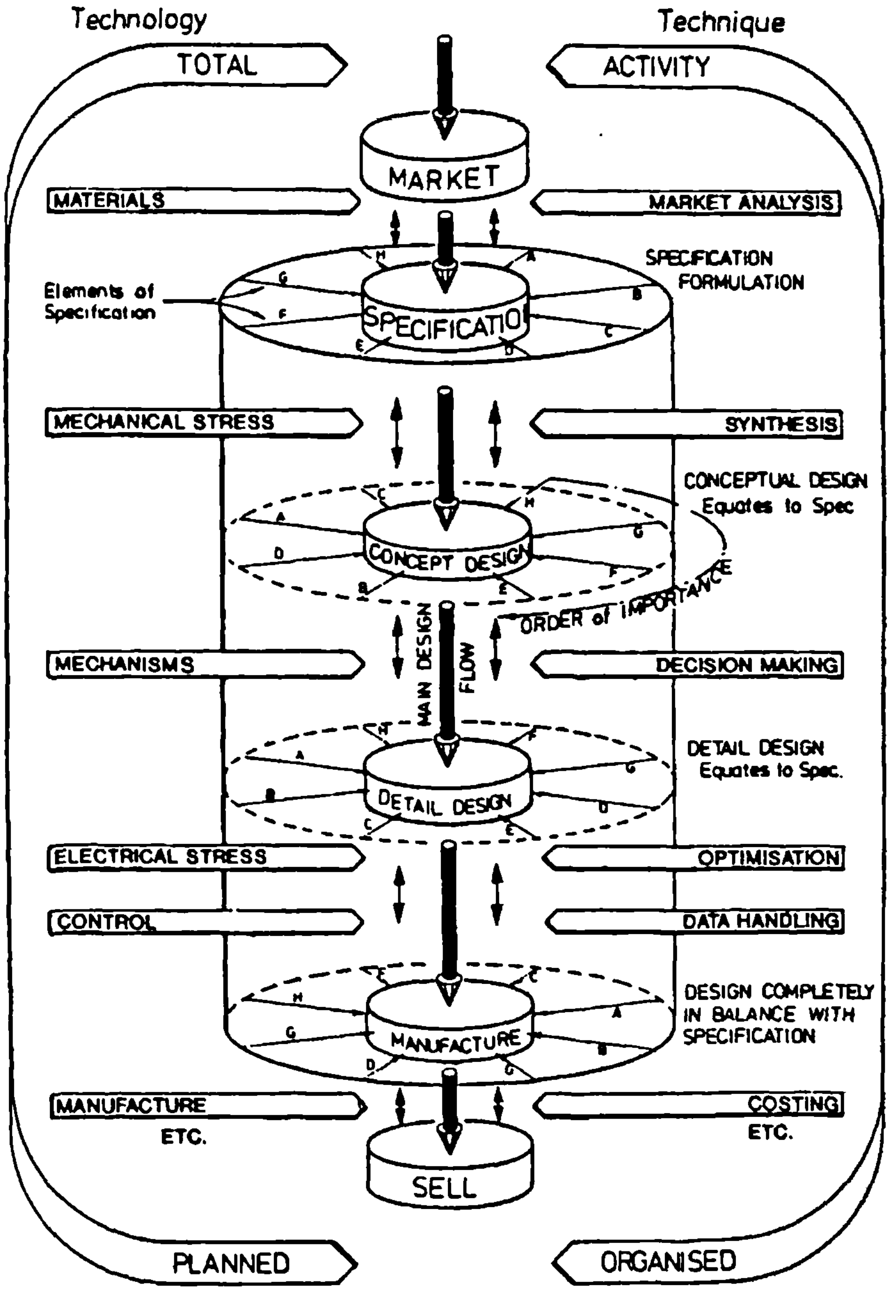


Figure 2.4: Model of design process by Pugh

(Source: *Total Design* by S. Pugh

c Addison-Wesley 1990)

Most authors usually differentiate between the originality of design problems. Pahl and Beitz (1984), recognising the contribution of other authors, have defined three distinct types of design activity:

- Original design - which involves elaborating an original solution principle for a system with the same, a similar or new task.

- Adaptive design - which involves adapting a known system to a changed task, the solution principle remaining the same.

- Variant design - which involves varying the size and/or arrangement of certain aspects of the chosen system , the function and solution principle remaining the same.

Adaptive and variant design activities are estimated to account for the overwhelming proportion of all engineering design activity (Pahl and Beitz, 1984). However, most of the design models have been developed with a view to resolving original design problems. A number of reasons are put forward to support this approach. Original design problems are seen to represent the most defiant and broad type of design in terms of the variety of possible activities; non-original design is argued to be a subset of original design, the overall process remaining the same, with only a change in emphasis being required; and non-original design may also involve elements of original design in the parts of the product being redesigned. Although most design models have been developed with a view to resolving original design problems, for adaptive and variant design, the general approach has to be modified. According to Hubka (1982) and Pahl and Beitz (1984) part or all of the conceptual and embodiment stages may be neglected, although a scan of these steps would be useful.

Notwithstanding the foregoing, a general criticism which is particularly applicable to the more systematic prescriptive models, are their erroneous assumptions of ideal, or conducive circumstances. The main emphasis with these models is on the quality of the design process and solution. These 'idealised' models assume no constraints in terms of time, resources, quality of the designers, management, working conditions, and so on. Consequently, when Hubka (1982) refers to the application of his procedural model, it is necessary to derive a procedural plan for a particular problem, by taking account of factors which influence the idealised model (Table 2.4).

It may be concluded with few notable exceptions, that it is not evident generally from the engineering design literature what the important influencing factors are. Where references are made, these are usually rather oblique. Consequently, it is not apparent how they influence the design process, and what should be done in particular situations.

Technical systems	Degree of complication Degree of originality (possible variants) Number / difficulty of requirements
Design process	Quality of designers State and availability of technical information Working means available to design team Working conditions
Production	Number of parts Time deadlines Experimental and manufacturing facilities Traditions Organisation
Societal	Standards Regulations Environmental protection

Table 2.4: Influencing factors on the procedural model (after Hubka, 1982)

2.7 Summary

Through the development of engineering design models over the last thirty years or so, and the prominence accorded to the prescriptive literature, a consensus model has emerged. However, doubts can be raised both to the extent that models map empirical reality, and as to their methodological validity. According to Cross and Roozenburg (1992), the nature of the design activity seldom resembles that prescribed by the consensus model. Similarly, Hollins and Pugh (1990) concur that "despite a long history of innovative engineering design in industry and development of many prescriptive methods and models, the engineering design process is not yet considered well understood or adequately exploited ... there is a mismatch between the design process as it is currently modelled in theory and what actually happens in practice". More specifically, it is the 'front end' area where much rhetoric and exhortation has been expended, with little positive tangible results (Pugh, 1990). One reason for this may be a lack of awareness or a shortage of the required skills amongst practitioners. However, the models are inadequate in a number of respects.

Whilst most design activity is known to be of a non-original nature, the prescriptive models have been developed with a view to resolving original design problems, with their main emphasis on improving the quality of the design process. The models on the whole assume that design proceeds from an abstract analysis and problem formulation, with the splitting of problems into subproblems (i.e. problem-focused), whereas design in practice is often an interactive, recursive process which relies on prestructures and anticipation of possible solutions (i.e. product-focused).

Most models propose methodologies that are deemed to be valid to a group of problems, and they tend to assume idealised definitions of the various influences relating to the problem context, including the unconstrained availability of time and resources. Also, the design process is typically viewed as an autonomous or bounded activity in its own right. The simultaneous interaction and integration with other business processes, including the upstream strategic and marketing activities, and the downstream manufacturing, sales, and servicing activities are infrequently and inadequately dealt with. Few authors deal with the actual contextual implications for design, beyond recognising some of the sources of potential influence. Hence, it is normally assumed that when dealing with a particular problem, the designer is able to develop a suitable approach by interpreting the general models in the context of their company's environment and the requirements of the particular project and sub problems within the project. Therefore, there is a clear need to better understand the implications of influences within the design context to allow informed decisions about the type of design strategy to adopt in particular circumstances.

Chapter 3

Product Development Literature

3.1 Introduction

This thesis aims to develop improved models of the processes of engineering design and product development. If these are to subsequently provide the basis for improved management guidelines, it follows that the strategic, organisational and procedural features related to managing the product development process should be considered. Therefore, the product development and related literature will be reviewed in this chapter.

The chapter is organised around several issues and themes which are common to the major texts. For some of these, there is inevitably some overlap between the product development and the engineering design literature. Where appropriate, therefore, references are made to the key sources in the engineering design literature. Additionally, where the product development literature is seen as being deficient in some respect, other complementary areas are referred to. The project management literature, for example, is used to identify some of the essential characteristics of contract-based projects.

Product development is used as a general term in this thesis to refer to all forms and types of design and development activities. In some instances, however, it is used with a more precise intent. For example, distinctions are made between 'product development projects' and 'contract projects', and between 'product development projects' and 'product improvement projects'.

3.2 The Business and Product Development Environment

The business environment for the 1990s is changing in response to a number of economic, demographic, environmental, market, technological, and competitive factors. These and many other drivers have been considered by PA Consulting (1989), and as part of the recent Foresight exercise (OST, 1995). Related to these factors, there are a number of pressures driving product development. These have been widely referred to in the literature.

One of the trends in overall economic activity is the concept of the global market place in which the protection of local supply or the nature of local markets is being re-engineered. The local has become open to internationalisation and many local and niche markets have been assembled into global markets. Some products have also been developed for sale on a global scale (Harland, 1995). This global reach has been enabled through advances in communication, information technologies, new organisational and regulatory forms, and is frequently expressed through the operations of the multinational enterprise (MNE).

Competition is becoming increasingly intense and dynamic. This is leading to reduced product life-cycles as markets demand a rapid response to new technological developments (Cobbenhagen et al, 1990). Indeed, time as a generic competitive variable appears as a desire for greater speed, flexibility and responsiveness. Moreover, it has been referred to explicitly - like technology, quality, and productivity - as a strategic dimension of competitive advantage (Takeuchi and Nonaka, 1986; Bower and Hout, 1988; Stalk, 1988).

Greater competition and changing customer tastes are resulting in fragmented and more demanding markets (Piore and Sabel, 1984). Therefore, markets are becoming more multi-niched, require greater choice and customisation to be provided, and give rise to opportunities for the smaller firms. This demands not only higher standards of performance and quality, but increasingly differentiated products that provide unique solutions to problems. Full life service factors are resulting in increasing 'design for' considerations in terms of product reliability, the provision of spare parts and after sales service, the need to consider ease of maintenance, and eventual withdrawal. Moreover, alternative forms of competition are also being introduced. Instead of tackling competitors head on, a broader competitive approach focusing on the total offering to the customer, and which makes reference to market potential, may be taken. This allows the market definition and, therefore, the nature of competition to be changed (Johne, 1991). This total offering implies an understanding of the competitive criteria such as price, delivery (lead-time and conformance), technical specification (quality, reliability, performance), time-to-market, service, and so on, and distinguishing between what Hill (1985) terms as the order winning criteria and the order qualifying criteria of specific markets.

Many engineering firms provide technical advice to customers concerning the best use of the product. In considering the trend to increasing product differentiation, it is the total package as expressed in the level of differentiation of both the product and support provision which must be matched to individual markets. This is giving rise to the notion of one-stop shopping, and complete project managed systems integration projects in which the contractor does not just supply the key product, but has to co-ordinate the whole system that the product becomes part of (Alderman, 1992). This may include managing the entire engineering, procurement, installation and commissioning (EPIC) of the project on behalf of the customer..

Technology relates to product development through the product itself, the support tools to design and development, and in using new technology in the manufacturing process. It is a source of competitive advantage, and increased application of technology to increase the performance and enhance the features of a product makes it less susceptible to price competition (PA Consulting, 1989).

The increasingly competitive markets of the 1990s have been cited widely as creating several imperatives for product development. These are to meet the market and business demands for higher quality and higher performing products, in shorter and more predictable development cycle-times, and at lower cost. This requires the ability to identify opportunities, instigate the necessary development effort, and bring new products to market in a quick and timely manner. With an increasing number of product and process technologies, and reducing product life cycles, this must be done effectively and efficiently to enable more development projects to be progressed by the same or fewer resources, whilst meeting the markets stringent requirements for value, reliability and distinctive performance.

The features of the competitive environment outlined in the synopsis above are clearly general, and it would be reasonable to expect these pressures to influence different industries and firms to greater or lesser degrees. It is also reasonable to suppose that these variations will give rise to particular requirements for individual firms, which in turn will have implications for their product development practices. Therefore, the research methodology must capture the discriminatory factors, and ascertain their relationship to the various elements of development practice.

It is clearly important that the product development process is effectively and efficiently managed. It is a complex and difficult task, involving both intra- and inter-firm processes. Therefore, in recognising the general changes in the competitive environment, and through observation of the development activities of 'blue chip' companies, a considerable literature on best practice in managing the product development process has been developed. The scope and details of the product development literature will be discussed in the remainder of this chapter.

3.3 Scope of the Models

The product development literature is distinguishable from the engineering design literature by its broader concerns for the strategic, organisational and managerial aspects of developing new or improved products. The distinction, however, is not an arbitrary one. There are areas of commonality, the support tools, methods and techniques, for example. In addition, some of the more recent design models (Pugh, 1990; Ullman, 1990) address concerns of the product development literature, such as product teams, design and progress reviews, simultaneous engineering, specifications, and so on. Other models, Hales (1993) and Hollins and Pugh (1990), for example, are distinctly hybridised, dealing with both the design activity and the management context. Therefore, these models are referred to as appropriate in the developing discussion.

There is a continually expanding literature on best practice in product development. This includes several texts which focus on the broad organisational and managerial factors deemed critical to success (BSI, 1989; Hollins and Pugh, 1990; Johne and Snelson, 1990; McGrath et al, 1992; Smith and Reinertsen, 1991; Walsh et al, 1992; Wheelwright and Clark, 1992). Other texts deal with specific aspects of product development, including concurrent engineering (Hartley and Mortimer, 1991), specifications (BSI, 1991; Smith and Rhodes, 1992), product development strategy (Cooper, 1984), technology management (Fellowship of Engineering, 1991; Twiss, 1986), product teams (Takeuchi and Nonaka, 1986), design / engineering project management (Hales, 1993; Leech and Turner, 1990; Westney, 1992), design audit (Turner, 1982), and performance measurement and process improvement (DTI, 1993; Zairi, 1992a; Zairi, 1992b).

Those issues which are emphasised in the literature as being crucial to successful product development may be grouped arbitrarily under several generic headings. These include: senior management and strategy, corporate and project organisation, decision mechanisms, structured development process, project planning and control, front-end processes, technology management, the hierarchical nature of product development, and performance measurement. Each of these will now be discussed in turn with a view to identifying those features of best practice prescribed in the literature, including, the extent to which the details of these are related to the context of companies and projects.

3.4 Senior Management and Strategy

Corporate planning, and the philosophy and strategy which are implied or made explicit, have a decisive influence over the development process. Even if design and development is not explicitly mentioned in a firm's strategy and plans, this itself has implications for the way in which it is regarded, the way resources are allocated, and the management of the process (Walsh et al, 1992).

Studies have also shown that the existence or otherwise, and type of strategy a firm elects is related to the performance of the firm. Amongst a sample of firms, Walsh et al (1992) observed that the most financially successful firms had strategies that derived from a combination of objectives (meet user needs, leadership in design, increased profits) and involved increased effort in marketing, sales, manufacturing and product development. They also found that for smaller firms a set of narrower objectives plus a clear-cut strategy could be a successful alternative to the total approach. Furthermore, Treacy and Wiersema (1992) suggest that with an expanding concept of value to the customer, from some combination of quality and price to one that includes convenience, after sales service, and so on, industry leaders have typically narrowed their business focus, not broadened it. This may be achieved by focusing on one of three value disciplines - operational excellence, customer intimacy, or product leadership - while meeting industry standards in the other two.

With regard to product development, Johne and Snelson (1990) found that in a comparison of large British and American companies, the high achiever businesses were more likely to pursue an explicit product development strategy than less successful businesses. Cooper (1984), in a study of 122 industrial product firms identified five new product strategies each associated with different performance characteristics. Of these, a strategy featuring a balance of technical innovation with a strong market focus, and which targeted high potential growth markets resulted in by far the best performance. Similarly, amongst a study of 10 small technology-based firms, covering 79 products, those that over the course of their evolution primarily focused on developing their core technologies for application in familiar markets tended to outperform those that did not (Meyer and Roberts, 1986). It was also determined that those firms that developed products for new market areas were most successful if they directed their efforts on their existing technology.

Strategic considerations are clearly of some importance and arrived at through consideration of a variety of intra- and extra-corporate influences. The aim of this thesis is not to address the performance impact of product strategy per se, nor to identify what strategies companies should pursue. However, having acknowledged the importance of the product development strategy, and the need for it to be carefully considered, it is necessary to understand the strategic possibilities and to relate these to product development practice.

A product development strategy is the starting and reference point for the development of new and improved products. It provides the framework used by senior management to make decisions and set priorities between competing and complementary development needs (McGrath et al, 1992; Wheelwright and Clark, 1992). Companies therefore need a well considered strategy, formulated on the basis of, and consistent with, the business strategy (BSI, 1989). As such, it should define: the types of product to be developed over a particular time-scale; the markets to be targeted; product features, differentiating factors and customer benefits; types of technology to be used, research areas, and how the technology is to be introduced; the means for prioritising between product developments; and the resources required (BSI, 1989; McGrath et al, 1992; Wheelwright and Clark, 1992).

The product development strategy establishes the appropriate types of project for a business. This is the starting point for constructing an overall development plan representing the mix of projects over the planning horizon. Wheelwright and Clark (1992) have suggested that this mix of projects is influenced by a number of factors, including, industry maturity, the rate of technological innovation in the industry, the firm's capabilities, and its strategy. However, they do not indicate how these factors influence the mix of projects.

In managing product development projects a distinction can be made between the different types of project. These can be related to the design disciplines appropriate to a particular task (Hollins and Pugh, 1990), and by recognising the implications for strategy, organisation, personnel and control procedures (Johne and Snelson, 1990).

The categorisation of projects, therefore, is clearly of some importance and several schema have been proposed. These are usually based on the degree of change represented by a development project. Unlike categorisations of design activity, which tend to capture the degree of functional change in the product (see, for example, the definitions of original, adaptive and variant design in Chapter 2), it is common in the product development literature to reflect collectively the degree of change in the product, the production process, and the market. For example, a most basic, and widely used distinction has been made between new product development and product improvement (Johne and Snelson, 1990). Wheelwright and Clark (1992) have defined four primary "types" of development project: research and advanced development, radical breakthroughs, next generation or platform, and product enhancement or derivative projects. An alternative perspective is taken by Lucas (1992). Various forms of project, both operational and developmental, are defined as being either runners, repeaters or strangers. However, such schema are general, and it is important to recognise that more specific and tailored definitions may be useful in specific circumstances (Wheelwright and Clark, 1992). The categorisation of strategy and project types are clearly of some importance and, therefore, these must be considered carefully by this thesis.

Many authors have referred to the importance of senior management's role in product development. Senior management has the overall responsibility for the design and development activities. It is responsible for developing, maintaining and implementing the product strategy, and for the approval and funding decisions of individual projects. Also, most authors refer to the importance of distinguishing clearly the relationship between, and the responsibilities of, the senior management and those they empower with authority to implement the project activities, and establishing clearly defined project objectives and review criteria. Therefore, senior management's influence on product development processes is a significant one, especially in the early marketing and project initiation stages. However, investigations have shown that whilst management's ability to influence a development project's outcome is highest in the early stages, management's' actual involvement typically is very limited (Wheelwright and Clark, 1992). Management tends only to become significantly involved late in the project as problems arise, by which time its influence is diminished, and the cost of change is high (Hartley and Mortimer, 1991).

Several mechanisms have been recommended to ensure senior management's role is effectively carried out. These include the formulation of a product development strategy, which was discussed above, and procedures for the initiation, approval and review of projects, which will be discussed later in this chapter. Because of the importance accorded by the literature to these activities this thesis will investigate the extent to which these are being implemented by companies. Also, given their importance, there is a need to establish whether the recommendations have general applicability to all companies, and what form their implementation should take under different circumstances.

3.5 Corporate and Project Organisation

3.5.1 Corporate Organisation

The corporate and company organisation needs to reflect the objectives and needs of the business, its customers and markets. Unfortunately, different needs - stimulating radical change or managing the business effectively - may require different organisational structures. Thus, what constitutes an effective organisational design is not easily defined (Johne and Snelson, 1990).

In responding to a generally more competitive environment and the need to create a more effective and organic internal environment, a move away from traditional functional structures it has been observed in companies, and widely recommended by the literature. Significant functional specialisation, it is claimed, may constrain change by limiting lateral communication and interfunctional collaboration. With functionally-based structures, operational processes are often fragmented between functions and departments. This gives rise to numerous interfaces at their boundaries and, therefore, frequent changes of ownership and complex information flows. As a consequence, there is often no overall ownership and responsibility for a process, a loss of customer focus, greater difficulties in planning and managing activities, more non-value-adding activities, complex support requirements, and longer lead-times (Lucas, 1992).

To overcome these organisational shortcomings several alternative approaches have emerged. These are based on the adoption of a systems approach to the design of processes and organisational structures. The systems approach requires consideration of the organisational elements as a whole, rather than looking at their individual roles. The approach taken may range from incremental business process improvements, which streamline or simplify processes without radically changing the process or organisation (Harrington, 1991), and which have their roots in the total quality initiatives of the 1980s, through to more holistic and radical restructuring of the organisation around redesigned / re-engineered key business processes (Davenport and Short, 1990; Hammer and Champy, 1993).

Such approaches enable the business to operate through responsive customer-focused cross-functional processes - the product introduction process, for example. These are integrated on the basis of co-located, multi-skilled groups, each of which has ownership and responsibility for a whole process. Integration is achieved either physically or by reporting line to a cross-functional manager or team leader (Lucas, 1992). This, it is claimed, leads to a flat organisational structure with fewer layers, comprising sets of teams, some of which are permanent operational groups, while others are temporary development or project teams.

By focusing on the tasks to be done, which do not usually fall within functional boundaries, various arrangements are available to remove individuals from their functional roles. In moving from functional structures, the organisation chart can vary from matrix forms, business centred forms, and highly decentralised separate project forms. It is apparent, that in developing the most effective organisational structures, a variety of approaches may be required.

When considering organisational structures, it is evident that a distinction needs to be made between the corporate organisational structure relative to an establishment, and those of the establishment itself. Furthermore, a particular feature which needs to be discerned, concerns the degree of autonomy possessed by an establishment within a corporate context, and the centralisation or decentralisation of activities. In the context of corporate R & D management, for example, Coombs and Richards (1993) in a study of 25 major UK companies, have recently identified a partial reversal of trends during the 1980s to decentralise R & D operations to the business unit level.

3.5.2 Project Organisation

Focusing now on organisational issues related to design and product development projects, these resources similarly require planning and organisation within an effective structure in order to meet the corporate objectives (BSI, 1989). To suit the mix of project types, a combination of project structures are available, and preferred forms of these have been suggested as being most appropriate. A review of the literature within both the product development and project management fields indicates differences in the use of terminology, but also subtle variations in emphasis. This creates some confusion, so that developing a definitive typology of available project organisations is not easy. However, these may be characterised as representing a general transition from the pure functional organisation, through a number of matrix forms, to autonomous team based approaches. Viewed holistically, six primary types of organisation may be distinguished. These are depicted in Figure 3.1. The terminology used in Figure 3.1 is appropriate to development projects and, to avoid confusion, will be used throughout this thesis. For completeness, however, some of the alternative terms used to denote the different forms of organisation are included in the description below.

With a functional form of project organisation (Figure 3.1a) the project is coordinated by the functional management. Each functional head is responsible for managing the activities within their respective function.

A project manager or project coordinator has overall responsibility for the project and interfaces with the functional managers in a project management organisation (Figure 3.1b). The functional managers in-turn organise the work within their functions according to the agreed programme.

With matrix project management (Figure 3.1c) there is dual control between a project manager (or project coordinator) and the functional managers. All personnel are permanently assigned to their functional area, being responsible to their functional managers as to how the work is to be undertaken. In the pure matrix form, the functional personnel are completely responsible to the project manager for what they do and when they do it. Alternatively, acting in a coordination or liaison role, the project manager may have limited influence over the work. This form of organisation has also been referred to in the product development literature as the lightweight team structure (Smith and Reinertsen, 1991; Wheelwright and Clark, 1992).

In the core project team organisational form (McGrath et al, 1992), a strong project leader exerts a direct, integrating influence over the functions (Figure 3.1d). The project manager (or team leader) has immediate access to, and responsibility for, all those involved in the project, and supervises their work directly through the senior members on the team. In this case the individuals are assigned to projects for the duration of their specialist work. This organisational structure is alternatively referred to as the heavyweight team (Wheelwright and Clark, 1992) in the product development literature, and is also known as hybrid project management in the project management literature.

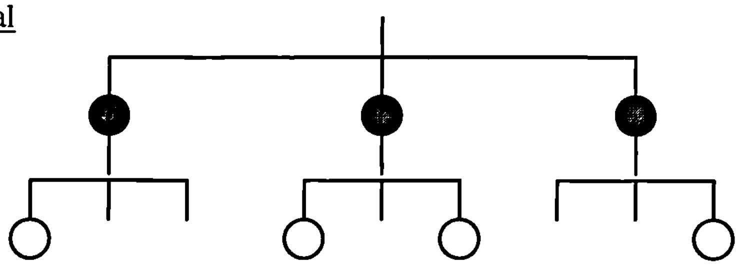
Figure 3.1f illustrates the autonomous team (McGrath et al, 1992; Wheelwright and Clark, 1992) or the separate project form (Smith and Reinertsen, 1991). It is referred to as line project management by the project management literature. Direct control of all project matters is under the control of the project manager (or team leader). The team is removed from the functions and dedicated to the single project, and co-located where feasible.

Sometimes it may be necessary for a project to be sub-divided into a number of sub-projects (Figure 3.1f). In this multi-project structure (Lucas, 1992), a project manager has overall responsibility for the project. The sub-projects are individually structured according to the most appropriate of the project organisations indicated above.

The key parameter which distinguishes between these is the relative authority of the project manager (or team leader) and functional manager over resources and decisions about the product (Smith and Reinertsen, 1991). With the translation from functional through to the project-orientated structures the team members progressively decrease their functional ties and improved interdisciplinary cooperation and communication is facilitated.

Beyond these six primary types of structure, more specific variants for organising and coordinating design and development projects have been recognised. Examples of these include: the customer-vendor approach, programme coordinator, multiple functional project managers, and project team by phase (McGrath et al, 1992); and development committees, informal groupings, and individual coordinators (Walsh et al, 1992). This demonstrates that while a basic division into functional and project team approaches may be easy to comprehend, in practice, many different forms between the polar extremes are used. The potential scope of this is apparent from the analysis of Holt (1987). He has developed a four-fold typology to identify ways of organising routine product development, ways of organising innovation, integration methods, and management style. In principle, this creates the possibility for many permutations. According to Walsh et al (1992), there is a whole spectrum of approaches to deal with the different degrees of cooperation required and, moreover, these may vary at different stages of the product development process. How these vary, however, is not adequately dealt with by the literature, particularly during the project initiation stages.

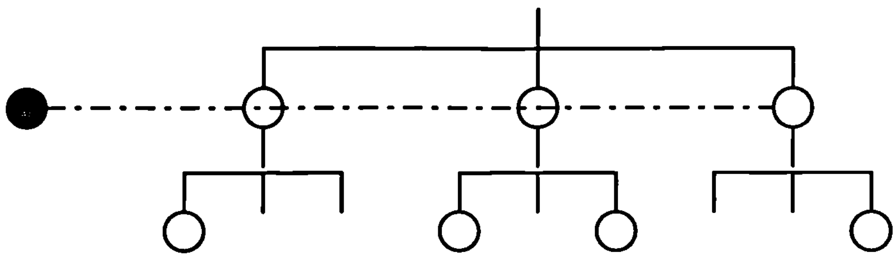
(a) Functional



With a functional form of project organisation the project is coordinated by the functional management. Each functional head is responsible for managing the activities within their respective function.

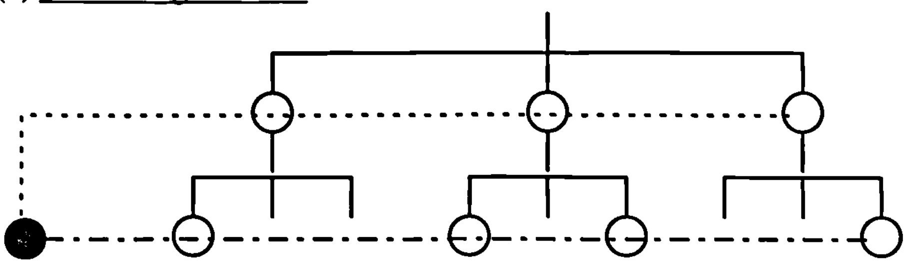
The remaining project organisations (b to f) are project-based forms of organisational structure.

(b) Project Management



A project manager or project coordinator has overall responsibility for the project and interfaces with the functional managers. The functional managers in-turn organise the work within their functions according to the agreed programme.

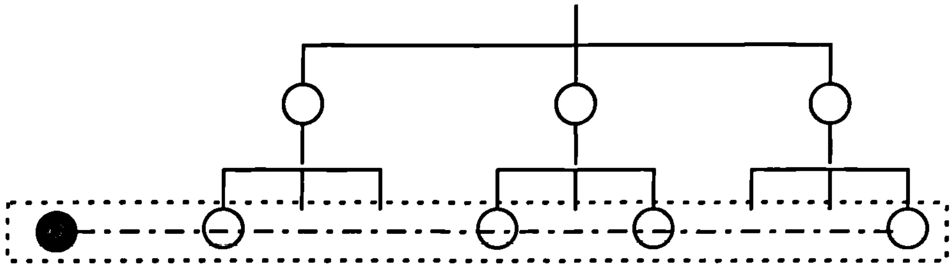
(c) Matrix Organisation



With a matrix form of project organisation a project manager or project leader operates notionally within a matrix structure. This is often in a staffing (i.e. coordinating) role as regards the project's activities. The functional managers will typically have some influence on how activities are performed and the nature of their outcomes. This structure is sometimes referred to as a lightweight team.

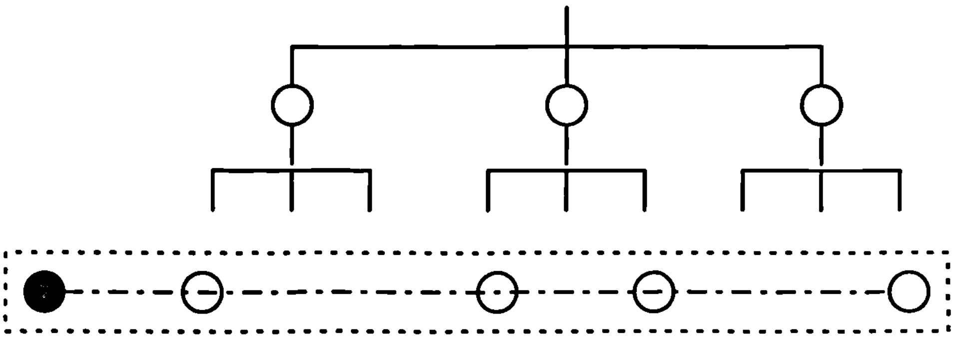
Figure 3.1: Basic forms of project organisation structure

(d) Project Team



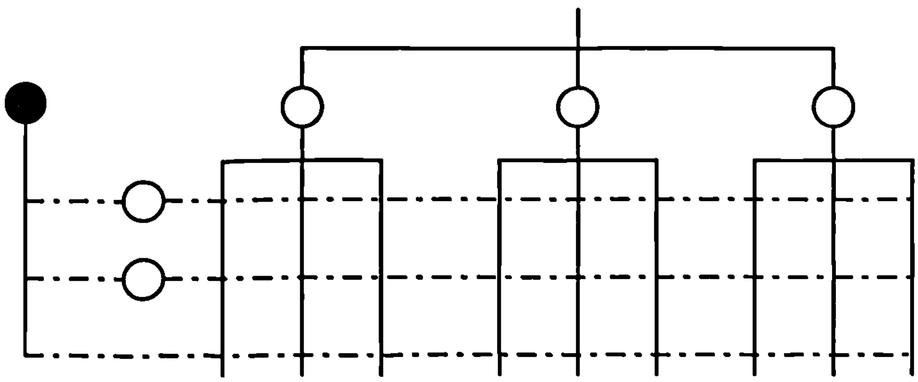
This is sometimes also referred to as a heavyweight team since the project leader or team leader exerts a strong influence over the project activities. The project team members usually retain their functional ties. Having agreed to assign individuals to the project team, the functional managers exercise no direct influence over the team's activities.

(e) Autonomous Team



This represents a form of project team in which the team is separated from the functional organisation.

(f) Multi-project Organisation



A project is sub-divided into a number of sub-projects. A project manager has overall responsibility for the project. The sub-projects are individually structured according to the most appropriate of the project organisations indicated above.

Figure 3.1 (Contd.): Basic forms of project organisation structure

Selection of the most appropriate form of project organisation from the range of choices available needs to take account of a variety of factors. For example, Walsh et al (1992) has identified these as being the size of the firm, general management structures, the type of product, the level of technology used, the nature of the market, speed of response required, through to idiosyncratic factors such as specific staff relationships, or the abilities of certain individuals. In general, the relationship between these factors and their influence on the choice of project organisation are not dealt with by the product development literature. When recommendations are given they tend to be predicated on assumptions of the nature of today's competitive environment and, hence, supported by some firm performance data (for example, see Johne and Snelson (1990) and Walsh et al (1992)), have been associated with a fairly universal recommendation for the adoption of interdisciplinary team-orientated approaches which break down interfunctional barriers (Bower and Hout, 1988). Indeed, it has been claimed (Smith and Reinertsen, 1991) that the functional organisational forms have generally been superseded by the project team-based approaches.

However, there are circumstances in which a functional structure has relevance. These are a reflection of its relative strengths and weaknesses. Cited strengths are that those who control the resources also control performance within the functional area; it supports skills specialisation and career development; and specialist skills may be focused on particular technical needs. Conversely, a number of weaknesses have been cited. Generally, those involved in the projects' details are not responsible for the overall results, and the specialists may focus on technical excellence rather the requirements of the overall system. To be effective, tasks must be subdividable at the outset and be somewhat independent of each other. As this is not always feasible, it may often be difficult to achieve adequate integration and coordination.

Consequently, it has been suggested that a functional organisation may be appropriate where one project is worked on at a time, allowing managers to be focused, or when many small development projects (too small for individual development teams) are being undertaken simultaneously (Smith and Reinertsen, 1991); for small firms, and firms in mature industries (Walsh et al, 1992); where technical excellence is paramount, effective resource utilisation is required, and development speed is not critical (Wheelwright and Clark, 1992); and for projects characterised by a defined set of steps, in small companies, with little product variability (McGrath et al, 1992). According to much of the literature, however, the pervasive nature of change means that even for firms characterised by some of these variables, it is increasingly necessary to adopt a project orientated approach to product development.

Lucas (1992) propose that the more routine runner and repeater projects (i.e. minor modification or product derivative projects) are most appropriately progressed through the normal functional organisation with a nominated lead functional manager who owns and manages it. Conversely, the more radical stranger projects (i.e. product development projects) should be progressed by a project team assigned to the project from their respective functions, and under the control of a project team leader. Similarly, having made a distinction between product improvement projects and new product development projects, Johne and Snelson (1990) suggest that high achieving firms display certain common organisational characteristics. For product improvement they encourage interdisciplinary cooperation, based around a multi-functional team of line managers who are operationally close to specific market places. It is also suggested that separate high level organisational units should be set up outside the mainstream organisation dedicated to handling new products. In this way new product developments are considered as a supra-divisional activity to be undertaken by business teams from idea through to commercialisation. It is important to note, however, that these recommendations follow from studies of large international companies, and it would not to be correct to assume that they are necessarily transferable to smaller firms. As Oakley (1984) acknowledges, although small firms face many of the problems associated with product design in large companies, the emphasis may be different. Furthermore, although they possess some advantages in managing product innovation, such as good internal communications, they have to cope with other problems and constraints (Roy and Potter, 1990). It follows that there is a need to establish more clearly what forms of project organisation are appropriate to companies and projects having different characteristics to those on which much of the best practice literature is based.

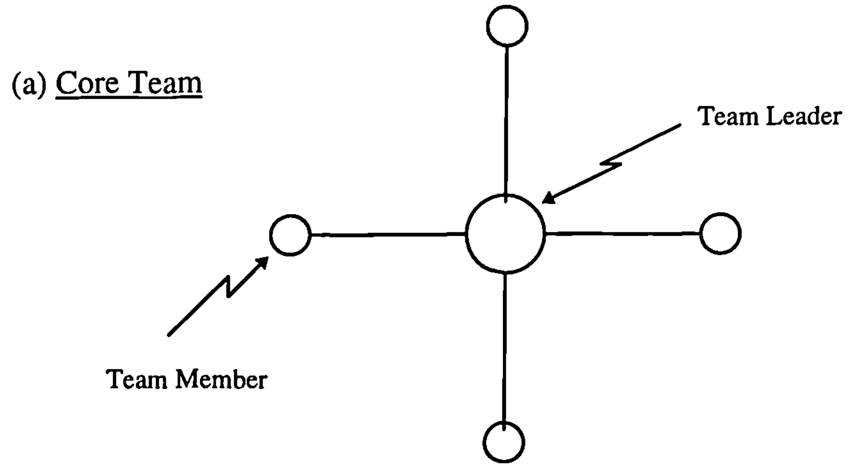
Projects need to be organised to achieve effective communication, coordination and decision making. Firstly, to be effective the project group needs to be empowered with authority and accountability for achieving the project's requirements, and with the provision of the necessary resources. Empowerment is enabled by clearly distinguishing the responsibilities of the executive management for strategic product decisions and those of the functions (or team) for tactical or implementation level decisions (McGrath et al, 1992). Secondly, with project-orientated approaches, it is necessary to consider the allocation of authority and responsibility between the project manager (or team leader) and the functional management. It is generally agreed that the matrix form of project organisation, with a project coordinator or lightweight team leader, suffers from a poorly matched and often conflicting arrangement of these. The autonomous team form, by severing ties to the functional structure, overcomes such difficulties. However, this organisational form has generally been associated with large organisations and their need to create independent, entrepreneurial environments - innovative developments or new business opportunities, for example. Therefore, of the available project organisations, forms of the hybrid project organisation, such as the core project team approach, in which the team leader is empowered with clear authority for all project related issues, are commonly prescribed in the product development literature. Thirdly, the literature cites the need for interdisciplinary integration. A strength of using a team-based approach is that it provides an effective means for communication. Moreover, the literature strongly recommends that all the main disciplines (Marketing, Engineering, Production, etc.), and suppliers and customers, are represented on the project team.

3.5.2.1 Team Features

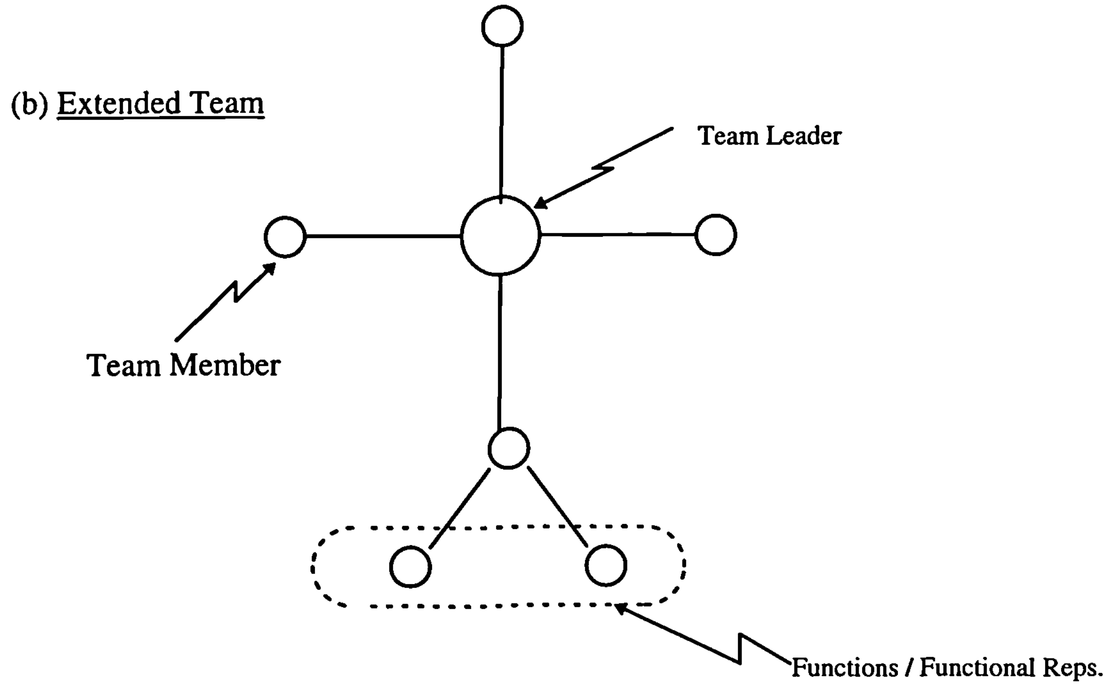
It is generally acknowledged that, due to the amount of time that must be spent communicating in large teams, a single project team should not comprise more than around ten individuals (Figure 3.2a). The forms of team organisation appropriate to larger projects is not adequately dealt with by most of the product development literature. However, extending the team into the function by having team members interface with individuals assigned to the project from their respective departments is one possibility (Figure 3.2b). This form of team structure has been referred to as the Core Team (McGrath et al, 1992) and as Design Circles (Hollins and Pugh, 1990).

There are conflicting views in the literature as to whether, and under what circumstances, team membership should be a permanent or temporary, and full-time or part-time commitment; whether a teams makeup should change as a project progresses; and at which stage in a product's development the team should hand over responsibility. However, the literature clearly recommends that the core team membership predominantly should be permanent and full-time. Indeed, it has been shown (Wheelwright and Clark, 1992) that beyond two projects, the productivity of a development engineer decreases inversely with the number of projects concurrently assigned.

Communication is more likely to occur between team members the closer their proximity to each other (Allen, 1977). Hence, several authors have referred to the need for co-location of teams as a means to improve their communications and organisational effectiveness. However, under certain circumstances - large projects and multi-site developments - physical co-location is not wholly practicable. In fact, Smith and Reinertsen (1991) qualify this by referring to the need for 'proximity'.



A single core team comprises the team leader (or project leader, etc.) and the representatives of the different functions or disciplines.



With the extended team approach the core team members interface with individuals assigned to the project from their respective departments.

Figure 3.2: Project team structures

3.5.2.2 Dominant Project Modes

Johne and Snelson (1990) establish that distinguishing between the organisation of new product development and product improvement projects (see Section 3.5.2) allows the application of different managerial systems and measures of performance. Notwithstanding this and, although it may be desirable for firms to match the project organisation and systems to each specific project's requirements, in practice it is not feasible to 'pick and mix'. A company's development activities will tend to involve particular types of project and, therefore, it will structure itself according to these, and will acquire proficiency in handling such projects. In this way, it develops what has been termed by Wheelwright and Clark (1992) as a 'dominant mode'. They argue that it is necessary for a company's dominant mode(s) to match its environment and product development plans. It must develop relevant capabilities (resources, skills, training, systems, etc.) in line with this, but, which also allow it to apply alternative modes for other less frequent, but nevertheless essential, types of project. To be effective, however, these need to be compatible with the approach of the dominant mode(s). For example, it would be unwise for a company accustomed to a functional approach to suddenly adopt a project team approach.

3.5.3 Contract Projects

The discussion so far, has identified preferred implementations of the six primary organisational types for undertaking projects to develop new or improved products for general market needs. Design projects, however, are often undertaken to specific customer requests. Typically, this may occur under the terms of an order or a negotiated contract, and may involve either the design of a new product or the customisation of an existing design. Projects of this type are not dealt with adequately by the product development literature. An insight, however, may be gained from the literature on project management, particularly that dealing with manufacturing projects, but also large capital projects.

Lock (1988), illustrates the organisational possibilities for a manufacturing firm moving from routine production of standard items, including some minor design variants, through to more complex projects. A basic functional structure is able to deal with the former. However, when a manufacturing project of more significant engineering content is compared to routine production, there is a change in emphasis from mainly line-based relationships, to more complex inter-functional connections. If the project is to be effectively managed, the nature of this has to be accounted for when determining the organisational structure. In more complex circumstances, someone must have overall accountability for the project, rather than responsibility being shared between the line managers. Thus, when a more complex project is undertaken alongside routine projects, a project manager may be used in a functional capacity to coordinate the work. Where several projects are being handled, a matrix structure may be adopted, with the project managers exercising a similar role.

Other alternatives would be to develop project team (hybrid project management) or autonomous team (line project management) structures for projects. With regard to these, and in addition to their relative merits, it is also necessary to consider the scale and duration of a project. According to Lock, large projects of long duration will usually require the formation of teams. However, with autonomous teams (line project management), unless the project is of sufficient size, the individual specialist groups assigned to perform the various activities will prove too small to allow adequate flexibility of resources. Thus, functional or matrix organisational forms are indicated for firms dealing with a number of small projects, in which the resources or timescales needed are limited. In order to maintain flexibility, a firm will sometimes adopt a matrix organisation in general, but establish teams for certain projects as the need arises. This viewpoint appears consistent with that of Lucas (1992) mentioned earlier in terms of the similarity of approach prescribed for handling routine manufacturing projects and stranger projects respectively.

It is also appropriate to consider the nature of the project management role. Lock (1988) states that in a small firm this may be conducted on either a part-time or full-time basis by a functional manager, or some other individual. This role may involve one or several projects simultaneously. Large companies may even have whole project management departments. Additionally, he suggests that the scope of this role requires a project manager to be at least of comparable seniority to a departmental manager.

Where contract projects and product development projects have comparable attributes, is reasonable to anticipate that the appropriate choice of project organisation would be common to both. Yet, by their very nature, contract projects may be of a much greater scale, and they may also be more numerous. Therefore, it may be argued that, even where they have comparable characteristics, there will be differences in their organisational details. Because of this, and the fact that contract-based projects are not dealt with thoroughly by the product development literature, this thesis will focus on the organisational forms appropriate to the different types of project.

It may be concluded, that after consideration of several generic forms of project organisation, and the possibilities for differences in their details, both at a general and project level, firms have a large number of organisational options available. Clearly, the appropriateness of an organisational structure is determined by the extent to which it furthers the objectives of the firm, and is conditioned by a variety of factors within the context of the firm and the particular project. Some of these have been inferred from the literature. However, the product development literature is presumptuous about the nature of the competitive environment and the types of firms and projects concerned. In seeking to develop an improved understanding of the organisational issues surrounding design and development projects, it is necessary to identify which forms of organisational structure are appropriate to the range of possible company and project characteristics.

3.6 Decision Mechanisms

All types of project require effective monitoring to ensure that the product reaches the customer as conceived, on schedule, and that resources are not expended inappropriately. This requires decision making mechanisms to be established both in relation to the initiation and execution of the project, and the progressive evolution of the product.

3.6.1 Project Initiation and Review

The product development process has been likened to a funnel (McGrath et al, 1992; Wheelwright and Clark, 1992) and managing this involves three distinct challenges. Firstly, the mouth of the funnel should be sufficiently wide to enable the identification of many product ideas. This includes concerns for the processes of knowledge acquisition. The important mechanisms and procedural requirements relating to this will be reviewed later (see Section 3.9). Secondly, the neck of the funnel needs to be narrowed so the resources are focused on the most attractive of these ideas. Finally, the selected projects need to be effectively managed through to their successful completion.

To promote clarity, ease planning and control, and manage risk, both management and the project need a division of the project sequence (Andreasen and Hein, 1987). Therefore, in reducing the number of project alternatives and subsequently monitoring their execution, several authors have emphasised the requirement for there to be a number of screening or review points over the course of the project. These enable the feasibility of the project, its risks and results to be evaluated and adjusted if necessary. Typically, for product development projects, this will require a go/no-go/redirect decision to be made, where approval, funding and empowerment is sought from the senior management group by those responsible for progressing the project (McGrath et al, 1992).

Wheelwright and Clark (1992) recommend that the project initiation stages involve a two-stage screening process. Following preliminary idea generation, development and proposal, an initial screening review should occur. This should be undertaken periodically (monthly or quarterly) either by a mid level group of functional managers or a cross functional team. This need not be a go/no-go decision point. Its basic aim is to determine what activities are necessary to provide any additional information to enable the second project approval decision to be made. The product proposal or initial business idea will often be incomplete in some respects concerning the degree of definition of the market, the product, and its production (Andreasen and Hein, 1987). Some form of preparatory work, therefore, may be required to provide a well defined project - market investigations, identification of sources of technology, and feasibility studies, for example. In particular, it may be necessary to instigate advanced development projects concerning the proposed product or production process technologies (see Section 3.10).

The importance of progress review meetings for monitoring the execution of projects, and which form part of an ongoing system for reporting progress in terms of time, cost and performance, is emphasised by the project management literature. Leech and Turner (1990) suggest that this will usually involve progress review meetings on a six monthly or quarterly basis, coupled to a system of regular documented reports. However, Wheelwright and Clark (1992) claim that using regular (e.g. monthly) meetings as the primary review mechanism for product development projects encourages management either to focus on the wrong problems or to deal with them inadequately. Hence, most authors recommend that these reviews should occur at key milestones in the process. Andreasen and Hein (1987), describes how these should occur during periods where the degree of definition or rise in knowledge concerning the market, product, and production disciplines are simultaneously static. On this basis, they suggest that several key review points will generally be appropriate, although this will ultimately depend on the nature of the development project. Furthermore, reviews should be built into the project schedule and conducted in a formal and structured manner, in which case, having too frequent reviews is likely to cause project delays (Smith and Reinertsen, 1991).

In addition to major project reviews, certain meetings will be necessary for the routine management of projects. Smith and Reinertsen (1991) suggest that routine project monitoring issues may be handled informally through regular (e.g. weekly) meetings between the project manager, team, and executive representatives as appropriate. However, where exceptions to the agreed scope arise, which may affect the outcome or direction of the project, then a full review may be required.

The nature of project reviews is discussed briefly by McGrath et al (1992). These must be related to the increasing quantifiability of project information. In particular, the specific requirements of each stage need to be modified to suit the particular company. There will be some commonality in the early stages which concern strategy, market, specification and planning issues, but there will be variations based on industry, company, market and product characteristics in the later stages. They do not, however, elaborate in any further detail.

More specific details are given elsewhere. BSI (1989) advocate that product development proposals should be reviewed regularly in terms of the market needs and utilising technological possibilities in potentially profitable markets compatible with the risks involved, being consistent with the product development strategy and having clear product development objectives. Wheelwright and Clark (1992) similarly emphasise the fit with technology and the product development strategy, but also the potential for executing the aggregate development plan, and the appropriate use of the development resources. More detailed lists for project evaluation and selection have also been developed by Twiss (1986) and Becker (1980). Notably, Becker distinguishes, and categorises, the criteria according to research, product development and process development.

A study by Dean (1968) has shown that very few criteria are actually used in practice. Only two factors - potential market size and profitability - were considered in project selection and evaluation decisions by more than half of the firms surveyed, and the majority of criteria were not used by over two thirds of the firms. It is evident, therefore, that many of the criteria which have been proposed for selecting and evaluating projects, and which are typically used in practice, tend to relate to assumptions of successful outcomes (i.e. forecasts for sales, market size and market share, profitability, etc.). They take no account of factors relating to the delivery of these outcomes and / or which may influence their realisation (i.e. resources, capital and revenue requirements, company's proficiency for executing the project activities, risks and probability of success, product need, compatibility with the companies strategic policies and objectives, competitor position, compatibility and effect on other company products, etc.) and over which the company has some influence. It follows, therefore, that these controllable variables also should be taken into account.

Project reviews for monitoring the execution of projects should be concerned broadly with issues of project status and future requirements, including those relating to targets set for performance, cost and timescale (BSI, 1989). According to Twiss (1986), the specific project screening and review criteria used over the cycle of a project will differ with the individual company and industry. Therefore, while it is possible to compile a comprehensive list, it may not have universal applicability. Although many individual criteria are likely to be of limited importance to the majority of project decisions, each may be of some significance at some point or other in time. It follows that firms need to develop their own definitions of which criteria apply to each of the project review points. The most common means for formally structuring the use of review criteria are through the use of checklists. Twiss (1986) also discusses the use of project profiles and merit rating schemes as means for engendering a more rational or quantitative approach.

Requirements relating to the preparation of information may be inferred from the different project selection and review criteria. Although some criteria apply to several review points (e.g. projections of market share, sales revenues, costs, and so on), the nature of the activities associated with this information, will change as a result of its increasing quantifiability. The cost of compiling the information for an exhaustive review may be significant and, therefore, some judgement is necessary when determining the critical criteria and the detail of information required.

3.6.1.1 *Contract Projects*

Much of the foregoing discussion has been concerned with the primary project review mechanisms required by product development projects. Decision making mechanisms are equally important to contract-based projects. Comparison of the recommendations of the product development literature with those of the project management literature, suggest that there are broad similarities.

The notion of the product development process funnel was discussed above. Although not discussed in these terms by the literature, the process of bidding for potential orders may also be conceived in this way. Here the aim is to ensure access to sufficient customer enquiries, and to identify and develop those which are considered most suitable. If the firms' proposal leads to the award of an order, the project will similarly require effective management.

Upon receipt of an enquiry, an initial decision on whether to bid must be made. This must consider many factors, including those relating to the type of project, availability of resources, profitability, technical and financial risks, and the likely time and cost to be incurred in developing a proposal (Hales, 1993). Similar factors, including technical resources, facilities, work load, competitor position, delivery and risks are referred to elsewhere (Hajek, 1977; Leech and Turner, 1990). Subsequent to this, and prior to the final review and submission of a bid (usually by the Board of Directors), a number of coordination meetings, plus intermediate and final reviews are usually required (Leech and Turner, 1990). In overall terms, however, the enquiry review and tender review represent a two-stage screening process that is similar to the literature's recommendation for product development projects.

The general requirement for undertaking project review meetings as part of an ongoing system of reporting and managing a project's progress during its execution, including their general details, has been discussed above (also see Section 3.8). However, with a contract-based project, the firm becomes committed to the completion of the project upon acceptance of the order. Clearly, in these circumstances the review process is not concerned with go/no-go type decisions, but evaluating the progress of the project to-date and taking corrective actions as necessary. Westney (1992) discusses the management of multiple small projects, a situation which often arises with contract-based projects. He suggests that when multiple small projects are being simultaneously project managed, the systematic, in-depth, managerial review of project status is unlikely, and a 'management by exception' approach is most probable. This is made possible by reporting formats which highlight problem areas. Notwithstanding these points, it is not clear from the literature what form of reviewing mechanisms are appropriate to different types of contract-based project.

3.6.2 Design Review

In addition to the project review process, procedures are also required to review the product's design and to compare it against the requirements of the design brief. BSI (1989) requires that at the conclusion of each phase of the design's development, a formal, documented and critical review of the design results should be conducted. Leech and Turner (1990) recommend that specific review points should be incorporated into the project schedule. The review schedule will depend on the projects significance, and the complexity and use of proven components and subassemblies. The specified timing of the different design reviews has been grouped into generally applicable milestone categories. Turner (1982) identifies these as follows:

- preliminary design review of the concept or proposal;
- intermediate design review, before the preparation of detail drawings, for which there may be several depending type of product or project;
- pre-release design review, before release for pilot production; and
- final design review, before start of full production.
- An additional final acceptance review, preceding delivery and handover to the customer (i.e. for contract projects), may also be needed in some instances.

In contrast to recommendations for structured design review schedules, Smith and Reinertsen (1991) indicate a preference for frequent and less formally managed design reviews. This they argue can help accelerate a project. However, this apparently contradictory approach may in fact be seen as complementary. In a similar manner to project reviews, design reviews may likewise be based on a two-tier approach comprising structured reviews at key milestones, and more frequent, informal, reviews at the intermediate design confluence points. This is an area which requires further investigation and clarification.

The precise nature of the design reviews will change over the course of a project. The individuals involved will vary according to the nature of the product or project, and with the type of review being undertaken (Turner, 1982). Design reviews have differing objectives to project reviews and, hence, whilst the members of the review meeting need sufficient authority to make decisions, design reviews should involve disciplinary peers rather than senior management. Also, due to their differing objectives and operational needs, the two types of review should be dealt with separately (Smith and Reinertsen, 1991).

The instigation of a post project audit is also stressed by both the project management literature and the product development literature. This final evaluation has two aspects: the evaluation of the product and its specification, and the evaluation of the project and its management (BSI, 1989). The former (product review) is concerned with validating that the various attributes of the design, the manufacturing process, sales, logistics, service support, and so on, are compliant with their requirements, and to identify any necessary changes on this or subsequent products. The latter (project audit) is a systematic review which seeks to identify and report to senior management opportunities for improvement and to make recommendations for future projects and, therefore, is an important means for companies to improve their design and development processes. Different organisational mechanisms for facilitating this have been suggested. For example, BSI (1989) propose that the project manager should initiate the review process, whilst Wheelwright and Clark (1992) and McGrath et al (1992) discuss the use of a multi-functional team or process engineering group. Turner (1982) advises that a product planning group (not the original designers) should undertake the product evaluation review

It may be concluded that there is a clear consensus in the literature as to the importance, and basic requirements, of project screening and approval mechanisms, project reviews, design reviews and post project audits. However, the literature's recommendations for implementing these, particularly with regard to contract-based projects, are sometimes contradictory or unclear. For example, it is not clear for the different types of project, how frequently the various reviews should occur, whether they should be pre-planned or ad-hoc, and whether they should be undertaken on a formal or informal basis.

3.7 Structured Development Process

The establishment of a structured process or standardised procedure is widely referred to in the product development literature. This essentially defines the sequence of activities and events, including the decision making and review mechanisms, their interdependencies, and the terminology associated with the development process.

Procedures may be heavily documented or just stored in the project leaders head, be rigidly adhered to or used flexibly, and be sequential or overlapping. Reviews of product development practice (McGrath et al, 1992) have identified three general deficiencies in the structure of companies' development procedures. Firstly there are companies without any defined structure, which effectively requires a redefinition for each project. Secondly, many have defined procedures, but they are not followed. Again this results in a project-by-project reinvention cycle. Thirdly, are those firms where an inherently inefficient process is proceduralised and followed. This institutionalises problems into the process. What is required, therefore, is a structured definition of good practice. A structured design and development process, that achieves a compromise between having no structure and too much structure, provides an overall framework which can accommodate flexibility, and enable process improvements to be consistently achieved over successive projects. Various benefits are claimed to result from establishing a balanced process structure. McGrath et al have listed some of these, which includes:

- a consistent use of terms and definitions;
- improved clarity of individuals' and functions' requirements and responsibilities;
- coordinated cross-functional planning;
- more accurate schedules and more reliable estimates of resources;
- a basis for continuous improvement and performance measurement.

The generic process structure for a particular firm will typically consist of a definition of the main phases or stages, major steps, and work packages or tasks (McGrath et al, 1992). It is also appropriate to identify the key milestones, including review or decision points, and the interfaces and interdependencies of activities (Andreasen and Hein, 1987).

According to McGrath et al (1992), the form of the generic structure appropriate to a particular company may be dependent on factors such as the nature of its products, markets, organisation and culture. Similarly, Smith and Reinertsen (1991) refer to culture as a partial determinant of the procedures a company uses. They also identify the degree of control needed as being dependent on the size of the project, not the company, and that control needs grow as a project progresses. This view seems somewhat dismissive of company size as a relevant factor, since company culture is generally assumed to be related to company size. Holt (1988) similarly relates process characteristics to the stage of development, the nature of the process being characterised as a progression from the relatively organic to the mechanistic but, also, the level of innovation, with the need for organic and creative mechanisms being associated with increased levels of innovation.

It will be argued in this thesis that, whilst companies are different in many respects (see Chapter 4), for a given company, many factors associated with it, can be considered constant in the short to medium term. The implication of this is to allow structured and standardised processes and procedures to be established in broadly similar product and market areas, whilst recognising that there will be project specific requirements. This is in many respects akin to the dominant organisational mode(s) discussed earlier (Section 3.5.2.2). Moreover, although not referred to in the product development literature, it may be inferred that, where there is more than one type of activity, there will be differing requirements which need to be balanced in terms of their respective organisational and procedural provisions. Two issues arise from this. Firstly, do companies have structured development procedures, and, secondly, are there process models which are generic to different types of company and/or projects?

3.8 Project Planning and Control

Project planning and control follows logically from the previous two sections on decision making and structured processes, and it is an important element of project management. There is a whole literature specifically focused on project management providing a thorough account of the important principles and associated techniques (BSI, 1984; Burke, 1992; Leech and Turner, 1990; Lester, 1991; Lock, 1988; Westney, 1992). The basic principles of project management are applicable to design projects, and some of the general product development texts provide brief accounts of their application.

Project management is the process of definition and manipulation of 'project parameters' such that the objectives of the project are achieved in an optimum way (Westney, 1992). There are, in general, four categories of project parameter: cost, time, resources, and quality standards.

In the context of small projects, which include R&D, product development, and manufacturing projects, Westney establishes four basic and necessary concepts. Firstly, is the use of planning networks. These provide the basis for the second concept, namely the integration of the cost, time, and resource parameters. Thirdly, is the use of project models in the specification and definition of the project. Finally, is the effective use of computer applications. To be effective, however, methods for achieving these must make provision for a standardised approach, be based on simple systems and technology, and facilitate fast responses to new project information. These requirements may be expressed in terms of a typical project profile (after Lucas, 1992):

- Preparation Phase: Project definition by senior management; establish project organisation, including project leader and team selection; and project planning, including plans and budgets.

- Execution Phase: Project control mechanisms, including routine reporting; frequent (e.g. weekly) control and recovery planning meetings, regular (e.g. monthly) or key milestone project review and budget review meetings; resource planning and project organisation review; and client liaison.

- Post Project: Post project auditing.

It may be apparent that this involves three principal activity groups: specification of the project's requirements, project planning, and project control and review. The latter of these has been dealt with already (see Section 3.6).

Most product development texts stress the need to undertake several preparatory activities prior to commencing the main development phase. The essential elements of a project's specification is contained in the project plan (Leech and Turner, 1990) or the project model (Westney, 1992) and should comprise:

- a documented summary of the project's aims and objectives, the means for achieving these, the design basis, and any important assumptions;

- a network plan (which requires a work breakdown structure and a citation of the key milestones);

- a project schedule;

- a resource plan (including a list of key personnel and their responsibilities); and

- a cost estimate / budget.

Leech and Turner (1990) state that the project specification need not be too elaborate for small projects. It should be depicted in the most simple fashion.

A number of project management techniques and support tools are now available to assist the planning and control of projects (BSI, 1984). These provide a number of facilities ranging from basic Gantt charts (bar charts) through to more sophisticated techniques such as critical path method (CPM), project evaluation review technique (PERT), hierarchical work breakdown, resource analysis and levelling, budget preparation, project scheduling, baseline tracking and reporting, and multiple project capability.

The unconstrained use of such tools has been criticised as being inappropriate for many development projects. Many of the established project management techniques have their origins in large scale complex projects. Therefore, for small projects, Westney (1992) argues that standard approaches are not suited to the short time-frame within which they are usually executed, the division of responsibility, or the possible requirement to deal with a number of projects simultaneously. Consequently, of the more elaborate techniques, PERT which deals in probabilities, is deemed inappropriate for small projects. More specifically, Andreasen and Hein (1987) point to how conventional planning projects differ from most product development projects. Firstly, with conventional projects, it is usually possible to have a reasonably detailed knowledge of the activities and their relationships from the outset. Secondly, any uncertainty associated with activities concerns their use of resources or time, and not their feasibility or the quality of the result. Additionally, because product development is essentially concerned with simultaneous information flows, and a physical entity is not usually realised until the prototype stage, it has also been argued (McGrath et al, 1992) that as techniques such as PERT and CPM were created primarily for managing physical flows, they are not suited to use in product development. They can encourage too much planning detail and have the potential to slow development progress. Smith and Reinertsen (1991) are similarly sceptical, suggesting that their only value is in being able to create a large project schedule, either in bar chart or network form. The schedule itself provides a simple but effective way to track progress and discuss problems. Hales (1993) also suggests that a simple Gantt chart is often all that is necessary. Unless kept simple, planning and updating can be a time-consuming task.

Interestingly, of the general project management texts dealing specifically with small projects, Westney (1992) considers the use of simple networks, and the CPM technique, to be appropriate for small projects. Their particular strength, he suggests, is in providing a basis for an integrated approach to managing the critical project management parameters of time, resources and cost, including activity planning, cost estimation, and the planning and control of resource utilisation. They are also flexible to cope with change, a characteristic of many small projects. However, although networks are useful for project planning purposes, when detailing these for scheduling purposes, they are more easily depicted as bar charts, where the plan and schedule are in one, and may be more easily followed by those using them (Westney, 1992; Leech and Turner, 1990).

Where a structured process (or standardised procedure) has been established, then this may form the basis for project scheduling on three levels (Andreasen and Hein, 1987; McGrath et al, 1992). At the top level, is the overall project overview, for use by senior management, which represents the main project phases, major steps, and the key milestones and their interrelationships. This would normally be produced before project approval. Greater planning detail is incorporated into project plans, which define the work packages necessary to complete the steps of the project. Below work package level are the day-to-day activities required to complete the work packages. If necessary, these may be defined by work package plans. However, it is important to recognise that the level of planning detail should be appropriate to the amount of planning and control required and, therefore, as a general rule, Westney (1992) recommends that 50 activities is probably a good maximum for small projects. Furthermore, the extent to which detailed planning is performed up-front or during the development stages needs to be balanced against the degree of certainty regarding the project. Andreasen and Hein (1987), for example, infer that more detailed plans should normally be available up to the next evaluation point, and be available in outline form thereafter. Indeed, Twiss (1986) identifies project uncertainty as being associated with the need for more flexible planning approaches, particularly in the early stages.

The considerations mentioned imply that although planning may occur at three levels, the level of detailed formal planning, and the presentation format required, will vary under differing circumstances. Therefore, although the literature's recommendations for project planning are fairly clear and consistent, there are questions as to whether companies are adopting these, and whether they are appropriate to the various forms of design and development project?

3.9 Front-End Processes

Much of the engineering design and product development literature emphasises the need to manage and resource the front-end activities (marketing through to specification and concept) effectively. This pertains to reasons of cost, quality and time.

The front-end is claimed to account for as much as 50% of development time (Smith and Reinertsen, 1991) and, therefore, as the most leveraged portion of the development process, it offers the most potential for lead-time reduction. It is also during the initial stages that the leverage on the total manufacturing cost is highest.

Depending on the nature of the product and its process features, up to 80% of a product's costs may be determined by the time the concept is fixed. Moreover, it is this part of the development process that is least understood and often inadequately managed (Hollins and Pugh, 1990).

Early in the product development programme where the main direction is established, the project costs are at their lowest, with costs much higher at the later stages. Errors occurring at the front-end can be carried undetected through to detail design or production, where the cost of rectification, or even abandonment can be substantial. Errors also imply delays, which may lead to a choice between having deficient products at market launch, or being late to market, so that opportunity costs associated with the impact on sales life, market share, initial pricing premium and the cost reduction learning curve are incurred. Eliminating early problems and making superior design trade-offs will also avoid down stream design changes and lead to improved designs and higher quality products.

Given the evident importance of the front-end activities, it is necessary to establish those features and requirements which are deemed to be related to their successful management. These are considered below.

3.9.1 Capturing Market Needs and New Product Ideas

Previously the product development process was likened to a converging funnel. An important challenge for management is to ensure its mouth is widened so that many potential ideas are available for investigation. This requires the company to develop its knowledge base and access to various forms of information.

A variety of sources of information and ideas are available. There are the outcomes of applied research and advanced development projects which are intended to provide a base technology or core concept necessary for a specific development project, or to spurn a number of projects. Related to this is the fostering of relationships with universities and other research establishments. There are also a large number of systematic and creative mechanisms more immediately associated with capturing market needs and identifying new product ideas. A number of these are shown in Table 2.1.

3.9.2 Proposals, Briefs and Specifications

Projects start in many different ways depending on the circumstances. Often a design project stems from an idea, identified need, or problem. This may result in an internal development project. Alternatively, if the instigator requires to subcontract part, or all, of the design of the product, then competitive bids will be solicited with a view to placing an order. Although there are similarities, the distinction between these two types of project is significant.

A product development project is often initiated in response to an idea or request. The initial product idea will usually include a brief description of a proposed new product, outlining why it might have potential for the organisation. A product proposal (or project brief) expands this, confirms its potential and is used to instigate a feasibility study (BSI, 1989). It should, therefore, briefly outline the projects objectives and the intended market for the product, as well as providing preliminary estimates for project costs, capital requirements, and projected financial indicators such as turnover, and profitability.

Upon approval of the product proposal a feasibility study (BSI, 1989) or preparatory study (Andreasen and Hein, 1987) usually needs to be undertaken. This is necessary if sufficient information is to be available to allow a fully informed decision by senior management on whether to approve or reject the project. Hence, more detailed work concerning the market, technical, financial, planning and risk related issues may be needed. However, the amount of clarification will depend on the company and its background, and what are deemed to be acceptable levels of ambition and risk (Andreasen and Hein, 1987). On the basis of a sufficiently developed project brief and a consistent and clear set of criteria (see Section 3.6.1) a project approval decision may be made, including what priority it should have or whether it should be delayed.

Notwithstanding the above, project briefs vary in format, and can range from simple verbal requests to detailed documents (Hales, 1993). Within a project brief (or separate from it, or in place of it), there could be a more narrowly defined design brief outlining the basic product requirements.

In contrast, if the design work is to be contracted out then a call for bids, an enquiry, or an invitation to tender will usually be issued. Depending on the organisation and the scope of the work involved, this may vary from a basic verbal request to a written, and possibly very detailed, request for proposal (RFP) (Hajek, 1977). If a decision to bid is made then the response to this is a project proposal, tender, or bid.

A call for bids may take different forms from industry-to-industry and firm-to-firm. However, it should indicate the information necessary for the offeror to prepare a technical proposal and price quotation, and will normally specify the content and form of presentation required. It may, therefore, comprise a covering letter, specification, contract schedule, technical proposal requirements (TRP), the required cost breakdown, and general clauses and additional data (Hajek, 1977). Warby (1984) details a suitable checklist to assist the review and evaluation of a call for bids. The technical proposal requirements, and thereby the latitude in what may be offered, may vary between being very definitive or very broad in scope. As bids are usually assessed according to criteria drawn from the technical proposal requirements, it is important to prepare a bid which is responsive to these (Hales, 1993) and to emphasise the appropriate competencies (Leech and Turner, 1990). The proposal is a written document, which may be variable in length, but of a format which will generally cover details of the company's credentials; statement of the problem; technical discussion; work to be carried out; project organisation, procedures and resources; project schedule; and cost breakdown (Hales, 1993; Hajek, 1977). This may include a technical synopsis, and a detailed technical specification (or design brief) may be developed, although this would not necessarily be for inclusion within the proposal.

It is evident that the project proposal (bid document) and project brief have some similarities. However, there are quantitative and qualitative differences as a consequence of their respective aims. Whereas a project brief is written with the aim of defining the development work to be carried out, the main aim of the project proposal is to secure a contract (Hales, 1993). In the first instance, the project proposal is used for bid selection and evaluation, then subsequently as a basis for negotiating contractual terms, where elements such as price, performance specification, work scope, and contractual terms may be subject to change.

Preparing a proposal can be a significant undertaking, and must be properly planned and managed. According to Leech and Turner (1990), responsibility for proposal development is determined by firm size, and the frequency with which project proposals are submitted. When a firm is of sufficient size and the number of proposals justifies it, a proposal manager with a permanent staff is required, whereas for a small firm preparing proposals sporadically, then it is best to appoint a senior manager to coordinate the effort. In either case they can be responsible for writing small proposals, with appropriate functional inputs as necessary. For large proposals they must take up a staff role, coordinating the activities of others. The manager will also be responsible for initiating the necessary reviews prior to submission to the Board of Directors (see Section 3.6.1.1). In large companies a formal proposal review committee may be constituted, whereas for smaller concerns an informal group may be convened.

3.9.2.1 *Specifications*

It is clear from the discussion above that specifications serve a variety of purposes and, hence, there are a number of different types, see, for example BSI (1991). Moreover, the engineering design and product development literatures have generated a whole plethora of terminology to characterise the different forms of specification associated with design projects. This inevitably leads to confusion. Not only are several terms often used to describe what is essentially the same type of specification, but there are also inconsistencies in their use. The design brief, for example, is used to refer to both an initial proposal or outline of requirements and a more definitive specification of the design project. According to Hales (1993) inconsistencies also arise in practice because different versions of the same document may be used during a project. Whilst some clarity and consistency would be desirable, clearly it is the mechanisms for developing specifications, and also the quality and scope of their content (Oakley, 1984) which are of most significance.

Many sources, including The Corfield Report (NEDO, 1979) and Walsh et al (1992) have identified comprehensive specifications as being vital to success in product design. Hence, the consideration and appropriate definition of all the key aspects is an essential pre-requisite to commencing the main project design activities. There are two important aspects to this: the specification of the product design requirements, and the more broadly defined specification of the project. The important features of these will now be discussed.

Prior to undertaking a design project it is necessary to establish a clear definition of the problem, and a specification of requirements and constraints for which solutions will be sought. In the engineering design literature the former of these is commonly referred to as clarification of the design task or objective. Often this will require some preliminary design studies and, depending on the initial design strategy adopted, may involve solution conjectures or abstractive analysis (see Section 2.4 and Section 2.5).

If an initial brief is provided this will usually state the general objectives, requirements and constraints. However this will not normally provide a proper basis from which to progress the main design stages and, therefore, the literature widely recommends that a more comprehensive, formal, and definitive working document is produced. Although, as indicated above, several names are applied to briefs and specifications, it most often referred to as the product design specification, or PDS (Pugh, 1990). It is this document which defines all the requirements and constraints that have to be observed (BSI, 1989), by establishing succinct and precise performance requirements for each of the required attributes of the product (Cross, 1994).

The importance of the PDS cannot be over emphasised. Indeed, Pugh (1986a) has described it as "the bedrock on which any competitive design must be based". It is the basic reference source with which all involved in product development interact - providing the main control for the product development activity. Consequently, the development and writing of the PDS is what Hollins and Pugh (1990) define as "the most important part of the design process". However, contrary to this, they have observed "the woeful inadequacy of the product design specifications in companies". It is common for many of the key elements, especially those relating to time and cost constraints, not to be properly dealt with (Walsh et al, 1992).

There is a broad agreement in the literature on what the basic content of a PDS should comprise. The goal is to establish a list of all the requirements and constraints that affect the design, as a failure to do this will result in a partial specification of the product (Pugh, 1990). To overcome this several authors have proposed checklists, organised according to type of requirement, for developing the PDS so that it is comprehensive, cohesive and unambiguous. Hollins and Pugh (1990) and Pugh (1990) list 35 primary design elements, and Hales (1993) has developed a detailed checklist from the one offered by Pahl and Beitz (1984). A more succinct listing is provided by Ullman (1992), and BSI (1989) group the requirements into three broad categories: performance, cost and timescale. Smith and Reinertsen (1991) similarly highlight the need to identifying the crucial factors and recommend the use of checklists. However, Walsh et al (1992) express that none of these have universal applicability as much depends on the particular industry and product concerned. Moreover, Oakley (1984) has suggested that the form and detail of the specification depends on the complexity and scale of the project. Clearly, there is no single format for a PDS which is ideal in all situations, and indeed each reference source proposes a different set of detailed headings. There is however a general consensus that the main areas of concern must be with the product's performance, and the time and cost constraints which apply. Some authors suggest grading the design elements, acknowledging that their relative importance will be influenced by the nature of the product change (Hollins and Pugh, 1990; Pugh, 1990). Similarly, Pahl and Beitz (1984) describe how in developing an appropriately formulated and well structured design specification, it may be useful to distinguish between those attributes or requirements that are demands and those that are wishes. This simple means for prioritising between the requirements has also been supported by others (Cross, 1994; Hales, 1993; Ullman, 1992). Lastly, as the PDS is a user document, it may be best written in a succinct and clear manner, using short definitive statements (Hollins and Pugh, 1990). Indeed, it appears that most exemplars provided by the literature have these characteristics.

The requirements and constraints of the PDS, establish the bounds of the potential solution space and thereby limit the range of acceptable solutions. Hence, the problem needs to be formulated in such a way as to leave the design team with an appropriate degree of freedom. In particular, many design methodologists stress the need for requirements to be stated in a way which is independent of any particular solution. Cross (1994) captures this when he states that "the purpose of the specification is to define the required performance and not the product". It should, therefore, not impose design solutions. However, several texts associated with the management of design or product development qualify this. In practice, briefs and specification are rarely produced without some idea of intended or possible design solutions, and successful design strategies may be based on a product-focused approach (see Section 2.5). Furthermore, the PDS itself may only be written following the creation and proof testing of feasible concepts (Walsh et al, 1992), and there may be legitimate reasons for using known principles, components, materials or designs (Andreasen and Hein, 1987). It may be concluded, therefore, that the PDS should not constrain the designers' choice of solutions unnecessarily.

Achieving this balance, however, may be difficult, as statements of customers or clients are often couched in terms of solutions. There may also be confusion between the attributes of a product and its engineering characteristics. It is necessary to ensure that what the customer wants in terms of product attributes are carefully translated into specifications of the appropriate engineering characteristics (Cross, 1994). Traditionally this is undertaken by the marketing or engineering function, depending on the relative dominance between them. However, the marketing function it is unlikely to convey the technical issues adequately and so create ambiguity, whilst the engineering department is likely to misinterpret or presuppose the market need. One approach, illustrated by Walsh et al (1992), is to develop a detailed market specification from the project brief, which is then translated into a detailed technical specification by the design and production engineers. In achieving a feasible specification, there will often be the need to qualify requirements and to acknowledge inevitable compromises. In ensuring that all the relevant design elements are addressed thoroughly, it is important that all views are taken into account, and that the development of the PDS is regarded as a multifunctional task to be accomplished by the whole design team (Ullman, 1992).

An alternative approach is the quality function deployment (QFD) method (Akao, 1988), which shares many of the desirable features already outlined above as well as drawing on other design methods, and provides a more formal and comprehensive method for matching customer requirements to engineering characteristics. The QFD method was developed in Japan during the 1970s, and although it has only recently received attention in the USA and Europe, it has been strongly recommended by recent design texts (Hales, 1993; Ullman, 1992) and updated editions of established texts (Cross, 1994). Differences have been expressed as to when it is appropriate to use the QFD method. Ullman (1992), for example, considers it as being suitable regardless of whether an original design or redesign is involved. Yet contrary to this, because QFD is customer and product driven and, as such, requires an understanding of the product, Pugh (1990) believes that it will be most suitable for existing product designs.

Most authors support the systematic preparation of design specifications, either based on the listing and ranking of requirements (performance specification method) or through more sophisticated and structured techniques such as QFD. Hales (1993), however, suggests that it may not always be necessary to compile a PDS in such a formal manner. Under certain circumstances the team may be so close to the problem that the requirements are clearly implied.

With design being a process which is iterative and interactive at the overall system, subsystem and component levels, Pugh (1990) suggests that it is useful to use this breakdown, and refer as appropriate to subsystem design specifications and component design specifications. Apart from the organisational logic in this, it is also appropriate since the relative importance and characteristics of the design requirements and constraints are likely to vary between the product, the subsystems and components.

Many of the major texts focus on the development of the PDS. However, as product development projects have much broader management concerns than this, it is necessary to provide some form of project brief (or project specification) for the entire project which relates the project to the commercial and strategic considerations of the business, and establishes what, and how, targets are to be attained. Andreasen and Hein (1987) refer to this as the Business Specification, stating that it should provide a complete description of the following:

- The project definition - outlining the project objectives and overall strategy; targets for different areas, including those relating to the product, and which are contained in the PDS; and the project plans, resourcing requirements, organisation, and procedures to be observed.

- The commercial and financial definition - outlining the potential sales, profitability, etc.; market characteristics, competition, and market strategy; product strategy, including the required product and cost structures; production strategy and costs; and a financial evaluation, including investments, liquidity and yield.

The mechanisms for developing specifications and the scope and form of their content are clearly of some importance. It is evident that these are related to the type of design strategy adopted and several influencing factors within the design context. The precise nature of these relationships is not readily apparent and requires some clarification.

3.10 Technology Management

One focus of product development is on the commercial exploitation of technology and, in order to ensure good probabilities of success, it needs to operate close to the market in a relatively predictable and repetitious manner. Technology management, on the other hand, has strategic concerns for the medium and long term development of a company's technological capabilities. This relates to both internally developed and externally acquired technology and knowledge.

Product development and technology management are closely related through the product development strategy, and effective technology management can greatly benefit development efforts by reducing cycle-times, minimising risk exposure, and improving product success rates (McGrath et al, 1992). Moreover, their effective management and, ultimately, success in the market, must be based on a clear understanding of the differences between them.

The strategically focused core technology projects are intended to provide a base technology or core concept necessary for one or possibly several development projects. Their aim is to develop a technical concept to the stage where it is suitable for commercialisation via a development project. Their need may arise as a consequence of senior management's deliberations on core technologies and anticipation of forthcoming development efforts, a function recognising a research need as being essential to support their on-going developments, or as a recommendation of a product proposal screening, so that the proposed product development may proceed as a viable project (Wheelwright and Clark, 1992).

Higher inventive projects by their very nature have greater inherent uncertainties, take longer, and are more difficult to specify and approve. Undertaking core technological developments as part of the processes of product development may introduce unacceptable risks. Major developments in core technology therefore need to be managed separately from development projects.

Managing the various technology related risks associated with product development projects is of some importance. Therefore, at the outset of a product development project, an assessment of technology readiness and the use of proven technology modules ensure an acceptable balance between new and existing technologies within the product (Holmes, 1993). Also, for high risk areas, contingency planning is appropriate. For example, Smith and Reinertsen (1991) recommend the use of substitute technologies to provide a backup position.

3.11 The Hierarchical Nature of Product Development

In Chapter 2 the hierarchical nature of design strategy and decision making within the context of design problems was discussed. The product development literature provides a broader perspective, extending the decision making hierarchy upwards, beyond that of the design task, to the management of the overall project, project initiation and product development strategy. With this view it is possible to observe the changing responsibilities for decision making between the senior management, those responsible for project management, and the individuals assigned to the project, including designers.

At the highest level are issues of product development strategy, and these are the primary concern of senior management (see Section 3.4). Senior management also has concerns prior to, and during, individual projects with regard to their approval and review (see Section 3.6.1). Below this are the implementation level decisions relating to project initiation or tendering activities, and the actual execution of the project itself. These decisions occur at two levels. Firstly, there are the project planning and control decisions (see Section 3.8), the responsibility for which will depend on the firm and project. Secondly, there are the routine operational decisions, made by the project manager and individuals assigned to the project, including the decision making processes of individual designers.

As discussed in Chapter 2, designers' decisions are bounded by the form of the design requirements and any constraints specified, and they are also related to the hierarchical nature of design problems and the design strategy adopted to solve different design problems within the hierarchy. It is reasonable to suppose that at the overall product level decisions made regarding product development strategy will be most strongly influenced by the most senior designers connected to the project. At progressively lower levels, which concern problems of a more detailed nature (i.e. subsystems and components) the type of design approach taken will increasingly be determined by the vagaries of individual designers.

The relationship between the project planning hierarchy and the design strategy hierarchy is illustrated in Figure 3.3. Due to their differing perspectives, they are in principle distinguishable from each other at the overall problem and project levels. Only at the level of detailed activities and methods will they be one and the same. This does not imply that they are disassociated from each other. On the contrary, choices relating to one are likely to impact on the other.

3.12 Performance Measurement

The complementary issues of performance measurement and benchmarking are two management issues which have come to prominence in the 1990s. They have built upon the foundations of the total quality management (TQM) initiatives of the 1980s which were based on the principle of continuous improvement, but largely predicated on the notion of incremental improvements by individuals and functions. Associated with the parallel development of business process analysis and business re-engineering, which encourages the creation of customer focused business processes, benchmarking provides a methodology for the comparative evaluation of processes and systems. A feature which distinguishes this approach from the TQM philosophy is that the attainment of best practice levels of performance may incur step changes as opposed to purely incremental changes of performance, and may involve benchmarking against the processes of external organisations. An integral part of all of these approaches is the requirement for suitable performance metrics.

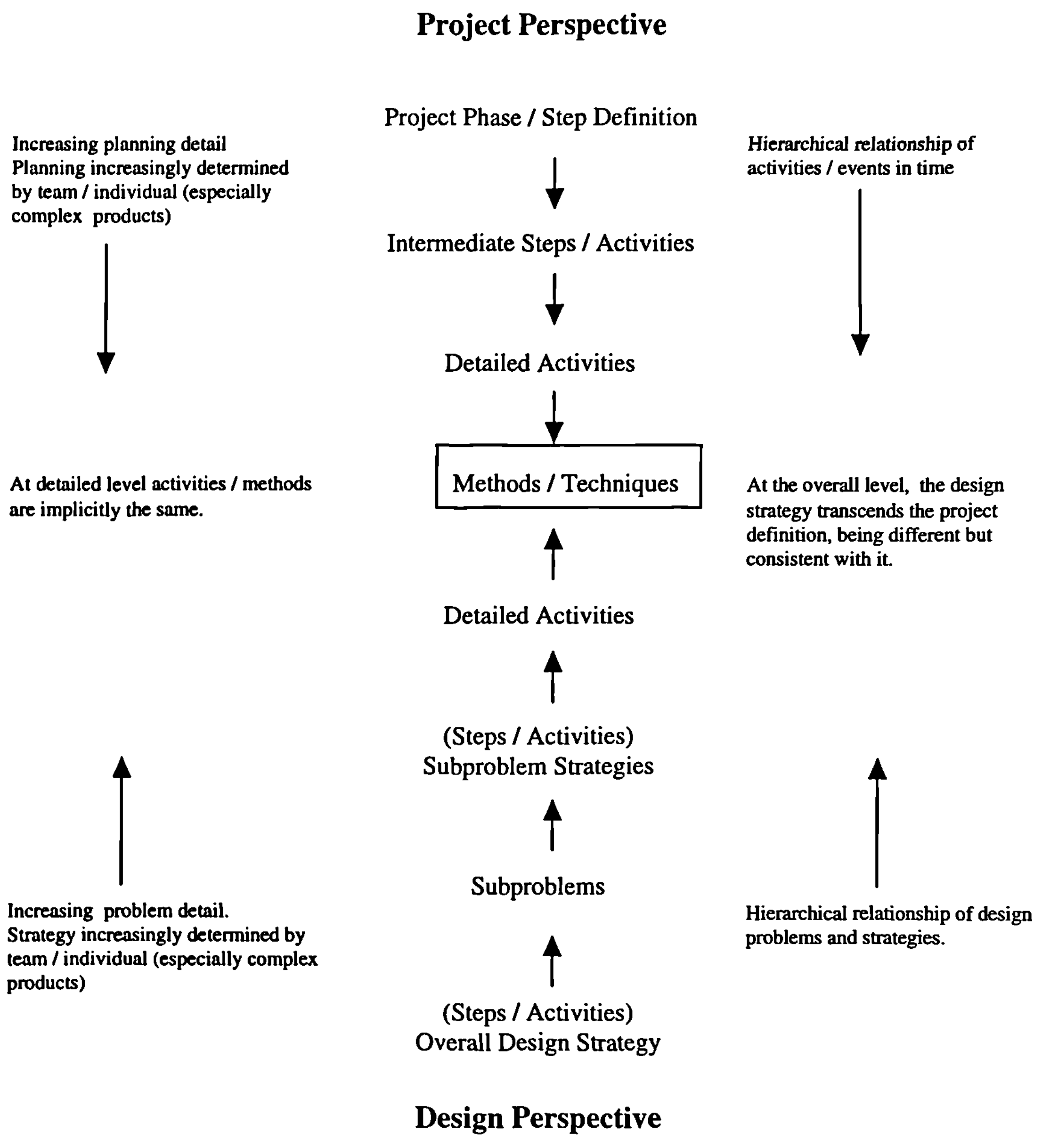


Figure 3.3: Relationship between project planning & design strategy hierarchies.

Several prominent texts have emerged in the performance measurement and benchmarking area (Camp, 1989; Spendolini, 1992; Zairi, 1992a; Zairi, 1992b). It is evident from these that overall measures of performance should be clearly chosen to reflect the views of the overall business (e.g. market share, profit) and customer (e.g. customer satisfaction, quality, price, lead-time and delivery adherence). These may then be cascaded down into relevant local measures to form the basis for continuous improvement and improved competitiveness. For lower level groups to improve their effectiveness to the benefit of the overall business processes, it is important that their performance metrics are consistent with those used to monitor overall performance.

The product development literature provides little insight into the most appropriate measures to use and, although some suggestions are provided elsewhere, they are often limited in quantity and represent either overall strategic measures (DTI, 1993; Zairi, 1992b) or very detailed measures (Harrington, 1986). Furthermore, they are not established within a hierarchical framework which distinguishes between the business and product development in overall terms, monitoring and improving the product development processes over time, and managing individual development projects. There is a requirement, therefore, to establish such a framework and propose suitable metrics. Also, given the importance of performance metrics as strategic tools for process improvement, and in the absence of adequate measures, there is a concern for what metrics companies are aware of, and what metrics they are using.

3.13 Contextual Characteristics

A number of organisational, managerial and procedural aspects of product development have been considered in this chapter. This has revealed a number of clear issues and themes, and it is evident that a consensus on best practice in product development exists concerning the most appropriate means for implementing these, although this is often expressed in very general terms.

In line with the aims of this thesis, this review of the literature has sought to identify the extent to which it considers the influence of the intra- and extra-company and project context on companies' practices. A number of contextual factors have been identified from the literature (Figure 3.4), and some insights into their influence on product development practice have also been inferred. However, although it is evident what the broad types of contextual factors are, they are rarely defined explicitly, and are presented in a rather laissez-faire manner, and usually without explanation of their effects. As a result their influence on the development process and, therefore, how it should be organised and managed in specific circumstances, is not readily apparent.

<u>External environment</u>: Economic Demographic Environmental Globalisation Internationalisation Product differentiation Product customisation Reduced product life-cycles Technological intensification Industry maturity Market type Competitive criteria: Price, quality, performance lead-times, etc.	<u>Corporate</u>: Business aims and strategy Establishment size Corporate organisation Culture Product variability <u>Project</u>: Innovation involved Project size Number of projects handled Frequent (dominant) types of project Managerial (disciplinary) complexity

Figure 3.4: Contextual factors suggested by the product development literature

The nature of the competitive environment, and the resulting requirements for product development, inevitably have consequences for the management and nature of the process. Much of the literature is influenced by the activities of large firms, often multinational, and often associated with the consumer electronics or automotive industries. Consequently, best practice is predicated on a consensus in which the competitive environment simultaneously requires firms to develop higher quality products, in shorter and more predictable lead-times, and at lower cost, and where product development is increasingly required to be managed as a concurrent, multi-disciplinary process. However, the universal usefulness of these recommendations in all industries, firms or establishments, may be questioned. For example, what of those firms in mature industries, or in intermediate engineering product markets, or operating under different market conditions, and what are the implications for smaller firms whose activities are assumed to be a microcosm of the larger firms? A primary focus of the literature is on processes for developing new or improved products. Projects undertaken to the requirements of a specific customer receive only fragmented attention. With few exceptions, this distinction is only explicitly observed in the project management literature, whose concerns are much broader than the specific requirements of design projects. Yet in a recent cohort survey of the mechanical engineering industry (Alderman, 1994), just over a third of establishments identified themselves as operating on an engineer-to-order basis. It is suggested, therefore, that the types of firms and industries on which best practice has been developed do not cover the range of competitive environment and corporate characteristics of UK engineering companies.

It is apparent that the competitive drivers and requirements of product development will vary between firms and their markets and, that, in similar competitive situations, other contextual factors also need to be considered. It may be argued that variations in the relative significance of the different competitive drivers, and the characteristics of companies, will give rise to different requirements for product development, thereby requiring alternative approaches to prescribed best practice. Consequently, interpreting current advice and, hence, understanding and managing the development function, represents a significant challenge to many companies. Indeed, the potential exists for its misapplication under inappropriate circumstances. Firms need to be able to make informed decisions on how to organise and manage their product development activities in both general and specific terms, and it may be concluded that, there is a clear need to better understand the implications of the important influences within a company and project context.

3.14 Summary

Managing the engineering design and product development processes effectively demands that they can be modelled, which accordingly requires their cognisance. Consideration of the competitive environment, the characteristics of companies, and the consensus of current best practice models, as outlined in Chapter 2 and Chapter 3, raise a number of key questions. Firstly, given the apparent complexity and variability in the characteristics of companies and their business environments, and their responses to these, how well do best practice models cope with this? To what extent is best practice sufficiently comprehensive and flexible to meet the needs of industry in practice? Secondly, to what extent are companies adopting best practice? Thirdly, are there constraints to adopting best practice for certain types of company and, if so, what practices are appropriate? The general scope and prescriptive nature of the literature's recommendations means that differences in the characteristics of companies and the competitive environment are not accommodated and, therefore, it is unreasonable to expect the existing recommendations of the literature to be universally acceptable or appropriate.

A fundamental concern of this thesis will be to establish the most appropriate development practices to adopt in specific circumstances. This requires an extension of the existing understanding of the processes of engineering design and product development. This implies more than an improved description of the process, but includes a recognition of those elements which apply to all companies and those which are related to company characteristics. A logical step forward is to recognise that, for the individual company, the critical factors that define it influence the nature of the engineering design and product development processes. Therefore, in addressing such concerns, there is a need to capture the key discriminatory factors, and to ascertain their relationship to the various elements of engineering design and product development practice. This requires a more qualified approach, based on a comprehensive and flexible contextual framework, to capture and explain the complexities of companies and their product development processes.

Chapter 4

Research Methodology

4.1 Introduction

The previous chapters have identified shortcomings in the recommendations of the literature on engineering design and product development and the need to develop improved models of the processes of engineering design and product development in a company and project context. The research therefore had the following objectives:

- To identify the generic and company specific features of the engineering design and product development process in a company and project context.

- To identify the extent to which recommended practices are implemented by companies and the constraints that may impede their adoption.

The research method adopted to realise these objectives is described in this chapter.

4.2 Research Method

4.2.1 Background

The long established and widely proliferated basis for the conduct of much research in the engineering and physical science fields is the scientific method. Although in practice it may be regarded as a somewhat heuristic representation, the scientific method is essentially a deductive process of developing a theory, deriving hypotheses and testing them to support or not the theory. This entails a commitment to a rational and systematic approach to investigations, which is founded on three central characteristics: reductionism, repeatability and refutation. The complexity of the phenomenon being investigated may be reduced in experiments whose results are validated by their repeatability, enabling hypotheses relating to a theory, or view, of such phenomenon to be established or refuted. Typically for engineers and scientists such experiments may take place in a laboratory or involve the construction of some quantitative model.

Many areas of research pose problems for the scientific method. Checkland (1981) associates these problems with the greater complexity of many systems. These he argues make it difficult to achieve the reduction required for controlled experiments. Instances of this occur in the physical and engineering sciences, but are most pronounced in the areas of social science and management, which deal with "problems of the real world" and have an ill-structured character. Research in these areas therefore tends to follow different approaches.

According to Bryman (1989), even quantitative research is unlikely to follow the deductive model, in which hypotheses are derived from theoretical postulations about an issue and hence from a desire to test a theory. Often hypotheses and their associated concepts are the product of deliberations in connection with the literature. Moreover, whereas quantitative research methods comprise specific objectives that derive from the researchers preoccupations, qualitative research approaches tends to adopt a more unstructured approach in order to capture peoples perceptions and their interpretations. Consequently, theoretical postulations and hypotheses tend to occur during or towards the end of the data collection process rather than at the outset.

Two particular principles which may distinguish between research strategies relate to the generalisation and replication of research findings. The generalisation of research findings beyond the confines of the specific investigation is commonly statistically based, in which inferences on the population are made on the basis of the data sample. In contrast to 'statistical generalisation', for some approaches it is inappropriate to think in terms of sampling notions. With case studies, for example, their usefulness is in terms of the theoretical inferences, or insights, that can be generated. The aim is not to infer the results from a sample to a population, but to enable the development of theory. Because of the apparent problems of validity beyond the specific cases, it is more appropriate to think in terms of 'analytical generalisation' which relies on a replication logic (Yin, 1994). If two or more cases are shown to support the same theory, then replication may be claimed. The result would be considered more potent if it did not support a rival theory. Thus replication is realised either when a case predicts a similar result (a literal replication) or produces an alternate, but predictable, result (a theoretical replication). However, where contradictions arise then the theoretical propositions need to be reformulated. This distinction was significant to the methodology adopted for this research. The aim was to develop contextual models of engineering design and product development. In other words, the research was concerned with developing and establishing the validity of a theoretical framework, rather than to generalise the results to a wider population. Clearly the most appropriate strategy to adopt in any instance is determined by the particular research issues being addressed. The scope of this research encapsulated a number of aspects which were social, organisational and managerial in character. Notwithstanding the need for a rigorous approach, it was therefore necessary to take cognisance of these factors when deciding upon the research methodology.

4.2.2 The Research Method

In terms of the overall research methodology three options were considered: a models approach, an empirical approach, and a hybrid approach. The first of these, a models approach, would have involved developing from the literature, and theoretical considerations, including suppositions based on the contextual framework, hypothesised proposals for models. These *ab initio* prescriptions would have then been subject to validation by a suitable means. The use of models in this way appears to be common to much work that has taken place in the engineering design field. A concern with a models approach was that the ability to make satisfactory conjectures presupposed a degree of understanding, or insight, of companies and the relative influences of the various contextual factors.

The second option would have been to adopt an empirical approach from the outset. This would have allowed the nature of the relationships between company context factors and engineering design and product development practices to 'reveal' themselves, including the distinction between the more or less influential ones, and the constraints which may have limited the adoption of particular practices by certain types of firm. However, a purely descriptive approach on its own could have lead to the development of models which included elements of both good and less good practice.

As the principal research aim was to develop models in industrial contexts, it was therefore proposed to adopt a hybridised approach which accommodated the respective strengths of the model and empirical approaches. This involved the adoption of an empirical approach, but supplementing this by allowing the models' development to be informed by additional means. Theoretical elements from the prescriptive literature were incorporated where relevant, and aspects of less good practice were filtered out by suitable evaluation techniques.

4.2.2.1 Literature Review

The first stage of the research was concerned with the review of the engineering design and product development literature. The purpose of the literature review within the research methodology was not only to determine the state of current thinking within the scope of the investigation, but also by identifying the key generic issues which are regarded as critical to successful development outcomes, to act as a basis for defining and constructing the theoretical concepts and empirical enquiries. This was important for three key areas of the research methodology: the contextual typology for classifying firms; to prestructure and bound the scope of the empirical enquiries and enable insightful issues for questioning to be formulated; and to provide the basis for constructing a composite model of prescribed best practice.

4.2.2.2 *Contextual Framework*

The second stage of the work focused on developing a proposed contextual typology for classifying different companies, their strategic policies, and key project variables. The classification of companies was based on six principal dimensions, each consisting of several factors which were considered likely discriminators. These were related to characteristics of the market/customer environment; the product; the nature of the manufacturing operations; the supplier environment; the company structure; and the global and local environment. Classification of companies' strategic policies included the strategic emphasis placed on operational excellence, customer focus, and product leadership. Classification factors relating to individual projects included variables relating to the type of project (contract project or product development project), innovation involved, and supplier collaboration.

4.2.2.3 *Empirical Work*

The empirical work was the focus of the third stage. This was undertaken by detailed case studies in ten companies, each of which focused on specific design projects. In addition, introductory interviews with two other firms, for which it was not possible to proceed with in-depth case studies, also yielded sufficient information for these to be included as mini case studies. This number of firms was chosen to allow the required breadth of the contextual variables to be sufficiently covered, and to subsequently enable the inference of theoretical propositions. A case study approach was dictated by the depth of understanding required. According to Yin (1994) case studies represent the most appropriate form of enquiry for investigating contextual conditions where the boundary between phenomenon and context is not evident. Survey methods, including self completion and interview surveys, although in general quicker to execute and able to solicit responses from a larger number of respondents, are less flexible, being limited in the amount and subtlety of information that can be captured. Usually these are necessarily limited in scope to fairly precise, pre-determined criteria, are less exploratory, and limit interpretation by the respondent.

Two forms of detailed case study design were considered. These were based in either longitudinal or retrospective approaches. Undertaking longitudinal case studies in real-time would have had the advantage of been able to most accurately track a project and gather information. However, since only a limited number of projects could be realistically studied in parallel, this approach would have constrained the number of cases which could have been undertaken within the required timeframe. Additionally, as some types of product can be several years in development, with a longitudinal case study approach it would have been necessary to exclude this type of project. The main drawback with retrospective studies is the possible problem of obtaining an accurate and unbiased recollection of events. However, it was considered that the nature of the issues in question were not likely to be adversely affected in this way. This approach was therefore chosen.

The case studies were undertaken principally on the basis of semi-structured interviews with several key individuals who had been associated with the particular project. The advantage of semi-structured interviews was that it allowed the interviewee to elucidate upon the relevant issues being addressed and in which they were involved, whilst allowing particular points to be probed in further detail. The outcome of these empirical studies was to provide a set of detailed descriptions of selected aspects of the engineering design and product development activities in a number of mechanical / electrical engineering firms.

4.2.2.4 Comparative Analysis

Having allowed the empirical evidence to reveal the nature of the engineering design and product development processes in the group of firms, the fourth stage was to compare and contrast the cases between themselves and against recommendations of 'best practice' derived from the literature. The purpose of the case study cross comparative analysis was to identify those features which were generic, and those which were specific, to company type characteristics. A thematic approach to the analysis was developed which permitted inter-process comparisons. This enabled the contextual typology factors to be systematically related to a series of themes concerned with the strategic, organisational, and procedural elements of firms development practices. This included making use where appropriate of analysis tools which presented the case study data in formats more suitable for comparison.

A specific objective of the research was to assess the influence, embodiment, and constraints to adopting best practice models. To this end, a composite model of success factors in engineering design and product development was constructed on the basis of an extensive review of the literature. The individual case studies were then individually and collectively compared against this. By this approach it was possible not only to ascertain key generic or firm specific relationships, but also to provide additional contextual insights to supplement and inform the findings of the case study thematic analysis.

The outcome of the comparative work was to hypothesise a series of generally applicable features of development practice, and specific relationships between contextual typology factors and features of development practice. Collectively these constituted a theoretical framework of engineering design and product development (figure 4.2) in which the various elements of the contextual typology could be related, via the thematic model, to the various facets of the organisation, management, and practice of engineering design and product development.

4.2.2.5 Interview Survey

The final stage of the research was to evaluate the proposed contextual framework using interview survey data. The aim was to demonstrate the validity of the theoretical propositions derived from the comparative analysis, rather than to establish their generalisation. Because of this, the survey did not need to provide a large statistical sample (50 or more firms for example). Hence, for the further replication of the key hypotheses obtained from the case studies, or, where necessary, their refutation and modification, interview survey data for a further group of firms (sufficient to provide the required coverage across the main classificatory variables) was used.

The research approach was exploratory in nature. This reflected the scope of the research problem and the forms of empirical enquiry used, with the focus of the key issues progressively being defined. Their were iterative features also, although in overall terms the research followed a linear process, in which the literature revealed the key issues to be investigated, the case studies and their subsequent analysis resulted in a number of hypotheses, and the interview survey enabled the testing of these hypotheses. For example, the case studies revealed areas for investigation, or insights, not addressed by the literature. Similarly, the interview survey material, which in effect provided a further set of focused case studies, also resulted in the generation of further hypotheses.

4.3 Contextual Frameworks

As indicated above, a number of conceptual frameworks were established to assist and provide focus to the research activities. These were a notional model of a manufacturing company, a contextual typology for classifying firms, their strategic policies and key project variables, and an analytical framework by which to capture the diverse and complex features of the engineering design and product development processes. The nature of these, and how they are interrelated, are discussed below.

4.3.1 Manufacturing Model

A first step to understanding the diverse and complex nature of the engineering design and product development processes was to set it in the context of a manufacturing company. A notional model of a manufacturing company which proved useful for analysis, or as a framework for discussion, was developed from that of Braiden et al (1993). This is shown in Figure 4.1. It illustrates how the structure is dominated by the market with which the business strategy interacts in a dynamic manner, and how the company as a whole interacts with the wider external environment. Therefore, the business strategy should be continually reviewed so that the changing market and environmental needs can be identified and a suitable response formulated. The business strategy interacts, again in a dynamic way, with the marketing, product development, manufacturing and financial strategies. Below the strategy level are the respective functional operations. Inevitably some exchanges of information occur between the functional departments, giving rise to information interfaces, the complexity of which depends on how well it, and the company's activities, are organised and managed. In particular, the manufacturing strategy and operational considerations (process technology and systems (infrastructure)) may be considered in parallel with those of engineering design and product development i.e. concurrent engineering.

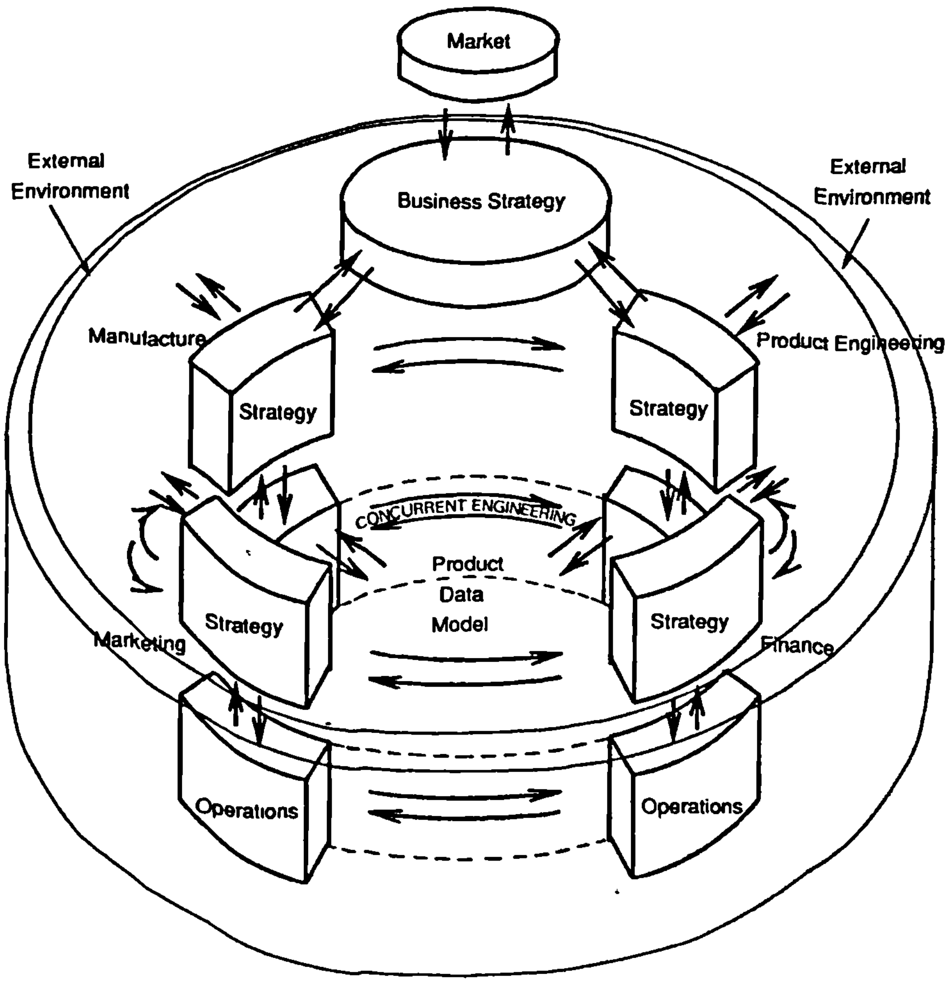


Figure 4.1: Model of a manufacturing company.

It will be evident from the internal logic of the model that what differentiates successful and non-successful firms, is the degree of fit between their functional and business strategies, and the level of integration both vertically between different strategic levels and horizontally between different functions.

The importance of such a model in the context of the research was that it established a dynamic framework within which the product development process could be seen to interact at the interfaces of the other major strategic and functional areas of the business. It implies that the mix of design requirements depends upon the type of company and/or its products which in turn reflects (among other factors) the nature of its business and external environments. The overall business strategy leads to particular types of product development strategies in different types of company. The product development strategy will give rise to specific design goals, and result in varying requirements for the different design activities. A company therefore needs to identify and organise these activities to meet such goals.

In understanding the integration of the above process, it was therefore important to recognise and take cognisance of a number of factors. These included the key company attributes; the role of environmental pressures and constraints; and the integration of manufacturing, marketing and product development strategies that fit overall business objectives, and the provision of appropriate company infrastructure as reflected also in the manufacturing model. In other words, a logical requirement for developing an improved understanding of the development process was to recognise, firstly, that the critical features that define a company needed to be captured within a suitable contextual typology, and, secondly, that a structured framework was required to handle the various features of the engineering design and product development processes. These are discussed below.

4.3.2 Contextual Typology

Existing models of engineering design and product development are inadequate in that they do not differentiate between, nor accommodate for, the characteristics of companies. They define approaches which, according to their proponents, are usually intended to have general applicability to companies. Because of this, they are defined at a high level of abstraction. In essence, the objective of introducing a contextual typology was to overcome these limitations by capturing a range of critical influences which offer greater discriminatory power. It also provided a significant part of the theoretical framework to bound and focus the empirical work. It follows that different classifications would have been suited to different objectives. In this case the primary interest was in the product innovation process and the classificatory framework needed to reflect this. The contextual typology proposed for this research allowed companies to be classified from three perspectives:

- General company attributes.
- Strategic policies.
- Key project variables.

4.3.2.1. Classification of Companies

There were a number of existing classification typologies available including:

- the commonly used Standard Industrial Classifications (C.S.O., 1979);

- classifications based on the dominant production process used, for instance de Jong et al's (1992) four-fold classification of manufacturing firms based on two variables (the degree of standardisation in the production process and the level of product variety);

- classifications which distinguish between high and low technology levels, often using the Standard Industrial Classifications as their basic building blocks, or relating companies to the product life cycle or some notional industry technology cycle;

- Pavitt's typology (Pavitt, 1984) of industrial sectors based upon their primary sources of technology, which identified four principal categories (supplier dominated firms, science based firms, scale intensive firms, and specialised suppliers) and features an innovation continuum from an emphasis on process innovation at one end to an emphasis on product innovation at the other; and

- a classification based on the segmented economy (Taylor, 1983) based upon notions of power and dependency between firms/establishments, by distinguishing between leaders, intermediates and laggards (which are equated with different technological profiles) within both the corporate sector and the small firm sector.

For a more detailed description and critique of these see Alderman (1995).

The foregoing were of limited use in the context of debates over suitable engineering design and development models because of their intended applications, for example, gathering aggregated statistical information, and studying technology and innovation in a spatial context, or the difficulties of applying them at the micro (establishment) scale, or because of inadequacies in terms of the available measurement tools for implementing the relevant concepts. Most of them are limited by being uni-dimensional or bi-dimensional at best. Firms similarly grouped under these typologies and therefore assumed to have similar features may be concerned with different products and operating in different markets under different conditions. Also, firms classified under a particular category may in actuality possess characteristics of other categories. It was therefore desirable to develop the classificatory framework further in the context of design and product development to overcome these limitations.

New (1977) considered a 'comprehensive' classification system based on three principal company characteristics. These are essentially how the production process is laid out within the factory (i.e. whether based on line, functional or group structures), the product structure - its depth in terms of components and sub-components - and the nature of customer orders. Barber and Hollier (1986) built upon this work by identifying a number of factors within five key dimensions relevant to the classification of companies. These dimensions include the market/customer environment; product complexity; nature and complexity of manufacturing operations; supplier environment; and company structure and manufacturing policies. They were concerned with classifying companies in the context of production control systems, but it was contemplated that these key dimensions were also relevant to a consideration of engineering design and product development processes. An additional distinguishing dimension which was considered relevant, was the global and local environment of the establishment.

The complex nature of companies suggested that the number and choice of the defining factors was an important consideration. It was necessary to capture the essential company features in sufficient detail to provide the required discrimination to the analysis, but it was also important to balance this against the number of variables which could be handled and the need to maintain a clear perspective of the company and its environment. This therefore led to a classification typology based on six key dimensions, each of which is associated with a set of defining factors selected in the context of the engineering design and product development activities. These are shown in Table 4.1. The rationale for regarding these as being key variables insofar as there influence on companies' development practices are concerned is outlined below.

In <u>organisational</u> terms the main factors relate to establishment size and the corporate structure. For corporate structure a distinction can be made between an independent company and an establishment which is part of a group. The principal feature, however, concerns the degree of autonomy possessed by the establishment in the corporate context for product development issues (product development strategy, approval of development resources and projects, etc.). By definition, an independent establishment, or one that is the headquarters of a multi-site organisation, will have autonomy over its development activities. Moreover, depending on corporate policies, other group establishments may similarly be considered as autonomous. In contrast, the non-autonomous group establishment will be subject to Group constraints. A further feature of the multi-site organisation is the possibility for some activities to be centralised within the organisation.

Company Classification Dimensions and Factors		
Company structure factors: Establishment size Ownership Autonomy Centralisation	*Process factors:* Process complexity Process flexibility Process constraint Production volume Internal span of process	*Supplier environment factors:* Rationalisation Degree of control Collaboration Locality
Market environment factors: Market type Market size and share Market complexity Market infrastructure Exports Number of competitors Competitive Criteria	*Product factors:* Product type (standard / special) Product variety / range Product complexity Product structure Product status Innovation rate Design capability	*Local and global environment factors:* Local labour market Skills Training Local support infrastructure Financing and grants Legislation and regulation Political and economic
Strategic Policies		
Business focus	Critical success factors (CSFs)	Product development strategy
Project Variables		
Project type	Project innovation: Product innovation Market innovation Process innovation	Key suppliers: Key supply items Design content Design by Supplier

Table 4.1: Proposed contextual typology for the classification of companies, their strategic policies, and key project variables.

The market and customer environment concerns the relationship between the company and the market. There are a number of relevant factors, but, in particular, it determines the competitive criteria and the way the order delivery process is configured.

The competitive criteria concern the relative importance of factors such as price, delivery (lead-time and conformance), technical specification (quality, reliability, performance) and so on, accorded by the particular product market. In addition, time-to-market may be an important competitive factor for product development activities in some markets.

Market type was regarded as a critical factor. The key distinction to be made is between made-to-stock (MTS), made-to-order (MTO) or assemble-to-order (ATO), and customised made-to-order (CMTO) or engineer-to-order (ETO). MTS companies are those whose products are typically relatively simple and low cost, where customers want to be able to buy on short lead times and manufacturers produce to stock according to some appropriate market demand forecasting procedures. MTO companies in their most basic form have a similarly catalogued range of products, but these may be too large, complex and/or expensive to permit capital to be tied up in extensive stocks and are therefore manufactured as and when orders arrive. ETO companies do not have a predetermined range of products as such. They have instead a set of product concepts and manufacture a new product tailored to each individual customer's order requirements. They are characterised by a high design content, each new order starting from scratch and often being designed according to the specifications laid down by, or developed jointly with the customer. In most companies aspects of more than one type may be apparent. Moreover, there are inevitably shades in between each category and a good example is the CMTO business that offers a basic product, but provides varying degrees of customisation.

Product factors were inevitably considered influential in determining the nature of the engineering design and development processes, both as a consequence of the technological content of the product and the range of process technologies required to support its manufacture. This dimension concerns aspects of the product, indicators of innovative change, and the design capability inherent in the product.

Two related factors, which characterise product features, are product complexity (number of parts) and product structure (levels in the bill of materials). Differences were anticipated between the development of products having low complexity and/or shallow product structure through to products of high complexity and/or deep structure. Other relevant factors are the type of product (i.e. standard or specialised), and the number of distinct product variants (i.e. product groups and ranges).

Product status is a concept introduced by Hollins and Pugh (1990) to describe the degree to which the overall product concept is likely to change or need changing at a given point in time. Hollins and Pugh related product status to the types of design disciplines required. Despite the concepts shortcomings (i.e. being a uni-dimensional indicator of a collective of contextual influences - see Chapter 2), it does provide a short term indicator of the likelihood and nature of product change. The rate of innovative change associated with the product in the medium and long term was captured by accounting for the frequency of substantial and incremental forms of technical change.

The design capability requirements inherent in the product captures the tacit knowledge acquired over time, the technical content or expertise relative any given level of product change, the R & D embodied in the product, and so on. This is not the same as the design capability of the establishment, which is dependent on the extent to which design expertise is internalised within the establishment.

Production process characteristics and emphases vary, and it follows that these will affect the types and timing of considerations which need to be addressed. These influences were captured in terms of the complexity, flexibility and constraints arising from the manufacturing systems. Process complexity reflects the number of operations, the nature of material flows, and scheduling and process control requirements. The degree of general or dedicated machinery and automated systems, and whether a product or process based manufacturing approach is used, collectively influence the degree of process flexibility. Process constraints on product development (e.g. on the choice of materials and the geometrical form of components) are associated with process flexibility, but additionally include considerations of investments in process technology and infrastructure, such as process R & D and automation. Further factors include production volume, since this has implications for the choice of production processes themselves, and, in reflecting companies' make / buy policies, the internal span of process (i.e. the proportion of the total production processes undertaken internally).

The influence of the supplier environment dimension is dependent upon the strategic decisions made regarding the degree of externalisation of the manufacturing process, the degree of externalisation of the design process, and extent of supplier rationalisation. A consequence of these decisions is that different relationships exist between companies and their suppliers. Decisions made about whether to 'make or buy' will be reflected in the location and nature of development activity within the value chain. Some supply items may be specialist and outside the company's area of competence, so that procurement from a supplier becomes an imperative. Alternatively, a policy adopted by some companies is to internalise all non-core activities. Ultimately, however, the critical factor concerns the extent and nature of collaboration with key suppliers.

The global and local environment may be influential for a variety of reasons. At a national and international scale firms' design and development processes may need to be flexible enough to take account of various social, political, economic, and legislative factors. Legislative and regulatory conditions may be particularly important to engineering firms through the setting of design standards, and so on. Within the locality of the establishment the labour market and skills base, along with the level and effectiveness of local technology support networks, including universities which encourage industrial partnerships and which are active in technology transfer, and the availability of appropriate financing and grant aid, potentially could have fundamental impacts not only in terms of company performance, but also on the levels and nature of its research and design activities. All of these factors could influence the capacity of the firm to meet market requirements in product development.

4.3.2.2 Strategic Policies

In meeting a company's goals within the business and company environments, certain critical success factors (CSFs) must be satisfied to deliver the required outcomes. These CSFs may be expressed in terms of the standpoints of the business (e.g. market share, profits, and so on) and the market (e.g. customer satisfaction, quality, price, lead-time, and delivery adherence). Clearly, many of these CSFs are related, or equivalent, to the competitive criteria factor in the market environment dimension. As conditions change, a company will formulate strategic policies by balancing its internal capabilities against the external environment. This may be undertaken in a more or less conscious and formal manner.

According to Treacy and Wiersema (1993), companies that take leadership positions within their industries frequently have a narrow strategic focus to their business. They focus and excel in one (or more) of three strategic areas - operational excellence, customer intimacy, or product leadership - whilst at the same time meeting industry standards in the others. From the perspective of the design and development function, the relative importance accorded to these will influence its role within the business and, therefore, the appropriate mix of design and development requirements. For example, is the company a product leader, developing products which excel in terms of their performance, quality and reliability? Or is the company an operationally effective manufacturer, in which the design role is concerned with minor improvements and minimising costs? It was appropriate, therefore, to take cognisance of the relative priorities assigned by companies to these three strategic areas (see Table 4.1).

The product development strategy pursued by the company will have a direct, albeit general, influence, by bounding the scope of the design and development activities of the firm, including the types of project undertaken (see Section 4.3.2.3 below). Whether formally devised and documented or not, it represents the companies plans for the types of products to be developed, timescales, product features required, technologies required and how these should be realised, required resources, and so on.

4.3.2.3. Classification of Projects

Product development is ultimately concerned with individual design projects. Indeed, this research focused on individual design projects relating to companies' products. Therefore, in addition to the general characteristics of companies and their strategic policies outlined above, the characteristics of projects are also of some importance.

The key project variables which were postulated to have most influence on development practices are shown in Table 4.1.

Firstly, a distinction can be made between product development projects and contract projects. There is a relationship between these project types and the market type factors mentioned above. MTO, ATO and MTS markets are associated with product development activities, and CMTO and ETO markets are associated with contract projects. Companies engaged in ETO and CMTO markets may however undertake product development projects.

Secondly, the amount of innovation relating to the product, production processes, and market are particularly important. Product innovation may range from minor improvements, through major enhancements (either a major enhancement to an existing product, or a major enhancement resulting in a new product platform), to new core products. Projects may involve no process change, relatively minor process changes (e.g. minor tooling or routing changes), or substantial process implications (e.g. procurement of new equipment or development of new processes). The market focus may be with an existing market (or customers), relate to a new niche or segment of a market, or establishing a new general market.

Finally, although the supplier environment factors establish a general approach to suppliers, factors relating to the existence and number of key suppliers, and the form of design inputs condition the nature of supplier collaboration at the project level.

4.3.3 Thematic Framework

The synthesis of influences from the various contextual characteristics of companies and projects was hypothesised to be manifest in terms of companies design and development practices. Capturing the complex and diverse nature of company practices represented a difficult task, and a suitable framework was required for this purpose.

Research undertaken into product development, but in the context of large firms (Johne and Snelson, 1990), provided an initial framework based on the McKinsey 7Ss structure (Peters and Waterman, 1982). The purpose of the McKinsey 7Ss framework is to capture essential management activities under seven critical headings. Since the product development activities involve a wide spread of persons and functions, the same basic framework can be used to investigate its important tasks. The seven factors are: strategy, structure, staff, skills, systems, shared values, and style. Although the focus of this research was less concerned with the social elements i.e. shared values and management style, the other elements were particularly relevant. Its usefulness was therefore in providing a structure around which to conceive and structure questions, test hypotheses and encapsulate findings. By way of example, typical overall issues relate to the provision of a product development strategy which defines the sort of product to be developed and the resources to be released for this purpose, the type of organisational structures used to implement product development activities, the types of functional specialists executing product development tasks, and the types of specialist knowledge and techniques applied.

The McKinsey 7Ss framework was used therefore as the basis for developing an overall framework appropriate to the research requirements. The thematic framework (Table 4.2) comprised a number of themes at strategic and project levels, which, in overall terms, included product development strategy, project organisation, processes and integration, methods, tools and techniques, procedures and systems, staffing and skills.

Using conceptual frameworks of the types described provided a theoretical and operational structure to the research methodology. They enabled an understanding to be gained in terms of the relationships between engineering design and product development, the other intra and extra corporate activities, and the important competitive, company type and project drivers. The contextual typology and thematic framework which represent the proposed contextual model are shown in Figure 4.2.

Product Development Strategy	Design Strategy
Format	
Aspects covered	Problem-focused and product-focused
Project Organisation	Methods and Techniques
Project initiation stages	Marketing techniques
Main project stages	CAE tools
- types of structure	Mutually supportable techniques
- team features	Formal design methods
- key personnel & responsibilities	Prototyping, internal testing & field testing
Process and Integration	Procedures and Systems
Principal processes, activities & key events	
Internal & external interfaces	General procedures
Concurrency & integration	Product proposal / enquiry review
	Project selection / tender review
Staffing and Skills	Design specification
Specialist, generalist, multi-skilling, experience	Project planning
	Project reviews
	Design reviews
	Performance measurement

Table 4.2: The thematic framework

Figure 4.2 indicates that the various classificatory dimensions of the contextual typology are not mutually exclusive. For example, the company and external business environments influence the strategic policies pursued by the company and, in turn, the product development strategy determines the types of development projects (i.e. project variables) undertaken. The various classificatory dimensions interact with each other to establish the organisation, processes, and procedures of design and product development. That is, different criteria combine to impact upon the development process in different ways, so that different types of company will have particular requirements vis-à-vis product development, and that these will give rise to different organisational forms and models of the product development process.

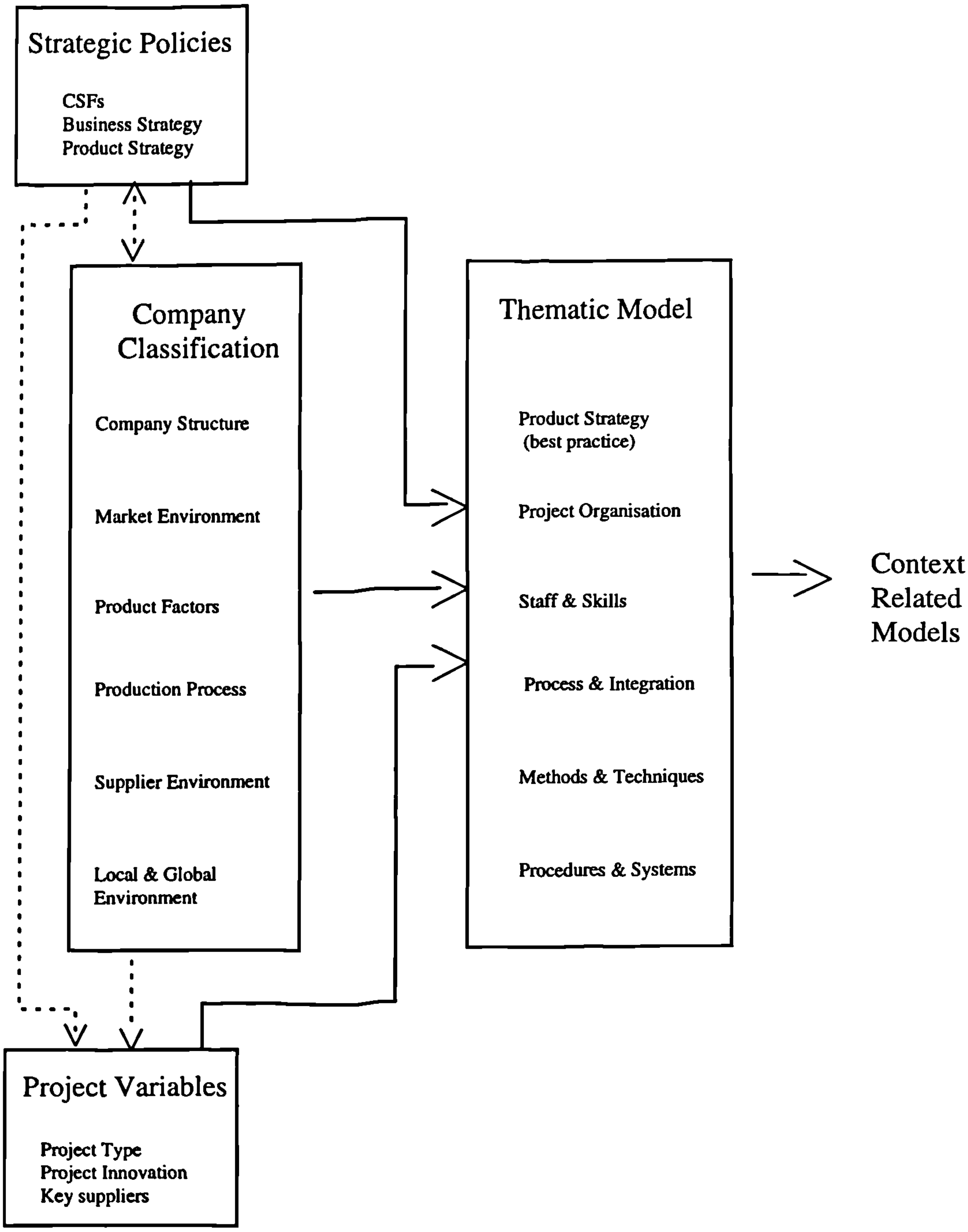


Figure 4.2: The proposed contextual framework.

The proposed contextual model provides a holistic perspective of product development, whereby the contextual factors and the engineering design and development practices which result from these are captured at both strategic and operational scales. The relationships between these, and the information associated with their investigation, are many and complex. Within the available time and resources, it was not possible to investigate all aspects of the contextual model and, therefore, it was necessary to bound the focus of investigation. As discussed above, some of the contextual factors influence the characteristics of others. Within the research, the approach was not to seek to explain these relationships, but to assume the various factors to be known. The main concern, therefore, was to focus on the relationships between contextual factors and the themes relating to engineering design and product development practices.

Inevitably, some of the contextual factors were found to be particularly influential, and others less so. There were also several factors, in particular those of a strategic nature (i.e. CSFs, product development strategy, and the general process factors and supplier environment factors), whose main influence was found to occur at a higher level than individual projects. Product development strategy, for example, clearly influences the types of development project undertaken and, in association with other factors relating to the product, supplier environment, and so on, would be expected to determine general decisions relating to staffing and skills, and other resources. Therefore, when relating these factors to company practices, the focus was to assess issues of general relevance (e.g. best practice requirements in relation to product development strategy), but not issues at the project level. Also, at the project level, the influence of some factors (e.g. process dimension) were found not to influence the themes, but were observed to influence issues of a more detailed nature (e.g. process constraints on design choices). Whilst these were observed on a project-by-project basis during the case studies, resource limitations also prohibited analytical investigations into these relationships.

Within the research the approach was to focus on a project relating to a particular product. Although most of the company classification factors applied to the company in general, some factors, particularly those relating to the market environment and product dimensions, were concerned with characteristics pertaining to a particular product. Some companies involved in the research had different types of products within their portfolio. Where these had significantly different characteristics, then consideration of these within the classificatory framework was appropriate, since companies practices will reflect the needs of different products and markets. Where there were such differences then these could be readily accounted for in the case studies given their in-depth nature. Moreover, in most of the case studies, the focus was on a core product, and the project studied was therefore representative of the establishments development activities. The more focused nature of the interview survey did not allow for the consequences of differences in product and market characteristics to be accounted for. However, the need for this was mitigated by focusing on a product which was strategically important to the company, and which was representative of its engineering design and product development activities.

The research approach adopted to operationalise these concepts is described in more detail in the remainder of this chapter.

4.4 Elements of Best Practice

A primary objective of the research was to assess the extent to which companies were adopting prescribed best practice principles. On the basis of an extensive review of the engineering design and product development literature a composite 'model' of critical *best practice* factors was identified. There is a consensus in the literature as to what constitutes best practice, however, where there are contradictions in the literature, the model reflects the predominant view. The model comprises 37 generic factors which have been classified into eight groups:

- Strategy.
- Technology Management.
- Marketing and Project Initiation.
- Organisation.
- Integrated Process.
- Modelling and Analysis.
- Project Management.
- Management and Decision Making.

The 37 best practice factors and their assessment criteria are listed in Table 4.6. The best practice model provided a focus for the issues which needed to be investigated in each case study. It also provided the benchmark against which companies' practices were compared (see Section 4.6.2).

4.5 Case Studies

The empirical stage of the research was undertaken on the basis of detailed case studies. The primary purpose of these was to provide a set of detailed descriptions of the engineering design and product development activities in a number of different engineering firms.

4.5.1 Selection of Companies

Methodological considerations, including the requirement to ensure that the breadth of classificatory factors were sufficiently covered, and time and resource constraints, suggested that between ten and twelve case studies should be undertaken. The process of identifying suitable companies had several requirements:

- The research was to be focused on the mechanical engineering related sectors of UK manufacturing industry, and the intention was to focus primarily on firms engaged in intermediate product markets.

- The companies should be engaged in engineering design activities.

- The cases should include a balanced representation of small (>50 employees), medium and large firms, and independent and corporate establishments.

- They should cover products of varying complexity, and different types of market.

- Non-competing companies were to be chosen, thereby ensuring breaches of commercial confidentiality were not possible.

On the basis of these criteria, sixteen companies were identified from sources which included existing research contacts, databases of UK manufacturing establishments developed and maintained by the Centre for Urban and Regional Development Studies at the University of Newcastle (see Alderman (1994)), and Queens Award winners. All the establishments identified for this phase of the research were located in England.

For each of the potential firms identified, a preliminary desk study was undertaken to provide relevant background information, including its ownership, employment levels, turnover and profitability, exports, main products, directors, address and telephone details. Sources for this supplementary material included company directories (Kompass and Key British Enterprises), on-line data base of firms' financial data (FAME), company reports, trade journals, and product literature available from previous research contacts.

4.5.2 Execution of the Case Studies

Following this preliminary desk study, an initial contact (letter of introduction, with a project summary enclosed, and a personal telephone follow up) was then made to instigate an introductory interview with either a senior executive (Managing Director or Technical Director) or a senior manager responsible for engineering design and product development.

This interview served a number of purposes. It provided an opportunity to outline the project in further detail, to assess the suitability of the company to participate in the research, and to solicit the firm's commitment to cooperate in the research programme. It enabled up-to-date background information to be obtained (including company and product literature) in order to classify the company in terms of the key contextual variables, and allowed a general understanding to be gained of the internal organisation of the company, both generally and in relation to product development (including organisation chart). One or a number of similar products which were considered suitable for study were then identified, along with the key process and organisational characteristics. Finally, the key individuals who were concerned with the implementation of a specific project pertaining to the product were identified at this time. In order to facilitate a reasonably structured and orderly approach to these introductory meetings a schedule in the form of an aide-memoir was used (see Appendix A).

In-depth case studies were then undertaken in order to provide detailed descriptions of companies' engineering design and product development practices within the areas of best practice outlined above in Section 4.4 and Table 4.6. The case studies were conducted on the basis of semi-structured interviews with several key individuals who had been involved with the project (or product) selected for study, and who in combination covered the total development process. The number of individuals interviewed ranged between two and eight. The lower numbers were usually associated with the smaller companies. The interviewees included representatives from Marketing, Engineering and Production and sometimes other relevant functions, and involved both managerial and functional representatives.

Using a semi-structured approach allowed the interviews to be configured in overall terms, with questioning focused towards the roles of the relevant individuals. For each interview a set of general, but nevertheless fundamental, issues were initially addressed. Essentially the interviewee was invited to describe the process for the project and their role within it. This enabled any biases or differences in perception amongst the interviewees regarding the project's details to be identified and, if necessary, to be subsequently qualified. The interviews then dealt with more specific issues relating to the interviewee. Undertaking the interviews in a semi-structured format enabled the interviewees to elucidate on the relevant issues being addressed and in which they were involved, whilst also allowing particular points of interest to be probed in further detail. Using this format also encouraged interviewees to make additional and unplanned contributions to this process.

The interviews usually took between one and two hours to complete depending upon the extent and nature of involvement of the respective individuals in the development process. The case studies involved several visits to the company. Although the focus of the interviews was usually concerned with a particular project, in some of the firms it was also possible to address features of other types of development activity undertaken by the company.

In addition to individuals' responses, documented information was also obtained where relevant and if available. This information was typically of two types: standard documents (product literature, procedures, checklists) and project specific documents (specifications, drawings, project plans, costings). These documents not only provided information relevant to specific issues, but also acted as secondary information to verify the validity of information obtained from the interviews.

A briefing document was written after each interview, and subsequent to this, a confidential company report was produced which assimilated this information, the results of the desk research, and included an analysis and commentary on the key issues and themes. The reports were produced according to a consistent format. This was done both to ease the report preparation process and to assist the subsequent analysis work. At this stage, however, they served two purposes: they provided an early feedback of the case study findings to the company and enabled the veracity of the findings and their interpretations to be checked by the company.

The introductory and in-depth interviews described above were undertaken jointly by the author and another research colleague. This ensured a more complete collation and documentation of the information provided by respondents during the interviews.

Of the sixteen companies approached at this stage, only two of these declined an introductory meeting. Of the remaining fourteen companies, ten agreed to participate in in-depth case studies, and a further two companies provided sufficient information to be included in the research as mini case studies. The other two companies had been keen to collaborate, but were in the process of restructuring. However, although they could not collaborate at this stage, these two companies subsequently assisted in pilot testing the interview survey questionnaire later in the research.

4.5.2.1 Interview Schedules

The critical review of the engineering design, product development, and other related literature, had revealed a number of key generic issues which were seen as being critical to successful product development outcomes, and formed the basis for the best practice model. Following this, and taking into account the application by Johne and Snelson (1990) of the Mckinsey 7Ss framework (Peters and Waterman, 1982) and the interview schedules used by Pugh and Morley (1989), a comprehensive list of issues and questions related to the various aspects of the total product development process was constructed.

In order to allow the true context and description of the process to be revealed within the scope of the research focus it was also important not to be presumptuous of a particular model of product development, and how it was organised and managed. Because of these factors, and in order to facilitate the semi-structured form of enquiry described above, the interview schedules needed to be flexible and generic in their application. The list of issues and questions was therefore developed into semi-structured interview schedules consisting of a series of question modules. Each of these was concerned with a generic theme of engineering design product development practice. The schedule comprised a total of thirteen modules as listed in Table 4.3.

Module 1:	Verification of the Product to be Studied
Module 2:	Strategy Formulation
Module 3:	Product Development Process
Module 4:	Engineering Design Process
Module 5:	Research and Development
Module 6:	Market and Product Planning
Module 7:	Product Design Specification
Module 8:	Organisation, Planning and Control
Module 9:	Production Issues
Module 10:	Information Systems
Module 11:	Quality
Module 12:	Performance Measurement
Module 13:	Supplementary Questions

Table 4.3: Interview question modules

Each module contained a detailed set of questions organised under sub themes, and augmented by an aide-memoire summary. Details of the case study interview schedule are included in Appendix B. The advantage of this format was to provide a degree of flexibility. Having identified who the key individuals were, and the overall nature of their involvement at the introductory interview stage, the question modules could then be easily mapped to the relevant individual. Thus for each interviewee the interview 'package' included the generic module (Module 3) plus the relevant modules and/or sub modules specific to their involvement in the project.

During the course of the initial case studies only very minor refinements to the schedules were required. This was essentially a reflection of the semi-structured approach adopted and its inherent flexibility, so that changes were concerned with the elimination of, or additions to, the schedules rather than the details of questions.

4.5.3 Company and Project Characteristics

The information obtained at this stage in the research allowed each company and the projects studied to be classified using the proposed contextual typology. A selection of the key company and project variables are shown in Table 4.4 and Table 4.5. respectively.

4.6 Comparative Analysis

The result of the case study work was to provide a set of detailed descriptions of the engineering design and product development processes in a group of establishments belonging to UK manufacturing industry. The purpose of the subsequent analysis stage of the research was to identify those features of good design and development practice which were generic to all the case study companies, and those which were specifically related to the characteristics used to classify companies, their strategic policies, and particular projects. The research approach was to compare and contrast the case studies between themselves and against prescriptive best practice. Therefore, rather than impose particular prescriptive models or opinions on the revealed process, the approach was to draw out the contextual relationships and then to interpret these in terms of the existing models.

4.6.1 Analysis Techniques

The case study information contained in the company reports and other supplementary information were structured with a view to assisting the subsequent comparative analysis - by using a consistent format and grouping information where possible according to the comparative themes. However, in many instances the information was not collated or presented in a format amenable to allow comparisons to be made, and additional mechanisms were required to facilitate this.

Company	A	B	C	D	E	F	G	H	I	J	K	L
Size												
Establishment size	L	S	M	S	S	S	L	S	S	L	L	M
Technical resource	L	M	M	S	-	S	L	M	S	M	L	L
Ownership												
Group establishment	*	*	*	*		*	*	*	*	*	*	*
Independent company					*							
Autonomous		*	*					*				
Non-autonomous	*			*		*	*		*	*	*	*
Centralisation:												
R & D						*	*			*		*
Product development strategy				*					(b)	*		
Marketing									(b)			
Production										(c)		*
Other												
	(b) Standard product range only					(c) Centralised manufacture but local assembly						
Market Factors												
Market Type:												
ETO	*				*		*	*	*		*	*
CMTO	*	(d)	*	*		*	*	*	*		*	*
MTO			*	*	*	*	*	*				*
ATO												
MTS			*	*					*	*		*
	(d) Customised-to-service											
Competitive criteria:												
Price	3	1	(e)	2=	2	2=	1	1	2	2	2	1=
Delivery lead-time	2		(e)	2=		2=	2	2	3			1=
Time-to-market				*		*	*			*		
Technical	1	2	(e)	1	1	1	3	3	1	1	1	3
	(e) Key criteria were H&S and operating cost savings											
Product Factors												
Innovation rate	H	M	M	H	L	M	M	L	L	M	L	M
Product complexity	M	M	L	M	L	L	M	H	M	M	H	M
Product structure	M	S	S	S	S	S	M	D	S	M	D	M
Design capability	H	L	L	M	L	M	H	M	L	M	H	L
Supplier Factors												
Key supplier collaboration	M	M	M	M	M	H	H	H	L	L	M	M
Strategic Policies												
Business focus:												
Market focus/customer intimacy	2	2	1=	1=	1	1	1	1	1=	2	1	1=
Operational excellence	3	1	3	3	3	3	3	2=	3	3	3	3
Product leadership	1	3	1=	1=	2	2	2	2=	1=	1	2	1=

Notes: Establishment size: S<250; M<500; L>=500. Technical resource: S<=10; M<=25; L>25.
Innovation rate: H<5yrs; M<10yrs; L>=10yrs. Product Complexity: L<10s; M<1000s; H>10000s
Product structure (shallow, medium, deep) and Design capability: based on relative assessment.

Table 4.4: Key company and strategic variables (case studies)

	Primary Projects												Secondary Projects				
Company	A	B	C	D	E	F	G	H	I	J	K	L	B	F	G	I	L
Project Type																	
Product Development			*	*	*	*	*			*	*		*			*	*
Contract	*	*						*	*			*		*	*		
Project Innovation																	
Product:																	
Minor	*	*						*	*			*		*	*		
Major (Existing)				*		*										*	
Major (Platform)					*		*			*	*		*				*
New core product			*														
Market :																	
Existing Market	*	*	*	*		*	*	*	*	*	*	*	*	*	*	*	*
New niche / segment					*												
New market																	
Process:																	
No process change	*	*						*	*		*	*	*	*	*	*	
Minor process change				*	*		*			*							
New equipment / process			*			*											*
Key Suppliers																	
Key supply items	*	*	*	*	*	*	*	*	*		*	*	*	*	*	-	*
Several key supply items						*	*	*						*		-	
Design content	*	*	*	*	*	*	*	*			*	*	*	*		-	*
Design by supplier						*	*	*			*	*	*	*		-	*

Table 4.5: Key project variables (case studies)

The comparative analysis involved making use where appropriate of several analysis tools to enable the qualitative data to be structured and compared in a rigorous manner. These included process modelling techniques, concurrency evaluation matrices, and methods evaluation matrices.

- Process modelling was performed using the principles of the Structured Analysis technique (Ross, 1977). This allows a process to be defined as a number of activities, along with the inputs, outputs, mechanisms and constraints relating to these (see Figure 6.1 and Figure 6.2 in Chapter 6 for examples).

- Concurrency evaluation matrices (McGrath et al, 1992) were used to capture the inputs and involvement of the internal disciplines, customers, and key suppliers over the main project stages. Companies have different organisational arrangements and therefore different functional definitions. However, standardising the definition of the internal disciplines (as Marketing and Sales, Engineering, Production, and Procurement) allowed inter-project comparisons of process concurrency to be made (see Appendix C for an example).

- Using matrices, the various methods, tools and techniques, were classified according to the project stages for both contract projects and product development projects.

4.6.2 Best Practice Evaluation

The case studies were individually and collectively assessed through a benchmarking exercise against the composite model of best practice factors derived from the literature. The model's formal assessment criteria (see Table 4.6) allowed an ordinal score (0 - 5) to be assigned to each generic factor, with a score of five being equivalent to *best practice*. As indicated earlier, in some of the case studies aspects of more than one type of project were studied and therefore where the model's criteria were project specific, the assessment was undertaken on the basis of the primary project studied.

BEST PRACTICE FACTORS	ASSESSMENT CRITERIA
Strategy	
1. Business Strategy	- Not rated for case studies.
2. Product Strategy	- Formal document = 2pts. - Assessment as to the degree it formally or informally defines: types of product; markets to be targeted; features, differentiating factors and customer benefits; technology to be used; research areas; prioritisation for product developments; resources required. <=3pts
3. Competitive Approach	- Based on 'total offering' appropriate <=2pts. - Knowledge of competitive criteria, including winning/qualifying criteria <=2pts. - Offering unique features = 1pt.
4. Business Focus	- Not rated for case studies
5. Customer Focus	- Know valuable/key customers =1pt. - Maintain frequent contact (both sites) and discuss future development/ideas <=2pts. - Monitor performance: individual (not just total) customer sales, delivery on time, customer satisfaction <=2pts.
6. Supplier Approach	- Know key suppliers and which supply competitors = 1pt. - Mutual benefit philosophy, maintain regular contacts, use single sourcing opportunities, vendor rating, preferred supplier status <=3pts. - Discuss future developments/ideas =1pt.
Technology Management	
7. Defined responsibility for technology and technical co-ordination	- Not rated for case studies.
8 Systematic Monitoring	- Proposed legislation, public opinion, social and environmental pressures; competitive technologies; patent searching; technology audits; internal seminars, meetings, and discussions; participation in standards setting and influence of regulatory bodies etc. <=5pts.
9. Technology Development Policy	- Basic science/techniques monitored through links with relevant universities/ research organisations = 1pt. - Support technologies monitored through collaborative contact with suppliers, customers, competitors =1pt. - Willingness to licence technology, acquisition/merger policy <=2pts. - Innovation support mechanisms =1pt.
10 Intellectual Property	- Not rated for case studies.
Marketing & Project Initiation	
11. Systematic Market/Customer Analysis Mechanisms	- Detailed market study/research =1pt. - Market feedback mechanisms: sales intelligence and product performance (complaints, etc.) <=2pts. - Competitor analysis =1pt. - Systematic search for product ideas =1pt.
12. Product Proposal/Enquiry Review	- Defined procedure, including regular review meetings <=2pts. - Reviewed in terms of (criteria): market needs, technical possibilities, profit potential, risks, product strategy, having clear objectives, competitor position <=3pts.
13. Feasibility Assessment/Tender Development	- Market, financial/commercial and technical (including manufacturing) <=3pts. - Risks (technical & commercial, incl. contractual, production, procurement, competence, etc.) <=2pts.
14. Project Selection & Screening Criteria	- Basic market/financial variables i.e. cost, sales, profit, ROI <=2pts, and broader variables/factors <=2pts. - Evaluate/prioritise i.e. go/no-go (applies to tender review for contracts) =1pt.
15 Market Brief & Specification	- Formulated prior to start of main project design =1pt. - Characteristics: Defines all requirements and constraints, ranks design requirements, states need but sol'n neutral in principle =1pt. Cohesive, unambiguous, comprehensive, succinct statements and standard format =1pt. - Used as a control document, changes recorded =1pt. - Subsystem and component specifications =1pt.
Organisation	
16. Technology (design) representation at senior level	Assessment of location/.influence <=5pts.
17. Project Organisation Structure	- New prod/major improvement/re-design by project team forms. Minor improvement / contract customisation by lead function/manager ownership. Project management or matrix organisation for large contracts/projects. Senior manager as process champion - product developments <=5pts.
18. "Team" Features	- All disciplines represented* <=2pts. - Permanent core team* =1pt. - <10 multi-functional team*, >10 extended team, >>10 project organisation =1pt. - Co-location =1pt. * For non-team structures interpret in terms of nominated individuals, and team principles.
19. Project Management Organisation	- All projects have an owner (internal customer) =2pts. - Overall manager or team leader (for larger project the project manager works through a controlling team) <=3pts.

Table 4.6: Model of best practice factors

BEST PRACTICE FACTORS	ASSESSMENT CRITERIA
Integrated Process	
20. Generic Process Structure	- Defined for main project types =2pts. - Identifies major phases, steps, and milestones (including decision points) <=3pts.
21. Integrated and Paralleled Activities	- Degree of overall concurrency <40%=1pt, <50%=2pts, <60%=3pts, ... 5pts.
22. Interactive Task (Specification)	- Multi-functional, interactive task involving Engineering, Marketing, Production, etc <=4pts. - Final document approved by all =1pt.
Modelling & Analysis	
23. Modelling, Analysis and Prototyping	- Use of analytical, performance simulation and graphical / physical modelling tools prior to 'proof of concept' = 1pt for each up to 5pts.
24. Mutually Supportable Techniques	- to make teams more effective and utilise cross functional knowledge: QFD, FMEA, Design to Cost, Design Poka Yoke, DFMA, Problem Solving (Brainstorming, etc.), Robust Design, etc. = 1pt for each up to 5 pts.
25. CAE Development & Project Management Tools	- Design tools (electrical design, CASE, mechanical design i.e. 3D/surface modelling), simulation tools, development tools (IC/PCB, rapid prototyping) <=4pts. - Project management tools =1pt.
26. Internal Testing	- Manufacture of working prototype using production equipment =1pt. - Thorough programme of testing/defined procedures/requirements. (for contracts relate to testing of suppliers equipment, testing and commissioning of systems/product) <=4pts.
27. Market Testing and Field Trials	- undertaken y/n = 2pts. - Well planned in terms of choice of customers, test programme, test parameters to be measured, site support to customer. (for ETO/CMTO relate to site performance test/trials) <=3pts.
Project Management	
28 Project Definition	- Clearly defined written, signed-off specification <=2pts. - Firm objectives and terms of reference <=3pts.
29 Planning and Control	- 3 level project planning including (as appropriate) overall plan, work package plan, and detailed plans, (which define key milestones, schedule activities and shows interrelationships/responsibilities) <=2pts. - Time phase resource plans; phase budgets/cash flow; responsibility matrix; contingency planning <=3pts.
30 Records	- Organised system/procedures for records management including change control and traceability (BS5750) =2pts. - All important meetings (include. phase and design reviews), critical decisions, documents, tests, etc. formally minuted, actioned and documented <=3pts.
31 Project File	Preparation Phase: - project definition by senior management, team leader and team selection, and project planning <=2pts. Development Phase: - weekly control and recovery planning meetings (team./manager); key milestone reviews; regular update/replanning (team leader/manager) <=2pts. Post Project: - Review =1pts.
Management & Decision Making	
32. Top Management	- Adopts 'loose-tight' style (autocratic/loose-tight/hands-off) =1pt. - Establishes clear project objectives and review criteria =1pt. - Empowers team with authority, by distinguishing management (strategic) and team (implementation) responsibilities, and provision of required resources <=2pts. - Undertaking major project reviews =1pt.
33 Project Reviews	Product Developments: - Go/delay/no-go decisions =2pts. - Basis for approval and funding of the next phase =1pt. - Specific milestones = 2pts, not calendar or ad-hoc =1pt. Contracts: - Key milestones =5pts, calendar based =3pts, ad-hoc based =1pt.
34. Review Criteria	- Defined formally =2pts. - Project status and future requirements =1pt. - Clearly address stage specific issues <=2pts.
35 Performance Metrics	- Clearly and formally defined =1pt. - Performance improvements/strategic tools =1pt. - Related to business (sales, profit, mkt share) and market (customer lead-time, price, customer satisfaction, quality) and involve a broad range of local measures (innovation, cost, quality, time, etc.) <=3pts.
36. Design Reviews	- Conclusion of each state or milestone =1pt. - Compared with result of design specification, consideration of manufacturability, cost, quality, design risk and possible problems <=2pts. - Formally documented procedure =1pt. - Distinct from progress reviews =1pt.
37. Senior Management Activities	- Not rated for case studies.

Table 4.6 (Contd.): Model of best practice factors

This assessment process was undertaken independently by both the author and another research colleague. If a different rating was found to occur for a specific factor then the reasoning for this was debated and a rating agreed upon. A consequence of the semi-structured and exploratory nature of the case studies, was that the evaluation exercise did require an inherent degree of judgement in some respects. However, applying common assessment criteria ensured that the comparative results obtained were internally consistent. The ratings assigned were therefore seen as relative rather than precise indicators.

The aim of this benchmarking exercise was not to rate the excellence of individual companies' performance per se, but to assess the extent to which best practice is sufficiently comprehensive to meet the needs of different types of company, how flexible the recommendations are to enable companies to adapt them to their particular circumstances, and the extent to which the recommendations are actually adopted. This aspect of the research involved:

- An evaluation of *actual performance* against the model (see Table 5.1).

- An assessment of what the author deemed to be *achievable practice* in each case (see Table 5.1).

The *achievable practice* rating for any given best practice factor may be equal to, or less than, the best practice rating of five. A lower rating may arise for two reasons. Firstly there may be constraints which limit the possibilities for some companies to implement best practice, such as small companies that are resource constrained. Secondly, best practice, as expressed by the current consensus, may itself be inappropriate to certain companies or types of project, such as those as those engaged in low volume and/or contract work, particularly as it is derived largely from the automotive and electronics industries and tends to focus on product development projects. Therefore, by rating companies' practices in this way, it was possible to ascertain what form best practice should take under different circumstances (i.e. *achievable practice*).

Differences may also exist between a company's *actual performance* and *achievable practice* for the various areas of best practice. The scale of these differences indicates the realisable scope for improvement in the company. For example, referring to Table 5.2, achievable practice for Product Strategy has been assigned a rating of five for all firms. This indicates that best practice is achievable by all the companies. The actual ratings shown in Table 5.1. show that in actuality companies A and J realised achievable practice (and in this case best practice), but that relative to this the other companies' actual performances indicated room for improvement.

The findings of the best practice evaluations, including the implications of the actual and achievable ratings, are discussed for each of the best practice factors in Chapter 5. These findings also supplemented and informed the thematic comparisons (see below).

4.6.3 Thematic Analysis

A primary aim of the research was to identify those features of *good* design and development practice which are generic, and those which are company specific. The best practice evaluation detailed above aimed to provide insight into many of these features. However, it was the thematic analysis, whereby the design and development practices of the case studies were compared and contrasted, which was explicitly concerned with this research aim.

A thematic approach was adopted in which the company classifying and project variables (see Section 4.3.2) were systematically related to a series of themes concerned with the features of firms' actual development practices at strategic and project levels (see Section 4.3.3) across the case studies.

Adopting a thematic approach to the analysis permitted inter-process comparisons to be made. Hence by positioning the companies on the classificatory dimensions and in relation to their activities, then the type of relationship (i.e. generic or specific) between classificatory factor and development theme became apparent, enabling a series of thematic relationships to be hypothesised. The findings from this part of the analysis are discussed in Chapter 6.

Inevitably, by comparing companies *actual practices*, aspects of less good practice were compared and contrasted. The assessments of *achievable practice*, undertaken as part of the best practice comparative evaluation, were used subsequently to inform the analysis, thereby allowing those features of *good practice* to be identified as appropriate under different company and project circumstances.

4.7 Interview Survey Data

The outcome of the comparative analysis work was to hypothesise relationships concerning those features of good design and development practice which were applicable to all companies, and those which were related specifically to the characteristics of companies and projects. Survey data was then used to validate, modify, or refute these hypotheses and, in this way, the theoretical framework was further developed.

Survey data from an interview survey in which the author had been involved was used for this purpose. This survey and its subsequent analysis had been concerned with testing the statistical generalisation of the hypotheses resulting from the case study comparative analysis and, therefore, had involved a sample of 46 companies. Using this existing data enabled the choice of companies to be controlled insofar as providing a coverage across the important company factors (size, ownership, product complexity, and innovation rate) and project variables (project type, product innovation, and supplier involvement) were concerned. Seventeen companies were chosen from the subset of 34 interviews undertaken by the author. Details of this survey, and how it was conducted, are given below.

4.7.1 Construction of the Interview Survey Questionnaire

The comparative analysis had yielded many questions concerning best practice and the extent to which contextual factors influence design practices. The most important of these were identified, along with the relevant variables.

Consideration of the time companies might be willing to make available suggested that the interviews should be undertaken in no more than one and a half hours, and preferably in less time than this. This led to two concerns in the design of the survey. Firstly, this placed a constraint on the number of issues which could be investigated. It was necessary, therefore, based on the perceived importance of the specific issues and whether the data was relevant to other areas of interest, to prioritise which questions were to be included. Secondly, it required the questionnaire to be designed for efficient completion. It was structured so that the background information on the company was initially gathered, followed by a logical progression through a project recently undertaken by the company in relation to a strategically significant product. The individual questions were also designed to maximise the use of ticked responses and, show cards were used as appropriate. Details of the interview survey questionnaire are included in Appendix C.

4.7.2 Pilot Testing

The questionnaire was pilot tested in two stages. Firstly, this was undertaken internally through a role playing approach with research colleagues. This verified the time duration required and indicated areas where some modifications were appropriate. Secondly, it was pilot tested on two of the companies who were unable to collaborate in the case studies, but were otherwise interested and willing to assist in the research. The resulting changes were of such a minor nature that these pilot tests were included in the survey data.

4.7.3 Selection of Companies and Execution of the Survey

Companies were identified from a database of manufacturing establishments from the mechanical engineering sectors of UK manufacturing industry maintained by the Centre for Urban and Regional Development Studies at the University of Newcastle. The database was based on surveys of a cohort of companies. The first survey was undertaken in 1981, and the database was subsequently updated through surveys in 1986 and 1993 (Alderman, 1994).

A consequence of using this database is that it does not include companies formed since 1981. However, the database was probably still representative of companies in the mechanical engineering related sectors. This supposition is based on the fact that this thesis is concerned with companies employing more than fifty employees and who are actively engaged in design engineering design and product development, whereas newly formed firms tend to be small (usually employing significantly less than 100 employees) and frequently associated with precision engineering activities.

A list of suitable companies was extracted from this database for the Yorkshire and Humberside, North West, Northern, and Scottish regions. The database included details on company size, main products, and type of markets (ETO, MTO, ATO, MTS). It also provided some indication of whether firms were engaged in design and development activities (existence of a drawing office and use of CAD). Other data sources (Kompass and Key British Enterprises) were then used to verify and supplement this information. Each company was then contacted by telephone to identify an individual having responsibility for design and development activities.

A letter of approach, including a project summary, was then sent, and a follow-up telephone contact made to arrange a convenient date and time to undertake the interview. 77% of companies approached agreed to an interview. This was a very good response given that the survey was undertaken during the summer months. A letter of confirmation was sent to each company. This confirmed the date and time of the interview, and outlined in overall terms what would be covered. It also requested general company and product literature, and an organisational chart. Some of the companies provided this information in advance of the interview, but most provided this at the interview. In most instances interviews were held with a senior manager or director who had been responsible for a particular development project. In several cases a second individual (e.g. design engineer or project leader) also participated.

4.7.4 Company and Project Characteristics

Details of the seventeen companies selected from the interview survey and their respective projects are shown in Table 4.7 and Table 4.8 respectively.

4.8 Research Findings

The results of the case study comparative analysis and the interview survey analysis are presented in the remaining chapters of this thesis. The reader is recommended to read the text in conjunction with the information presented in Tables 4.6, 5.1 and 5.2. The style of presentation is to present best practice (as appropriate), discuss the results of the case study comparisons, present the interview survey information (as appropriate), and to draw initial conclusions relating to each best practice factor or comparative theme. Overall findings are drawn out in Chapter 7.

The presentation of the research findings is structured according to several areas concerned with the initiation and implementation of development projects. These include strategy, marketing and project initiation, organisation, process and integration, design methods modelling and analysis, design strategy, and project management and decision making. Some of the themes used for the comparative analysis are cross-cutting in relation to these areas, and are drawn out as relevant to the various areas of discussion. For example, in an area such as project planning and control, themes such as project organisation, methods, tools and techniques, and procedures and systems are relevant.

Company	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Size																	
Establishment size	M	L	M	S	L	S	L	S	M	S	M	M	M	L	M	S	S
Technical resource	M	M	L	S	L	S	L	M	M	L	M	S	M	L	L	M	M
Ownership																	
Group establishment	*	*	*	*	*	*	*	*		*	*	*		*	*	*	*
Independent company									*				*				
Autonomous						*	*	*		*	*				*		
Non-autonomous	*	*	*	*	*							*		*		*	*
Centralisation:																	
R & D	*	*		*	*					*	*			*		*	
Product development strategy	*	*		*	*									*		*	
Marketing	*	*			*									*		*	*
Production		*												*			
Other																	
Market Factors																	
Market Type:																	
ETO			*					*	*			*		*	*		*
CMTO		*	*	*	*			*	*	*		*	*	*	*	*	*
MTO	*	*	*		*		*	*	*	*	*	*		*			*
ATO	*	*	*	*	*			*									
MTS	*	*	*			*		*				*			*		
Competitive criteria:																	
Price	2	2=	2	1	2		1	1	1=	1	1=	3	3	1	1	1	1
Delivery lead-time		2=	3	3			3	2	1=	2=	1=	2	1				2
Time-to-market	*	*			*	*			*		*						
Technical	1	1	1	2	1	1	2	3	2	2=	3	1	2	2	2	2	3
Product Factors																	
Innovation rate	M	M	L	L	H	H	H	M	H	H	M	M	M	L	L	L	L
Product complexity	L	M	M	L	M	M	M	M	L	H	L	L	M	H	H	H	M
Product structure	S	M	M	S	M	M	M	M	S	D	S	S	M	D	M	M	M
Strategic Policies																	
Business focus:																	
Market focus/customer intimacy	2	1	2	1	-	3	1	1	1	3	1=	2	2	1	1=	1	3
Operational excellence	3	2=	3	3	-	2	3	2	2	2	3	1	3	2=	1=	2	2
Product leadership	1	2=	1	2	-	1	2	3	3	1	1=	3	1	2=	3	3	1

Notes Establishment size: S<250; M<500; L>=500. Technical resource: S<=10; M<=25; L>25.
Innovation rate: H<5yrs; M<10yrs; L>=10yrs. Product Complexity: L<10s; M<1000s; H>10000s
Product structure (shallow, medium, deep) based on relative assessment.

Table 4.7: Key company and strategic variables (survey)

Company	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Project Type																	
Product Development	*	*	*	*	*	*	*	*									
Hybrid (p)									*								
Hybrid (p/c)										*							
Hybrid (c)											*						
Contract												*	*	*	*	*	*
Project Innovation																	
Product:																	
Minor								*			*	*			*	*	
Major (Existing)		*		*	*								*	*			*
Major (Platform)	*		*						*								
New core product						*	*			*							
Market :																	
Existing Market	*	*	*	*	*	*		*		*	*	*		*	*	*	
New niche / segment							*		*	*			*				
New market																	*
Process:																	
No/minor process change				*					*				*	*	*		*
New equipment / process	*	*	*		*	*	*	*		*	*	*				*	
Key Suppliers																	
Key supply items	*	*	*	*	*	*	*	*		*	*		*	*	*		
Design content	*	*	*	*	*	*	*			*	*		*	*	*		
Design by supplier		*	*		*	*	*			*	*		*	*	*		

Table 4.8: Key project variables (survey)

4.8.1 Statistical Analysis

Section 4.2.1 described how the research was concerned with developing and establishing the validity of a theoretical framework. The research approach was to generate hypotheses from the case studies which were then tested using the interview survey data. Because the research was concerned with the development of theory, hypothesis testing was undertaken with a view to the replication of results rather than demonstrating statistical generalisation. Where appropriate, however, statistical tests (t-test and non-parametric tests) were used as a basis to quantify the strength of, and support for, the hypothesised relationships. Testing for normality in the data was based on a simple comparison of the mean and median values. Established practice is to adopt a level of significance of 5% or less when the intention is to generalise results to a population. However, as the research was concerned with the development of theory rather than statistical generalisation, it was important to avoid missing possible relationships. For this reason a 10% level of statistical significance was used throughout. The case studies were selected to capture a diverse range of values for the main variables used to classify companies (i.e. establishment size, product complexity, etc.). The survey establishments were drawn from a random survey sample. These were also pre-selected on the basis of known characteristics to cover a range of values for key variables.

Chapter 5

Comparative Analysis - Best Practice Evaluation

5.1 Introduction

Primary objectives of the research were to assess the extent to which companies are adopting prescribed best practice principles and to determine whether there are particular constraints which apply to certain types of company. These were undertaken through a benchmarking exercise against a composite model of prescribed best practice derived from the literature. As discussed in the previous chapter (Section 4.6.2) this involved an evaluation of *actual practice* against the model and what was considered to be *achievable practice* for each case study, the results of which are shown in Table 5.1 and Table 5.2 respectively. A comparison of these results was then undertaken. The assessment and comparative evaluation was undertaken for each of the case study companies[1], with the exception of company K, for which there was not deemed to be the necessary depth of information to make a valid assessment for several factors. The findings of this part of the research are discussed in this chapter. In addition, data for the interview survey companies is included where relevant.

5.2 Overall Company Performance

Looking at the overall results (indicated by the % of maximum totals in Tables 5.1 & 5.2) a notable difference was found between product development projects (i.e. companies C, D, E, F, G, J & K) and contract projects (i.e. companies A, B, H, I & L). Although there was little distinction in terms of their actual performance, as far as their achievable performance was concerned, a mean overall rating of 95% of

[1] The case studies and interview survey were concerned with the activities of particular establishments. In this and subsequent chapters of this thesis the terms establishment, company and firm are used interchangeably. Whichever of these terms is used in the text the meaning is intended to be that of establishment.

maximum for product development projects was found to compare with a lower 88% rating for the contract projects. Moreover, this difference in means was a statistically significant result ($t=3.83$, $P<0.1$, one tailed test). Indeed, the highest overall contract rating (A) was equivalent to the lowest of the product development ratings (E, F). This suggests that the companies engaged in contract-based projects are constrained in adopting prescribed best practice, or it could be that prescribed best practice is not appropriate to contract projects in some respects.

Lower product complexity and shallower product structure (B, C, E, F, & I) was associated with lower overall mean performance, as was the requirement of the product for a low design capability (B, C, E, I & L). These findings applied to both actual and achievable performances, although they were less pronounced for achievable practice. Interestingly, company size did not appear to make any identifiable difference to overall performance.

Notwithstanding these particular findings no other relationships were found. However, relationships were identified for a number of specific best practice factors. These are explored in subsequent sub-sections.

5.2.1 Performance by Factor Groups

Comparisons for the actual and achievable ratings at the level of best practice factor groups yielded several important observations. In particular, was the notable difference between the low actual and high achievable mean values for: Management and Decision Making; Marketing and Project Initiation; and Project Management. Moreover, the high achievable mean values obtained were associated with very low variation between companies and, given the high variation between companies for the actual mean values, substantial improvement opportunities were suggested for many companies in these areas.

	Company	A	B	C	D	E	F	G	H	I	J	L	MEAN	VAR
Best Practice Factors														
Strategy	Product Development Strategy	5	4	3	3	2	3	4	2	2	5	4	3.36	1.25
	Competitive Approach	4	4	4	4	4	4	4	5	5	5	4	4.27	0.22
	Customer Focus	4	5	4	4	4	4	3	5	4	4	4	4.09	0.29
	Supplier Approach	2	2	2	3	2	3	3	3	2	2	3	2.45	0.27
	Sub Total	15	15	13	14	12	14	14	15	13	16	15	14.18	1.36
Technology Management	Systematic Monitoring	5	2	3	3	1	4	3	2	0	1	3	2.45	2.07
	Technology Development Policy	3	2	3	3	1	2	2	1	2	1		2.00	0.67
	Sub Total	8	4	6	6	2	6	5	3	2	2		4.40	4.49
Marketing & Project Initiation	Systematic Market Analysis Mechanisms	4	3	3	4	3	3	3	2	3	2	3	3.00	0.40
	Product Proposal / Enquiry Review	5	2	4	5	2	3	5	5	5	2	5	3.91	1.89
	Feasibility / Tender Development	4	2	4	5	2	3	4	4	4	3	4	3.55	0.87
	Project Selection & Screening Criteria	3	3	3	5	2	3	4	4	5	1	3	3.27	1.42
	Market Brief & Specification	3	3	2	5	1		4	5	3	2	3	3.10	1.66
	Sub Total	19	13	16	24	10		20	20	20	10	18	17.00	21.78
Organisation	Technology Representation on Board	5	3	5	5	5	3	5	5	3	5	3	4.27	1.02
	Project Organisation Structure	4	5	3	5	4	3	5	3	3	4	3	3.82	0.76
	Team Features	3	3	1	4	3	2	4	1	4	3	2	2.73	1.22
	Project Management Organisation	3	3	4	4	4	3	5	1	3	5	3	3.45	1.27
	Sub Total	15	14	13	18	16	11	19	10	13	17	11	14.27	9.02
Integrated Process	Generic Process Structure(s)	3	4	4	5	2	3	5	3	4	2	5	3.64	1.25
	Integrated & Paralleled Activities	1	1	2	3	2	1	3	3	3	2	2	2.09	0.69
	Interactive Task (Specification)	4	2	3	4	1	4	3	3	4	3	2	3.00	1.00
	Sub Total	8	7	9	12	5	8	11	9	11	7	9	8.73	4.22
Modelling & Analysis	Modelling & Rapid Prototyping	5	1	1	2	2		5	3	2	3	1	2.50	2.28
	Mutually Supportable Techniques	2	0	1	4	2	0	5	1	1	1	2	1.73	2.42
	CAE Development & Project Mgt Tools	4	2	1	4	1	2	4	3	2	1	1	2.27	1.62
	Internal Testing	5	na	4	4	5	5	5	5	5	4	5	4.70	0.23
	Market & Field Trials / Site Testing	5	na	4	5	4	na		5	5	4	5	4.63	0.27
	Sub Total	21		11	19	14			17	15	13	14	15.50	10.86
Project Management	Project Definition	5	5	4	4	2		5	4	5	3	5	4.20	1.07
	Planning & Control	5	5	3	5	1	2	5	4	4	2	4	3.64	2.05
	Records	4	4	3	5	3	4	5	5	4	4	5	4.18	0.56
	Project Profile	4	4	3	4	3	3	5	3	4	3	4	3.64	0.45
	Sub Total	18	18	13	18	9		20	16	17	12	18	15.90	11.88
Management & Decision Making	Top Management	4	4	3	4	1	3	4	3	5	3	4	3.45	1.07
	Project Reviews	3	1	2	5	1	2	5	3	3	1	3	2.64	2.05
	Review Criteria	2	1	3	5	1	2	3	2	2	1	4	2.36	1.65
	Performance Measurement	3	4	1	4	2	2	4	2	3	2	4	2.82	1.16
	Design Reviews	3	3	4	5	2	3	4	2	4	2	5	3.36	1.25
	Sub Total	15	13	13	23	7	12	20	12	17	9	20	14.64	24.25
	TOTAL	119	87	94	134	75	79	128	102	108	86	108		
	MAX TOTAL	160	150	160	160	160	140	155	160	160	160	155		
	% OF MAX	74%	58%	59%	84%	47%	56%	83%	64%	68%	54%	70%		

Table 5.1: Best practice evaluation for actual ratings

	Company	A	B	C	D	E	F	G	H	I	J	L	MEAN	VAR
Best Practice Factors														
Strategy	Product Development Strategy	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Competitive Approach	5	4	5	5	5	4	4	5	5	5	5	4.73	0.22
	Customer Focus	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Supplier Approach	3	3	4	4	4	4	4	3	3	3	4	3.55	0.27
	Sub Total	18	17	19	19	19	18	18	18	18	18	19	18.27	0.42
Technology Management	Systematic Monitoring	5	4	5	5	4	5	5	3	3	4	5	4.36	0.65
	Technology Development Policy	5	4	5	5	4	4	5	3	4	5	5	4.45	0.47
	Sub Total	10	8	10	10	8	9	10	6	7	9	10	8.82	1.96
Marketing & Project Initiation	Systematic Market Analysis Mechanisms	5	4	5	5	5	5	5	4	4	5	4	4.64	0.25
	Product Proposal / Enquiry Review	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Feasibility / Tender Development	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Project Selection & Screening Criteria	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Market Brief & Specification	5	5	4	5	4	4	5	5	5	5	5	4.73	0.22
	Sub Total	25	24	24	25	24	24	25	24	24	25	24	24.36	0.25
Organisation	Technology Representation on Board	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Project Organisation Structure	5	5	3	5	5	3	5	5	3	5	3	4.27	1.02
	Team Features	4	4	4	4	4	4	5	4	4	5	4	4.18	0.16
	Project Management Organisation	3	3	5	5	5	5	5	3	3	5	3	4.09	1.09
	Sub Total	17	17	17	19	19	17	20	17	15	20	15	17.55	3.07
Integrated Process	Generic Process Structure(s)	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Integrated & Paralleled Activities	2	2	3	4	3	3	3	4	3	3	3	3.00	0.40
	Interactive Task (Specification)	4	4	5	5	5	5	5	5	5	5	3	4.64	0.45
	Sub Total	11	11	13	14	13	13	13	14	13	13	11	12.64	1.25
Modelling & Analysis	Modelling & Rapid Prototyping	5	3	2	4	3	3	5	4	3	4	2	3.45	1.07
	Mutually Supportable Techniques	3	3	5	5	4	5	5	3	3	5	3	4.00	1.00
	CAE Development & Project Mgt Tools	4	3	3	5	4	4	5	4	3	5	3	3.91	0.69
	Internal Testing	5	na	4	5	5	5	5	5	5	5	5	4.90	0.10
	Market & Field Trials / Site Testing	5	na	5	5	5	na	5	5	5	5	5	5.00	0.00
	Sub Total	22		19	24	21		25	21	19	24	18	21.44	6.28
Project Management	Project Definition	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Planning & Control	5	5	4	5	4	4	5	5	4	5	5	4.64	0.25
	Records	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Project Profile	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Sub Total	20	20	19	20	19	19	20	20	19	20	20	19.64	0.25
Management & Decision Making	Top Management	5	5	5	5	5	4	5	5	5	5	5	4.91	0.09
	Project Reviews	3	3	5	5	5	5	5	3	3	5	3	4.09	1.09
	Review Criteria	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Performance Measurement	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Design Reviews	5	5	5	5	5	5	5	5	5	5	5	5.00	0.00
	Sub Total	23	23	25	25	25	24	25	23	23	25	23	24.00	1.00
	TOTAL	146	129	146	156	148	141	156	143	138	154	140		
	MAX TOTAL	160	150	160	160	160	155	160	160	160	160	160		
	% OF MAX	91%	86%	91%	98%	93%	91%	98%	89%	86%	96%	88%		

Table 5.2: Best practice evaluation for achievable ratings

On a similar basis, a more moderate improvement potential was indicated for the Strategy area, for which consistently high achievable ratings were obtained for most companies. Technology Management, Organisation, Integrated Process, and Modelling and Analysis, also indicated improvement possibilities. However, the higher mean achievable ratings were also associated with some variation across the companies for specific factors, implying that any improvement opportunities might be company specific rather than general opportunities.

The high variances associated with the achievable ratings for some of the best practice factors, as noted above, might be due to company related constraints to the adoption of the recommendations of best practice. These are explored in the following sections in relation to the individual best practice factors.

In what follows, statements concerning the recommendations of best practice, which are encapsulated in the model of best practice factors (see Table 4.6), are drawn from the literature on engineering design (see Chapter 2) and product development (see Chapter 3). To avoid the need for repeated referencing of the sources in the literature during this, and subsequent chapters, the reader is referred back to the relevant sections of Chapter 2 and Chapter 3.

5.3 Strategy

5.3.1 Product Development Strategy

Best practice: Having a formally defined product development strategy is widely considered to be an important contributory factor to improving companies' performance. It should define the types of product to be developed; markets to be targeted; product features, differentiating factors, and customer benefits; types of technology to be used; research areas relevant to future product developments; the means for prioritising between product developments; and the resources required.

Discussion: Nearly all the case study establishments had some form of product development strategy. However, although two thirds of establishments had a formally written product development strategy, of these, only a third were separate from the overall business plan. Very similar findings were observed for the survey establishments. This may partly reflect the fact that, for some non autonomous group establishments, the product development strategy resided in the parent company and not at the establishment level. For both the case study establishments and the survey establishments, it was found that written product development strategies were a distinct feature of the larger establishments. Higher innovation rate was also found to be indicative of a written strategy for both the case study and survey establishments (Table 5.3).

	Cases n=11		Survey n=16	
	No.	Written	No.	Written
Establishment Size:				
Small	5	2	6	1
Medium/large	6	6	10	9
Innovation Rate:				
Low	4	2	5	2
Medium/high	7	6	11	8

Table 5.3: Incidence of written product development strategy according to establishment size and innovation rate.

As shown in Table 5.4, most case study establishments' product development strategies referred to the markets to be targeted, types of product to be developed, key research areas, and resourcing requirements. However, issues such as the types of technology to be used and how it should be introduced, the critical features, differentiating factors, and customer benefits, and the means for prioritising between prospective developments, were less frequently specified. Similar findings were also observed for the survey establishments.

	Case Studies n=6	Survey n=9
Types of product	5	7
Target markets	6	8
Product features	3	5
Types of technology	3	4
Research areas	4	8
Means for prioritising	3	7
Resources required	6	8

Table 5.4: Elements of product development strategy

In terms of achieving best practice, it was considered that some form of formally documented product development strategy which covers the scope of the main elements specified by best practice could have been attained by the establishments studied. This is apparent if, for example, one considers a non autonomous establishment which is a member of a group in which the product development strategy is formulated at the group level. If product proposals which are consistent with the product development strategy are to be put forward by the establishment, or if revisions to it are to be proposed, or if tender enquiries are to be adequately assessed, then the establishment needs to be aware of the Group's product development strategy. Moreover, considering the strategic emphasis on market focus and product leadership expressed by many companies, this gap between actual and recommended practice should perhaps be a concern.

5.3.2 Supplier Approach

Best practice: The need to maintain a good awareness of suppliers, adopting mutual benefit and single sourcing policies, engaging suppliers in regular contacts and discussions on development opportunities, and partnership sourcing opportunities is strongly emphasised by best practice.

Discussion: Consistently low actual performance ratings for the strategic approach to suppliers were observed, to the extent that for all firms, with the exception of company H, some scope for improvement was inferred. This is an important point given that suppliers were important for some of the firms (B, C, E & F).

Generally, most companies possessed a detailed knowledge of their key suppliers, including those which supplied their competitors. However, most did not discuss ideas and future developments with suppliers, or adopt a mutual benefit philosophy based on single sourcing opportunities. Indeed, in actuality, most of the firms adopted an explicit multi-sourcing policy.

A critical issue is that which relates to the strategically important make-or-buy decisions. Firstly, the internal span of processes determines the number of supply items. Secondly, there is the distinction between standard supply items and/or sub-contract processing requirements, and critical supply and/or sub-contract items which have significant impacts on design performance, costs, or involve particular processing skills, for example. These key supply items are a major determinant of the strategic importance of the supplier dimension and have most relevance to the opportunities to adopt the principles recommended by best practice such as single sourcing, and so on. However, all the firms, but A, B, H, I, and J in particular, were constrained with respect to their opportunities to adopt best practice in these areas. For example:

- It may be necessary to take into account the capabilities of suppliers. Suppliers may have particular competencies and/or limitations in their design or production processing capabilities. For example, the stringent processing capabilities required to make a critical casting limited the choice of foundry for Company E.

- Key supply items may be a customer specific requirement. For company H, the specification of a number of key items, each with several possible sources of supply, were variable between contracts, being dependent on individual customer preferences. The standardisation policies of its respective customers effectively resulted in multi-sourcing requirements for the company and, hence, a moderate rating for achievable practice.

- A company may constitute a small part of the supplier's business and therefore have only a limited degree of control over its suppliers. With company I, this required key pieces of supply equipment to be procured according to their availability within the project lead-time on a contract-by-contract basis. Company K adopted an explicit policy of seeking alternative sources of supply. Single-sourcing it regarded as being too risky, citing the case of a competitor for whom a larger supplier of an important item had decided to vacate the market, leaving it without any assured source of supply.

Through the process of evaluating the individual case studies in terms of their achievable practice, it was observed that there were less opportunities for mutual benefit, single-sourcing, and development collaboration with suppliers for companies operating in ETO/CMTO type markets than those operating in MTO/MTS type markets. However, as will be discussed in Chapter 6, key suppliers were found to be highly integrated into some projects. All this suggests that, given the strategic importance of the make / buy decision and the supplier constraints some companies face, the best practice assumptions are stated too generally and, in terms of achievable practice, it is more appropriate to seek the *opportunities to implement* best practice.

5.3.3 Technology Management

Best practice: Technology management is a strategically important factor, being concerned with policies on, for example, links to research establishments, suppliers, customers and competitors. It is also concerned with mechanisms to monitor and influence the external drivers of technical change, and the internal appraisal of technological opportunities.

Discussion: The case study companies were, on the whole, rather weak in this area compared to best practice. The achievable ratings, however, implied some constraints to the adoption of best practice. As far as technology development policy was concerned, criteria such as the willingness to license technology, acquire technology or firms, and maintaining links with universities and other relevant bodies, were found not to be relevant, or to be less relevant, for reasons specific to certain companies. A low innovation rate was a relevant factor in the case of firms E, H & I. Firms with low rates of innovation would be expected to have less need to license or acquire technology, or to maintain research links with research organisations. Technology acquisition and company merger were also considered a less feasible option for company E, which, being a small independent firm, did not have the capacity or resources for this.

Systematic analysis mechanisms such as legislative monitoring, reviewing competitive technologies, patent searching, technology auditing, internal seminars, and so on, are highly regarded elements of best practice. Company size, however, was found to have an effect on this. Some of the smaller firms (E, H & I) were in effect resource constrained, which limited the extent to which they could reasonably engage in many of these mechanisms, so that achievable practice was below best practice. In contrast, the larger firms in general, and the larger or smaller firms which were part of a group, potentially had access to wider resources and best practice could be realised more readily. Centralised technology management resources were available in several group companies (A, D, F, G, J, K and L). Company A, for example, had access to legislative monitoring resources elsewhere in the group. Companies J and K had access to generic research which was undertaken centrally by their respective groups. This also applied to Company F and Company G, but they also used these central facilities for some of their own research and development work. Patent searching capabilities were also provided centrally for some establishments.

It may therefore be concluded that small firm size and not being part of a group were the main limiting factors to adopting best practice. In comparison with companies' achievable practices their actual practices suggested opportunities for improvement.

5.4 Marketing and Project Initiation

The evaluation found that since there were only minor constraints to adopting best practice, this group of best practice factors were otherwise attainable by the case study companies. Despite their importance, the initiation stages of projects have been cited in the literature on product development as an area not well managed by companies (see Chapter 3). This was also borne out by the analysis of actual practices in specific areas for the case study projects and, also, the survey projects. These shortcomings in companies' practices are outlined for each best practice factor below. The striking feature of these is that most relate to straightforward procedures which are relatively easily rectified.

5.4.1 Systematic Market Analysis Mechanisms

Best practice: Systematic market analysis mechanisms are required, and should be reflected in the use of market studies, market feedback mechanisms, competitor analysis, and the search for new product ideas.

Discussion: Most of the case study companies rated moderately against this factor. The principal reason for this related to the generally limited use, in most cases, of detailed market studies and the lack of a systematic search for product ideas. Significantly, six companies did not systematically search for product ideas, and a further three only did this in a partial sense. Three companies did not do detailed market studies, with a further five also only undertaking these to a partial extent. In terms of the other criteria - sales intelligence, product performance (monitoring complaints, etc.) and competitor analysis - nearly all the firms used these mechanisms, and in most cases they were undertaken in a thorough manner.

The achievable practice ratings were equivalent to best practice in most cases. However, the systematic search for product ideas and detailed market studies were considered to be of lesser relevance to some of the firms who were primarily engaged in contract projects (B, H, I & L), particularly those associated with lower innovation rates. These companies had direct and ongoing contact with their customers through, for example, on-going personal contacts, pre-tender discussions, and the formal interfaces which existed during the tendering and contract stages. Consequently, the nature and requirements of their markets were generally understood and, therefore, there was less need for the types of market investigations frequently recommended for, and associated with, product development activities. This meant that marketing methods were more inclined to be based on less structured mechanisms such as personal contacts.

The differences between the moderate ratings assigned for actual practice and the generally high ratings assigned for achievable practice suggested some scope for improvement in most cases.

5.4.2 Product Proposal / Enquiry Review

Best practice: Companies should have clearly defined procedures and a broad scope of criteria against which to assess product proposals or enquiries. Suitable criteria include market needs, technical or market possibilities, profit potential, risks, consistency with the product development strategy, clarity of objectives and requirements, and competitor position.

Discussion: This principle of best practice was found to be applicable to all the firms, and the majority of the case study firms were rated highly. Moreover, those that did not - Company B had a narrowly focused review, and Company E and Company J had no formal procedure for preliminary screening - indicated that they had revised their development procedures following the projects studied for this research.

Although all tender enquiries were screened by the case study firms and, also, the survey firms, this was not so for all product development proposals (Table 5.5). Moreover, amongst the survey firms a quarter of product proposal reviews did not determine what further activities were required to enable a full project approval review to proceed.

Best practice: Product development proposals should be reviewed regularly.

Discussion: Product proposals were reviewed regularly by less than half of the case study establishments, the remainder preferring to initiate reviews on an ad-hoc basis (Table 5.5). However, two of the case study establishments (E & J) had initiated regular proposal reviews subsequent to the projects studied. As shown in Table 5.5, product proposals were handled similarly by the survey establishments. Although there were some tentative indications that ad-hoc reviews are appropriate under certain circumstances (see Chapter 6) best practice was otherwise found to be applicable to the companies studied and, therefore, scope for improvement was suggested for the screening of product proposals in some companies.

	Product Development		Contract	
	Cases n=6	Survey n=10	Cases n=5	Survey n=7
Product screening / enquiry review	5	8	5	7
Regular product screening reviews	2*	5		
Project approval / tender review	5	10	5	7
* Data available for 5 case studies.				

Table 5.5: Project screening procedures

5.4.3 Feasibility Assessment / Tender Development

Best practice: These initial stages should include assessments of the market, financial, commercial, technical and manufacturing implications of projects as appropriate. A broad assessment of the potential sources of risk, including technical, commercial, contractual, production, procurement, competencies, and so on, are also of some importance at this stage.

Discussion: This best practice factor was found to be applicable to the all case study companies, and their ratings for actual practice were high in most cases. Notwithstanding this, companies tended to take a narrow view by mainly focusing on the marketing and technical issues. Lower actual ratings for some companies resulted from them not considering, or only taking partial account of, the broader issues, such as those relating to manufacturing, and were frequently related to an inadequate assessment of risks. In this respect, moderate opportunities for improvement were suggested for most of the case study firms.

5.4.4 Project Selection / Tender Screening Criteria

Best practice: As part of a two stage screening process a go / no-go approval decision is recommended at this stage.

Discussion: An approval decision regarding the proposed development project or tender was made in all but one case (Table 5.5). At Company J, because of the critical importance of the product development project to the continuation of the business, a decision to proceed had been made at the outset by the manager of the business unit, and there was never any doubt over the project being undertaken. This may be regarded, therefore, as an exceptional case.

Best practice: The importance of evaluating projects on the basis of a broad range of criteria is also stressed by best practice. These should include both those relating to assumptions of successful outcomes (i.e. forecasts for sales, market size and market share, profitability, etc.), and those concerned with delivering these outcomes or which may influence their realisation (i.e. resources, capital and revenue requirements, risks and probability of success, product need, compatibility with the company's strategic policies and objectives, competitor position, compatibility and effect on other company products, etc.).

Discussion: This best practice factor was assessed as being relevant to the case study companies. However, whilst a basic evaluation against key marketing (i.e. sales) and financial (i.e. cost and profitability) variables was undertaken by all the case study firms, the vast majority made limited use of the wider variables and factors, including those indicated above. It may be concluded, therefore, that, although companies undertook approval reviews in line with the recommendations of best practice, in nearly all cases the need for more comprehensive procedures was identified.

5.4.5 Design Specification

Best practice: The development of the design brief or specification is generally considered to be one of the most important parts of the engineering design process. Whilst companies adopt different means to develop and present specifications, there is a clear consensus in best practice terms as to their requirements and characteristics. A fairly comprehensive (not necessarily detailed) specification of the project and design requirements should be established prior to the commencement of the main project phases. It should also be used as a control document which reflects changes in the definition of the product as the project progresses.

Discussion: Other empirical research has concurred that the specifications used in industry are typically inadequate for their intended purpose (Hollins and Pugh, 1990). This evaluation exercise also identified this problem in specific cases, but not to the same extent in general. A specification was developed prior to the main project in all but one of the case study projects and all but two of the survey projects. Also, whilst most of the case study companies appeared to incorporate most of the requirements, constraints and issues relevant to their projects, some of these were frequently omitted. The survey also supported this finding (Table 5.6). There were, however, legitimate reasons for elements of specifications being omitted in particular circumstances (see Chapter 6). This partly explains why system and subsystem requirements, and production volume were less frequently included in specifications. These considerations gave rise to achievable ratings below the recommendations of best practice for a few companies. Specifications were used as a control document during most case study projects. There were two cases, however, where this did not occur (E & J).

	n=17
Existing concepts	12
Manufacturing requirements	11
System & subsystem requirements	9
Testing requirements	12
Legislation, standards and codes	12
Project time & costs	13
Target product costs	14
Production volume	8

Table 5.6: Inclusion of selected elements in design specifications by survey companies

Best practice: An additional best practice characteristic is that, being a user document, the project and design specification(s) should be based on the integrated input of all interested parties.

Discussion: Certain project characteristics were found to limit the requirement for some of these inputs in specific cases (see Chapter 6). Despite this, however, the inputs to the specification were often limited to the engineering and/or sales and marketing functions and, therefore, was not in line with achievable practice. This finding was also supported by the survey (Table 5.7).

Therefore, to conclude this section, apart from the non-applicability of some specification elements in specific circumstances, best practice was found to apply in general. However, companies' actual practices relating to the way in which specifications were developed, and their format, indicated less good practices and substantial opportunities to improve practices in some cases. This should be a concern given that, as reiterated above, specifications are widely recognised in the literature as being critical to the successful completion of design and development projects.

	Case Studies n=11	Survey n=15
Marketing / Sales	10	14
Engineering	9	14
Production	2	5
Quality	1	4
Purchasing	0	4
Other	1	4
Customer	6	9
Suppliers	1	3

Table 5.7: Inputs to formulation of project specification

5.5 Organisation

5.5.1 Technology Representation

Best practice: The representation of technology at a sufficiently senior level (e.g. Technical Director) to be able to provide the necessary strategic and operational influence is of some importance, and particularly so when the role of engineering design and product development is viewed to be strategically important to the business.

Discussion: The key strategic business areas (market focus and customer intimacy, operational excellence, and product leadership) were ranked, and product leadership was ranked first or second in all but one of the case studies (see Table 4.4). This was in most cases reflected by good actual ratings for the representation of technological matters at a senior level in the company.

5.5.2 Project Organisation

5.5.2.1 Project Organisation Structure

Many different forms of project organisational structure have been described in the literature. However, these may be regarded as variations on several basic forms of project organisation. The six basic forms which are referred to in this thesis were outlined in Chapter 3, and include functional, project management, matrix, project team, autonomous team, and multi-project forms of organisational structure.

Best practice: A great deal of credence is attached to team-based approaches, and best practice strongly recommends project teams for major enhancement and new core product projects. It also supports using a functional organisation where a lead function has ownership of the project for minor improvement projects, and the use of project-based structures for larger projects. The product development literature is particularly unfavourable towards matrix project structures (which are sometimes referred to as lightweight teams).

Discussion: Although half of the case studies did not comply with best practice, there were doubts as to whether this would have been the most appropriate approach. For example, Company C and Company F both adopted functional approaches for their major developments. However, being projects which tended to focus on individual functions (as opposed to ones which required inter-functional integration), the approaches adopted were deemed appropriate. Company I and Company L adopted matrix organisational approaches for their contract projects. As these were minor improvement projects the best practice would have recommended a functional or project management structure, yet the degree of integration required indicated that project teams were appropriate. The balance between the need for control over schedule and costs and the need for integration between those assigned to the project was provided by the matrix structure. With a very large contract, and given the need to maintain control over schedule and costs, a project management structure might have been anticipated for Company H. In principle this might have been adopted. However, the low variability between the characteristics of its projects enabled the company to effectively adopt a functional structure with the use of a specialist planning department. It is evident from these exceptions to best practice, that having being developed primarily on the basis of product development projects undertaken in the electronic and automotive industries, best practice is too generally stated. It does not capture some of the subtle, but nevertheless, influential characteristics of the case study projects. These issues are explored in some detail in the corresponding section of Chapter 6.

5.5.2.2 *Process Champion*

Best practice: A further best practice factor which is most relevant but not exclusive to product development processes concerns the assignment of a process champion to facilitate support for development activities and to ensure their continued improvement through revised procedures, improved IT support systems, training in new techniques, and so on.

Discussion: Amongst the case study firms, this role, when undertaken, usually took place in an ad-hoc and informal manner, only being clearly defined in two cases, Company D and Company G. Interestingly, both of these were engaged in product development activities, and had intentionally implemented best practice approaches.

5.5.3 'Team' Features

Best practice: Project team characteristics or featuring team working principles within non team-based structures, and the issue of co-location are highly stressed best practice principles.

Discussion: Co-locating individuals assigned to a project, either collectively or within their individual functions, was found to be a source of difficulty for most of the case study firms. The assignable factors were small firm size (in which case it was a less critical issue due to the natural communication mechanisms which existed) and

CMTO/ETO market types. In these respective circumstances individuals were more likely to have a number of responsibilities or to have been assigned to more than one project. None of the cases involving team-based structures co-located their core team members, although co-location was deemed feasible for two large companies (G & J). For most firms, therefore, it was the application of team working concepts in general, and the relative proximity and accessibility of individuals which were of importance. Company A, for example, had recently located its design and drawing office personnel within the same work area.

The principal issues concerning team working were firstly, whether team structures were used, and, secondly, for other types of structure, whether individuals were formally constituted as a team collectively or within their individual functions. Three quarters of the case study projects were organised using some form of team working. Indeed, the same proportion was also observed for the survey projects. However, it was inferred from the case study projects that teams were virtually self selecting with a small firm or small technical resource, so that team working was an inherent feature of these establishments. Also, establishing functional teams was not relevant with a small technical resource. Consequently, as will be discussed in Chapter 6, team-based forms of project organisation were found to be less common to the small establishments or establishments with a small technical resource, but a distinct feature of the large establishments and establishments with a large technical resource. In the absence of a team-based structure it was also suggested that the larger firm or firm with a larger technical resource was also likely to formally establish collective or functional teams and, therefore, the broad use of team working was less frequently associated with small establishments and those with a small technical resource than with larger establishments and larger technical resources (Table 5.8). These findings were also borne out by the survey projects. Moreover, as shown in Table 5.8, a notable feature of both the case study and survey projects was that all the large establishments, and all establishments with a large technical resource, used some form of team working.

	Case studies n=11		Survey n=17	
	No.	Team working*	No.	Team working*
Establishment Size:				
Small	6	3	6	4
Medium	2	2	7	5
Large	3	3	4	4
Technical resource:				
Small	3	2	3	1
Medium	4	2	8	6
Large	3	3	6	6
* Refers to use of team-based structures, and establishing collective teams or functional teams for non team-based structures.				

Table 5.8: Formal application of team working according to establishments size and technical resource size

Generally this best practice factor was associated with very mixed actual practices by the case study firms. Despite the constraints to implementing best practice identified above and, therefore, the achievable practice implied, some scope for improvement was nevertheless indicated in specific cases.

5.5.4 Project Management Organisation

Best practice: Two frequently emphasised features associated with the management of projects are to appoint a project owner to act as the internal customer, and to have a clear point of responsibility through a lead functional manager or project leader.

Discussion: In terms of achievable practice, the project owner had less relevance to contracts as the customer's concerns were represented directly. This occurred through mechanisms such as negotiations, project reviews and design reviews. With regard to product development projects, and actual practice, this role was only explicitly defined by a few companies, although it was partly performed in most cases.

5.6 Process and Integration

5.6.1 Generic Process Structure

Best practice: For a given company many contextual factors may be considered relatively constant in the short to medium term. The implication of this is to allow a structured and standardised process to be established within broadly similar product and market areas for the different types of project activity, while recognising there will be project specific requirements. A structured process will usually define the key stages, milestones and activities which are generic to a type of project. The degree of detail included need not be substantial. In this way, by achieving a compromise between having no structure and too much structure, a structured definition can provide an overall framework which can accommodate flexibility and enable process improvements to be consistently achieved over successive projects.

Discussion: Written procedures were defined for projects by all the case study companies. However, although a process structure was recognised by most companies, for several, this was not defined in a formal manner (Table 5.9), and in about half of the cases the process structure was limited to the key stages and milestones. Similarly, written procedures were defined by most of the survey firms, of which all but one included the definition of a standard process structure for the key activities, events and milestones (Table 5.9).

	Case Studies n=11	Survey n=17
Written procedures	11	14
Standard process structure	7*	13
* Data available for 9 case studies		

Table 5.9: Standard procedures & process definitions

If the revised procedures of Company E are taken into account (which included a formal process structure) then there was some evidence from the case studies to suggest that product development processes were more likely to be formally defined, and in some detail, than contract processes. This may have been a reflection of the minor levels of change observed and the familiarity with their processes on the part of the contract-based companies. However, the survey did not support this finding. Formal process structures were defined for a similar proportion of contract projects as for product development projects.

It is evident from the achievable practice ratings that the definition of structured processes having the features outlined above for the main types of project were relevant to all the case study companies. Structured procedures and process definitions are an essential part of effective process improvement and, therefore, it should be a concern that a number of case study and survey companies did not have these. Opportunities existed for these companies to formalise or revise their process definitions.

5.6.2 Integrated and Parallel Activities

Best practice: Best practice presupposes a substantial involvement from all the main internal functions, and customers and key suppliers throughout a project.

Discussion: Definitions of concurrency tend to emphasise the simultaneous design of the product and the process, see for example IDA (1988). Focusing in this way on the parallel activities of the engineering and manufacturing functions provides a rather narrow interpretation of concurrency. Design and development projects involve other internal functions and external organisations. Indeed, most texts on concurrent engineering, or simultaneous engineering, take a broader perspective, see for example Hartley and Mortimer (1991) and Carter and Baker (1992). Therefore, in this thesis concurrency is defined as the degree of simultaneous involvement of the primary internal functions and external organisations over the course of the development process. This was measured for each case study project. Firstly, the involvement of the marketing & sales, engineering, production and purchasing functions, as well as suppliers and customers were assessed (on a scale of zero to two) for each project stage, using a concurrency evaluation matrix (see Appendix C) and, secondly, these were analysed to calculate measures of overall concurrency, core concurrency (marketing, engineering and production), and the concurrency of the individual functions, customer and suppliers. The ratings of actual practices on projects are shown in Table 5.10.

	Primary Projects												Secondary Projects					Best
Company	Ac	Bc	Cp	Dp	Ep	Fp	Gp	Hc	Ic	Jp	Kp	Lc	Bp	Fc	Gc	Ip	Lp	Pract.
Overall concurrency (%)	50	46	43	61	56	-	60	63	48	51	41	46	-	-	45	48	-	86
Core concurrency (%)	50	47	50	80	70	-	77	69	56	69	61	52	-	-	56	60	-	94
Involvement of disciplines (%):																		
Sales & Marketing	42	42	50	83	87	-	83	66	60	83	50	58	-	-	60	70	-	100
Engineering	58	50	83	83	62	88	83	83	70	83	92	58			60	60		92
Production	50	50	25	75	62	83	66	58	40	41	41	41	-	-	41	50	-	92
Purchasing	42	33	16	42	37	-	40	42	20	25	25	25			30	30		75
Suppliers	33	41	33	33	25	50	60	58	30	25	25	33	80	-	10	30	-	83
Customers	75	66	58	50	62	-	33	75	70	50	42	58	-	-	60	50	-	75

Table 5.10: Summary of project concurrency ratings for case studies

Company	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Best Pract.
Overall concurrency (%)	54	54	76	36	69	51	68	33	43	53	68	42	48	44	54	45	49	86
Core concurrency (%)	64	64	83	50	83	58	75	61	50	53	70	50	55	33	50	63	53	94
Involvement of disciplines (%):																		
Sales & Marketing	66	42	83	50	75	33	83	33	42	17	70	37	66	42	50	30	58	100
Engineering	83	83	92	66	92	100	83	83	66	83	60	87	66	58	66	90	75	92
Production	42	66	75	33	83	42	58	66	42	58	80	25	33	0	33	70	25	92
Purchasing	33	25	83	33	42	50	75	0	33	25	40	37	25	33	25	20	25	75
Suppliers	25	83	75	17	58	50	58	17	17	66	80	0	33	42	83	0	17	83
Customers	75	25	50	17	66	33	50	0	58	66	80	62	66	92	66	60	92	75

Table 5.11: Summary of project concurrency ratings for survey

On the basis of any identified deficiencies in the actual practices of companies a rating for achievable practice was similarly obtained. This indicated that moderate improvements were possible in most cases. These evaluations were compared with a best practice model (after McGrath et al, 1992), which presupposes idealised assumptions of project characteristics and a substantial involvement from all the main participants throughout the project. It was found that the actual and achievable concurrency ratings were below the best practice ratings for all the case studies, and for some substantially so. Moreover, as Table 5.11 shows, this was also the case for the actual concurrency ratings of all the survey projects. In reality a number of factors were found to limit the involvement of certain functions, suppliers and customers, suggesting that it is necessary to consider what levels of concurrency constitute good practice for any one company or project. These factors are discussed in some detail in the corresponding section in Chapter 6.

5.6.3 Interactive Task (Specification Development)

The aspects of this best practice factor were dealt with under Marketing and Project Initiation above.

5.7 Design Methods, Modelling and Analysis

5.7.1 Modelling and Analysis and Rapid Prototyping

Best practice: This best practice factor is concerned with the use of analytical, performance simulation, and graphical / physical modelling tools during the early design stages.

Discussion: As might be expected, a comparison of the achievable scores for the use of these tools indicated a strong relationship with product complexity and product structure, and the design capability inherent in the product. Low product complexity and shallow product structure were associated with a lower rating (<=3) than with higher product complexity and deeper product structure (>=4). Low design capability likewise was associated with a lower rating (<=3) than products requiring high levels of design capability (>=4). Company F was the only non-conforming case. Its product required a medium level of design capability but was associated with a moderate rating. The design capability required by its product, however, was the most moderate of those assigned a medium rating. With regard to design capability an underlying factor for a high score appeared to have been the degree of reliability, technical performance, etc. required in the product (A, G, J & K) and / or the costs or other constraints on prototyping (A, G, H & K), and which were reflected in the need to be able to predict product performance at an early stage. Lead-time pressures on projects were also associated with higher ratings (<=5) than in their absence (<=3). These relationships are explored further in Chapter 6.

Actual practice for the case study projects was on average low, but was also very variable. The achievable scores for this best practice factor were similarly low and variable, so that fairly moderate improvements were inferred in most cases.

5.7.2 <u>CAE Tools for Design and Development and Project Management</u>

Best practice: Companies should make use of appropriate CAE design tools, simulation tools, development tools, and project management tools.

Discussion: There is a variety of computer-aided engineering or CAE tools for design and development available to suit different requirements and domains of application. It would therefore have been inappropriate to evaluate companies' practises against a prescriptive list and, hence, a more general assessment of usage was made. Some variation in the achievable scores was again noted.

For the achievable ratings, medium and high design capability was associated with greater CAE use (A, D, F, G, H, J & K), whereas for low design capability fewer CAE applications were observed (B, C, I & L). Company E, with a low design capability but fairly high achievable CAE rating, was the only non-conforming case. Major product innovations were related to higher levels of CAE use than minor improvement projects. However, minor improvement projects at Company A and Company H involved fairly high CAE use, apparently as a consequence of the high levels of design capability required by their products. Also, Company C had a moderate CAE use for the development of its new core product. Low product complexity and low design capability were mitigating factors in this case. Lead-time pressures were also associated with higher ratings for achievable practice. Thus, higher design capability and / or higher product innovation and / or higher product complexity and / or lead-time pressures collectively implied a greater use of CAE design and development tools amongst the case studies. These relationships are also discussed in Chapter 6.

The appropriateness of project management tools and techniques to the case study projects were also found to be determined predominantly by product complexity and product structure (see Chapter 6). In the case of lower product complexity and shallow product structure only basic planning techniques were found to be applicable. For medium and high complexity products project management tools and associated techniques were found to be appropriate. The achievable rating for companies were assessed on this basis, which resulted in achievable ratings below best practice in some cases.

As with the modelling and analysis tools above, the achievable ratings for the use of these tools in projects were relatively low. Companies' actual practices were very mixed in comparison with these. Although around half of the cases were rated highly the remainder were rated poorly. The case studies suggested that some companies were not aware of, or had some difficulty in identifying, or were not adopting, the appropriate enabling technologies. This may reflect the fact that the role of process champion discussed earlier (see Section 5.5.2.2) was not clearly defined in most cases. Two of the smaller companies (E & H), for example, were investigating CAE options, but were finding the costs of enhancing their existing CAE modelling and analysis applications somewhat prohibitive. Company G, which was well rated in the best practice evaluation, also stated that it was aware of further CAE needs, but was constrained from procuring these by restricted resources.

5.7.3 Mutually Supportable Techniques

Best practice: This best practice factor concerns the need to use techniques intended to assist cross-functional activities. These include quality function deployment, failure mode effect analysis, design for manufacture and assembly, and brainstorming.

Discussion: The achievable scores for the case study companies indicated strong relationships with project type, product innovation, and managerial complexity (integration characteristic). Contract and minor improvement projects tended to involve less use of these techniques than product development and more innovative projects. It is likely, however, that the project type association was in some respects one of consequence rather than causality. A more extensive application of these techniques was also identified for projects characterised as integration projects than for more narrowly focused projects. There were two exceptions. The first of these was a development project at Company F. Although this was essentially functionally focused, there were some major cross-functional considerations, including production process implications, which suggested the use of selected techniques to be appropriate. The second was the contract at Company L which had an integration characteristic but, being a minor improvement project, had less need for the techniques. These thematic relationships will be discussed in the wider context of the interview survey in Chapter 6.

The use of these techniques realised the lowest average and largest variance for actual performance of any best practice factor. In comparison with achievable practice, fairly substantive potential for improvement existed in most cases. These techniques were more frequently used by the survey companies (Table 5.12). It was notable, however, that despite the considerable emphasis on techniques such as quality function deployment, or QFD, and robust design in the best practice literature, some companies were not aware of these. This may explain their lower usage compared to the other techniques. Again, this may reflect the fact that, as discussed in Section 5.5.2, few companies had a clearly defined role for consideration of enabling technologies and methods. However, a few of the survey companies indicated that they had considered, or tried out, QFD, but had found it too demanding on time and resources.

	Cases n=11	Survey n=17
Quality function deployment	0	4
Failure mode effect analysis	1	8
Value engineering	4	10
Robust design / Taguchi	1*	4
Brainstorming	4*	15
* Data available for 10 case studies.		

Table 5.12: Use of cross-functional techniques

5.7.4 Internal Testing and Field Testing

Best practice: Products and / or prototypes should undergo a thorough and well planned programme of internal testing and field testing according to clearly defined procedures and requirements.

Discussion: Other than in cases of non-applicability (B & F) consistently high actual and hence achievable evaluations were observed for these aspects of best practice. Moreover, similar proportions of the survey projects involved internal testing and field testing (Table 5.13).

	Cases n=11	Survey n=17
Internal testing	10	15
Field testing	9	13

Table 5.13: Internal and external testing of product / prototype

5.8 Project Management and Decision Making

The main conclusion to be drawn from this important group of best practice factors was that whilst there were some very mixed actual practices, the achievable practice assessments indicated that nearly all of the best practice criteria were applicable to the case study companies. Thus, companies should be able to perform well against these criteria, although the form of implementation may be dependent on the characteristics pertaining to the different companies (see Chapter 6). For most of the best practice factors there were some criteria against which the case studies tended to perform less well than others. These are highlighted below along with the particular constraints to the adoption of best practice.

5.8.1 Project Definition

Best practice: According to best practice projects should have a firm set of objectives and terms of reference, and a clearly defined, written, and signed-off specification.

Discussion: No constraints to these requirements were identified from the analysis. Moreover, most companies' actual practices were rated highly. The exceptions were company E and Company J. However, their subsequently revised procedures would negate any criticisms.

5.8.2 Planning and Control

Best practice: Requirements for the planning and control of projects include resource planning, budgeting, and activity planning and scheduling. Project planning may be considered to occur at three levels: overall project plans, work package plans, and detailed activity plans.

Discussion: A project schedule was developed for all the case study projects and, also, for all the survey projects. With regard to the achievable practice ratings of the case study projects, lower product complexity (C, E, F & I) was considered to limit the level of planning detail required (see Chapter 6). However, in actuality, the degree of detail and the scope of the planning activities undertaken over the course of the project were in some cases limited to defining the key milestones or an overall plan, when more detailed plans were appropriate.

5.8.3 Records

Best practice: There should be organised procedures and systems in place for records management. An additional requirement is for all important meetings, critical decisions, documents, tests, and so on, to be formally undertaken and documented.

Discussion: Some important meetings, critical decisions, documents, tests, and so on, were not always undertaken and documented in a formal manner. This was reflected in the actual ratings assigned to some projects and, given that the analysis had inferred the applicability of this best practice factor to all the companies, moderate revisions to some companies' procedures was possible.

5.8.4 Project Profile

Best practice: This best practice factor requires several project management activities to be undertaken over the course of a project. During the project initiation stages these include establishing the project definition, project organisation, and developing the project plans. The development stages require regular 'team' meetings, major project reviews, and update planning. Finally, an audit of the project should be performed upon its completion.

Discussion: This best practice factor had general applicability to all the case studies. However, in some cases regular (e.g. weekly) control and update / recovery meetings were not used when it was appropriate to do so. Post project audits were usually undertaken, the exception being Company H which adopted a management by exception approach. Post project audits were however usually limited to product related issues. Issues concerned with the project and its management were not usually addressed. Indeed, if addressed, this was not necessarily part of a formal procedure for process improvement, but a response to a particular problem. At Company E, for example, following a major schedule overrun, an internal review was instigated by the Managing Director. Very similar practices were found for the interview survey projects (Table 5.14). Post project audits are a way in which companies can learn from, and improve, their procedures and processes and, therefore, the findings suggest that this should be an area of general concern.

	Cases n=10	Survey n=16
Post project audit undertaken	9	13
Product related issues considered	9	13
Project related issues considered	6	7

Table 5.14: Post project auditing

5.8.5 Top Management

Best practice: Senior management has the overall responsibility and authority for design and development activities. Senior management is responsible for developing and maintaining the product development strategy (see Section 5.3.1), and also for implementing it through the approval, initiation and monitoring of projects. How effectively this role is performed is related to the relationship (managerial style), and distinction in responsibilities, between senior management and those empowered with authority to implement the project activities. Associated with these responsibilities are the additional responsibilities for establishing project objectives and review criteria, monitoring progress, and ensuring the provision of the required resources.

Discussion: In terms of achievable practice, although the focus of the best practice is very much on product developments, these best practice criteria apply equally to contracts, although the precise form of their implementation has been found to be different (see Chapter 6).

The most common shortcoming in the role of senior management was not to distinguish adequately its own (strategic) from the project (implementation) level responsibilities. Project team approaches enable this distinction to be more easily made explicit than with functional approaches where the senior management and sometimes the executive management are usually actively involved in the execution of projects. However, senior management or senior executives may be active participants on project teams. In these circumstances there is the potential for difficulties to arise through conflicting interests. At Company E, for example, the effect of not establishing clear project objectives, and a lack of clarity regarding the roles and divisions of responsibility between the senior management and project team, resulted in a source for changes and delays in the project and, ultimately, the disempowerment of the team. Apart from Company E, most companies' actual practices were such that minor or moderate revisions were indicated for this best practice factor.

5.8.6 Project Reviews

Best practice: There is a consensus within best practice that it is preferable for major project reviews to be conducted at key project milestones, rather than on a calendar or ad-hoc basis. Also, for product development projects, these should involve go / no-go decisions, and form the basis for approval and funding of the next phase.

Discussion: Calendar-based or ad-hoc project reviews, as opposed to pre-planned key milestone reviews, were used for major project reviews in several case studies and, also, the greater proportion of survey projects (Table 5.15). However, because of project organisational features (see Chapter 6), it was considered that calendar-based reviews were equally applicable to the contract-based cases (A, B, H, I & L) where there were often particular concerns to monitor schedule and costs. This was therefore reflected in the achievable ratings. Indeed, for both the case study projects and the interview survey projects, all the senior management reviews undertaken involving key milestone reviews related to product development projects. Nevertheless, ad-hoc or calendar-based project reviews were used on several projects when it was not appropriate to do so. Indeed, it was evident from the case studies that several companies (C, E, F, & K) who were engaged in both contract projects and product development projects were using the types of project review mechanisms on product development projects which they would usually use on their more numerous contract projects.

	Cases n=12	Survey n=17
Predefined milestone review	2	5
Calendar or ad-hoc review	10	11 (12*)
* Includes additional group level review for Company 1.		

Table 5.15: Conduct of major project reviews

Although, in principle, go / no-go decisions were found to be applicable to all the case study product development projects, they were usually only made at the project approval stage, and project reviews were not usually used as a formal basis for funding the next stage during product development projects. Exceptions to this were Company D and Company G (and the revised procedures of Company E) who had explicitly implemented best practice. Go / no-go decisions are not relevant to the main stages of contract projects as the company usually becomes committed to the project with the award of the contract. The achievable ratings assigned to the contract projects therefore reflected this.

5.8.7 Review Criteria

Best practice: Review criteria need to be formally defined, address project status and future requirements, and focus on stage specific issues.

Discussion: This best practice factor, which was relevant to all the case studies, was generally associated with some fairly mediocre ratings for actual practice. This was most frequently due to project review criteria not being formally defined and not being phase specific. This pattern of activity was also observed with the survey (Table 5.16).

	Cases n=11	Survey n=17
Formal project review criteria	3	8
Phase specific criteria	2*	3
* Data available for 10 case studies		

Table 5.16: Project review criteria

5.8.8 <u>Design Reviews</u>

Best practice: The main best practice requirements for design reviews are that they should be undertaken in a formal manner at the conclusion of each milestone in the development of the design, compare the design against the specified design requirements and consider other relevant issues (manufacturability, quality, etc.). It is also considered good practice to treat project reviews and design reviews separately and, for a peer group not involved directly in the project's activities, to provide an independent perspective.

Discussion: The major design review mechanisms were evaluated for the case study projects. The best practice criteria were found to be applicable in all cases, except that, with a small technical resource and some project team structures (see Chapter 6) it was both observed, and considered feasible, that design reviews could be undertaken in conjunction with project review meetings provided a clear distinction was maintained between the two review activities. Notwithstanding this clarification, relative to the general applicability of this best practice factor, mixed actual practises were observed amongst the case study companies for all the assessment criteria.

Varying scope for improvement was therefore possible. Table 5.17 illustrates that, although design review criteria were formally specified in less than half of the projects, most major design reviews in the survey were otherwise undertaken in accordance with the recommendations of best practice. The survey also identified that individuals not involved in the project (i.e. senior management, disciplinary peers, and so on) participated in most design reviews, and that this included a group of disciplinary peers in half of the design reviews (Table 5.18).

	n=17
Major design reviews	17
Undertaken at key design milestones	12*
Formal procedure	13
Separate from project reviews	15
Formal review criteria	6
Intermediate design reviews	11
Undertaken at key design milestones	5
Formal procedure	3
Separate from project reviews	9
Formal review criteria	4
* Data available for 16 projects	

Table 5.17: Conduct of design reviews in survey projects

Intermediate design reviews, which are usually concerned with the subsystems and components of products, were less frequently undertaken than major design reviews in both the case study and interview survey projects. However, this was accounted for by the low complexity of some firms' products, for which the intermediate design reviews were not necessary or relevant (see Chapter 6). Intermediate design reviews were more likely to be ad-hoc and informal than major design reviews. This suggests that the recommendations of best practice may be inappropriate for the purposes of these more detailed design reviews. The thematic considerations relating to design reviews are explored in more detail in Chapter 6.

	Major reviews n=17	Intermediate reviews n=11
Non-team members	13	8
Non-managerial peers	7	6

Table 5.18: Participation of peers in design reviews in the survey

5.8.9 Performance Measurement

Best practice: Performance measurement is concerned with monitoring the progress of projects and a strategic emphasis on continuous improvement and improved competitiveness. For best practice overall measures of performance should be related to the business (e.g. market share, profits, etc.) and market (e.g. customer satisfaction, price, delivery adherence). Measures for project monitoring and improving the effectiveness of product development processes (e.g. relating to cost, quality, time, etc.) need to be consistent with the overall measures of success.

Discussion: Performance measurement criteria are relevant to all companies. A list of product innovation metrics has been collated from the best practice literature, and structured according to their respective uses at strategic, overall process, and project levels. This list is incorporated into Appendix D.

Although applicable to all the case study companies, in general, companies rated poorly against this factor (see Table 5.1). Although performance metrics were defined by most companies, invariably they only addressed a narrow set of issues (i.e. project schedule and budget adherence), and they were not widely used as a strategic tool for process improvement. This was essentially consistent with the limited application of post-project audits discussed above. These findings were also borne out by the interview survey (Table 5.19).

	n=15
Performance metrics:	
Performance, time, cost, profit	15
Other measures	3
Application of performance metrics:	
Project level	15
Strategic level	3

Table 5.19: Performance measures and their application in the survey

All the survey establishments used a basic set of measures at the project level. Only one in five, however, used wider measures. Only one in five made any strategic use of measures and, of these, application was usually limited to a narrow set.

5.9 Summary

This chapter has described the findings of the analysis undertaken to benchmark the case study companies' projects against the recommendations of best practice derived from the literature. Several conclusions may be made on the basis of these findings.

Some areas of best practice - Marketing and Project Initiation, Project Management, and Management and Decision Making - were found to be almost universally applicable to the case study companies. However, companies tended to perform poorly in these areas, suggesting substantial improvement opportunities for most companies.

Individual best practice factors for other best practice factor groups were also found to be appropriate to all the case study companies, however, for most of these, company specific constraints to the adoption of best practice were identified. In particular, best practice was found to be wanting with regard to small companies, and companies engaged in contract-based activities. This suggests that recommendations of best practice, which are largely predicated on studies of the automotive and electronics industries, are inappropriate to this group of UK engineering companies. The analysis has also indicated what form the recommendations of best practice should be under different circumstances i.e. what is achievable practice. It is necessary, therefore, to consider what the recommendations of best practice should be in general terms, and, also, what recommendations are appropriate to different company and project situations.

Best practice as currently stated in the literature provides a set of prescriptive principles to guide practitioners in industry. Aspects of these general recommendations have been found to be inappropriate under certain company and project contexts, implying that best practice needs to be revised in the light of these findings. Moreover, because of their general nature, these recommendations have been found to be too broadly stated to provide guidance which is sufficiently detailed for effective application. Companies are therefore required to interpret these recommendations and to develop procedures which are appropriate to the context of their own company's and projects' needs. The next chapter will discuss the thematic analysis which was undertaken to determine what form the implementation of the broad recommendations should take in both general and specific terms.

Chapter 6

Comparative Analysis - Thematic Considerations

6.1 Introduction

Previous chapters have established that best practice, as deduced from the literature, establishes some general principles or requirements, but is defined too broadly to provide an adequate understanding of how the processes of engineering design and product development should be undertaken. Moreover, some features of best practice have been found to be inappropriate to some companies. Consequently, a considerable onus is placed on companies to interpret the recommendations of best practice in terms of their own company and project contexts. A primary aim of this thesis, therefore, is to identify those features of good design and development practice which are generic, and those which are company specific. The findings of the best practice evaluation described in the previous chapter provided some insight into a number of these features. However, it was the thematic analysis which was explicitly concerned with this aim. This involved comparing and contrasting the design and development practices of the case studies to establish a series of hypotheses, which were subsequently tested using data from the interview survey. The findings from this part of the analysis are discussed in this chapter.

The thematic analysis was concerned with the comparison of companies' actual practices and, inevitably, some elements of less good practice were observed. It was therefore important to be aware of the possibilities of drawing out inappropriate conclusions. The research method dealt with this in two ways. Firstly, it was possible to recognise clear examples of poor practice amongst the case studies: these are highlighted in this chapter where appropriate. Secondly, the thematic analysis was informed by the findings of the best practice evaluation for achievable practice. In particular this enabled possible features of less good practice amongst the case study and survey projects to be highlighted and considered.

6.2 Strategy

Strategic issues of a thematic nature were dealt with in the previous chapter, however, it is worth reiterating the pertinent points. Although the case study and survey companies' actual practices indicated that product development strategies were a feature of the larger establishments and those whose product was associated with higher rates of innovation, it was considered that all companies should have some form of product development strategy.

The case studies also suggested that most companies, but those engaged in ETO/CMTO type market in particular, were constrained from implementing the recommendations of best practice on the strategic approach towards suppliers. A low innovation rate in the product, small establishment size, and not having the availability of centralised group resources were also suggested to be limiting factors on companies policies and practices in the area of technology management. The interview survey did not seek to verify these findings.

6.3 Marketing and Project Initiation

6.3.1 Product Proposal / Enquiry Review

Product proposals for the case study and survey projects came from a variety of sources, most frequently a single department. Whereas half the proposals arose from an individual or department, under a third came from cross functional sources such as inter-departmental groupings or executive committees. Rarely was the product idea attributed to an external party. Moreover, only two of the case study companies (D & F) mentioned external sources as significant catalysts for product ideas in general. This was not surprising given Company D's emphasis on market feedback mechanisms, and the importance of materials suppliers to Company F.

In order for a product idea to be formed into a proposal suitable for initial review, some preliminary information is usually required. The case studies indicated that, although the source of the product idea was usually responsible for compiling this information, there was a tendency for more interdepartmental collaboration at this stage. In Company K, for example, development ideas were usually formulated by the Engineering Department, and in order to provide the necessary market and financial information other departmental inputs were required.

An initial screening of the product proposal was undertaken by all the case study companies except Company E. Indeed, Company E had subsequently initiated screening reviews as part of revisions to its development procedures. A go / no-go decision on whether or not to pursue the proposal was also usually made at this point. Similar practices were also observed for the survey companies. Also, two thirds of proposal reviews in the survey were used to determine what further activities and information were required to enable a full project approval decision to be made.

Although screening reviews were most commonly undertaken on a regular monthly basis, there were several cases in which they were initiated on an ad-hoc and / or less frequent basis. It was hypothesised by the author that a low rate of innovation was associated with the use of ad-hoc and less frequent product screening reviews, since infrequent product changes would be expected to be associated with sporadic product proposals. Indeed, this had been given as an explicit reason for using ad-hoc and infrequent reviews by Company E (and some of the survey firms). However, this was only weakly supported by the survey. Ad-hoc and less frequent (> quarterly) reviews were almost as likely with a medium or high rate of innovation as with a low rate of innovation. One or more of the following reasons may explain this. Firstly, screening reviews are based on general company procedures and other factors would be expected to have some influence. At Company 4, for example, which had a low innovation rate, internal proposals for product changes were discussed at a quarterly meeting of the Engineering Committee. However, this was mainly concerned with other matters and, hence, the frequency of product proposal screening was being driven by other considerations. Different rates of innovation in other products from that of the product studied, and the number of product groups and range sizes could also influence the number of product proposals to be handled and, therefore, the need for these to be screened. Secondly, innovation rate, which was used as a surrogate indicator for the number of product proposals, may not be an adequate discriminator. Innovation rate is determined by the cumulative effect of both substantial and incremental changes. A few substantial product changes in association with infrequent incremental product changes can give rise to a high rate of product innovation, but be associated with infrequent product proposals. Indeed, this was the case for two companies (7 & 9) in the survey.

For the case study and survey projects product proposals were screened in a variety of ways. Their screening was undertaken most frequently (a half of all proposals) by an executive group or committee and rarely by an individual director or manager. Moreover, revisions made to their procedures by two of the case study companies (E & J) following the projects studied required proposals to be reviewed by an executive group. There was also the possibility for proposals to be screened by the parent company for the non autonomous group establishment. Indeed, four of the nine non autonomous establishments in the survey had their product proposals screened in this way. The research also identified that companies often have alternative mechanisms to consider minor improvement ideas which, for example, are often initiated in response to design change requests. Company D had an interdepartmental committee to review and approve such projects. Company E also handled minor projects separately from its more substantial projects, with proposals or requests for these being screened by the functional management.

With contract projects the initial enquiry review was undertaken by a number of means. The case studies suggested that these were determined by reasons specific to the individual companies. Organisational characteristics were found to be very influential. The distinction between whether an enquiry was reviewed by an individual or a department was sometimes semantic, however, the presence of a specialist tendering department or a product/business area group was one determining factor in how the enquiry was handled. Company B and Company G had an influential Commercial Department which handled their enquiries. This was also the case for two of the survey companies (12 & 14). In Company L the Business Manager for the product division undertook the review and, similarly, for the two instances in the survey when an individual reviewed the enquiry (11 & 13), this was undertaken by an Account Manager to a major client or the Business Manager for the product area. The strategic importance or size of the contract also appeared to be of some significance. The larger case study contracts or those of strategic importance were reviewed at a more senior level, either by a senior executive (H, I & L) or an executive group (A). Furthermore, at Company H, although most enquiries were reviewed by a senior executive, those for major projects would be reviewed by an executive group. The three enquiries of this type in the survey (15, 16 & 17) were also reviewed in this way for this specific reason. Moreover, for two of these companies (15 & 16), projects were usually less substantial and were reviewed by their commercial management / departments. These findings reinforce those outlined above for the main case study and survey projects studied. It was also postulated from the case studies that, in smaller companies, enquiries were more likely to be handled by an individual, this being explicitly clear in two of the case studies (H & I). The survey found no support for this, however, the company organisation and project characteristics discussed above predominating.

Company A was a good example of the potential implications from being a non-autonomous group company. It was required to gain approval from the Group to initiate projects in excess of a pre-given sum. However, all the tender enquiries relating to the case study or survey projects were reviewed at the establishment level.

Summary: It may be concluded that it is good practice for projects to be reviewed initially as part of a two-stage screening process. The initial screening review may make a go / no-go decision and its purpose should be to determine what further activities need to be undertaken prior to the second stage project approval / tender review. Although best practice suggests that the screening of product proposals should be undertaken on a regular (<= quarterly) basis, ad-hoc and less frequent reviews were often undertaken by companies. However, fewer product proposals (which was partly a reflection of a low rate of innovation in the product) may reduce their required frequency or enable them to be initiated on an ad-hoc basis. Due to their strategic importance product developments tended to be reviewed by an executive group and, in the case of the group establishment, by the parent group. Tender enquiries were handled according to the organisational characteristics of the companies, but larger contracts or those of some strategic importance were more likely to be reviewed at a senior level by a company executive or an executive group. The non-autonomous group company could also be required to gain group approval to commence the tender.

6.3.2 Feasibility / Tender Development

Although there was a notable prominence of inter-departmental interaction during the feasibility stage of product development projects and the tender development stage of contract projects in the case studies, this was often restricted to the engineering and marketing functions. However, with projects which were characterised by particular features, such as integrational requirements, or production process implications, other functions were more likely to be involved (see Section 6.3.4).

Variations to inter-departmental collaboration amongst the case study product development projects occurred at company D and Company J, which set up multi-functional project teams at the product proposal stage. For Company D, however, additional inputs from the other functional departments were still elicited once the project team had undertaken an initial feasibility and prepared a draft technical specification. The main exception was Company C, where the project was very much championed by the Engineering Director and the proposal was in effect worked-up by the Engineering Department.

With regard to the tendering activities, although it was common for there to be an interaction between departments (this occurred in five out of six tenders in the case studies and six out of seven tenders in the survey), the case studies suggested that the precise form of this was dependent upon the scope and scale of the tender. Characteristics such as product complexity and the technical content, coupled with the specific tender requirements specified by the enquiry (for example, the level of technical information to be provided, options to be quoted, and so on), were hypothesised to determine the amount and scope of work involved and, therefore, the inputs required. Because the nature of the tender was influenced by a number of factors it was not possible to identify relationships for these, and their collective influence could only be observed on a case-by-case basis. Organisational differences were found, however, for the different types of tender. With a small proposal, an individual (I) or department (G) wrote the proposal drawing on other functional inputs as necessary. With a larger proposal (A, B, H & L) an individual or department coordinated the inputs of others. Two good examples were Company G and Company H. The Tendering Department of Company G had its own applications engineers, so that most tenders could be handled within the Department. With projects involving a greater element of technical content and risk the Engineering Department would become involved. Because of the breadth of engineering disciplines and the highly complex product associated with the tendering process at Company H it was usual for the Commercial Department to compile the commercial and contractual aspects of the tender, whilst collectively coordinating the technical activities with the other departments. However, when only a minor change or revised quotation was required then the department would handle this internally. Given the complexity of these relationships the interview survey did not seek to examine them. However, secondary information obtained during the interviews indicated that tenders were usually handled as suggested by the case studies.

Summary: In conclusion, inter-departmental cooperation was very common during the feasibility stage of product development projects and during the tender development stage of contract projects. Alternatively, other inter-disciplinary mechanisms (i.e. multi-functional project teams) or departments were used. The scope and scale of tenders was determined by several factors. With a small tender proposal, an individual or department usually wrote the proposal drawing on other functional inputs as necessary. With a larger proposal and/or one having specific technical implications an individual or department coordinated the inputs of others.

6.3.3 Project Selection / Tender Review

For all the product development projects in the case studies the authority to proceed was provided internally at senior executive level or, in the case of some group establishments, externally at group level. This was hypothesised to be a reflection of the strategic importance of product development projects to companies and, also, that all the projects studied involved either a major enhancement (to an existing product or to develop a new platform) or the development of a new core product (Table 6.1). Secondary information acquired during the case studies suggested that minor change projects were handled differently. At Company D, a lower level interdepartmental committee was responsible for the approval of minor change projects, which, for example, were often initiated in response to design change requests. Company E also handled minor projects separately from its more substantial projects, with proposals or requests for such projects being assessed and approved by the functional management. The survey also supported the findings of the case studies, since all the projects, with the notable exception of a minor improvement project which was approved by a senior manager, were authorised at senior executive or group level (Table 6.1).

	Case studies n=6				Survey n=10			
Product Innovation	Group	Exec've group	Senior exec've	Senior mgr	Group	Exec've group	Senior exec've	Senior mgr
Minor								1
Major (E)		1			3		1	
Major (P)	1	2	1		2			
New core		1				3		

Table 6.1: Approval of product development projects

Two forms of external approval were required in some instances. Firstly, for Company C, the project was associated with European Union funding and ultimate approval was provided by its industry grants board. Secondly, non-autonomous group establishments may be required to obtain approval from the Group. For example, at Company I, both the sales and marketing and product development strategy for its standard products, and the initiation and approval of projects were centralised within the Group. Alternatively, although Company K had an annually agreed development budget through which to fund minor developmental changes and feasibility studies for major prospective developments, the actual initiation of major developments then required Group approval. Notably, all of the non autonomous establishments in the survey were required to obtain approval from the Group.

The responsibility for the internal approval of tenders in the case studies was commonly undertaken either by a senior executive or a senior executive group. However, as shown in Table 6.2, they were reviewed more frequently by an individual senior executive than by either an executive group or the Group. This was also found to be the case for the survey projects, of which three were reviewed by a senior manager. Table 6.2 shows that, unlike the product development projects studied, all of which involved major enhancements (to an existing product or the development of a new platform) or new core product developments, the contract projects, all of which involved minor improvement or major enhancements to existing products, were more likely to be reviewed at a lower managerial level and based on an individual's decision. The case studies also suggested that the scale of the tender, commercial considerations (price, risks, etc.) and being a group establishment were influential factors. In general, the greater the scale of tender and the commercial implications, the higher was the level of managerial approval involved. At Company H minor or more routine tenders were signed-off by the Commercial Manager and/or Commercial Director, whereas larger or more significant contracts were typically signed-off by the Managing Director. In either case, where there was a particular significance attached to the tender, then a review meeting was called, although the size of the executive group reflected its perceived significance. In company A and Company G procedures formally specified the parameters (e.g. contract price) which required signing-off at a particular level. Given the complexity of these relationships the interview survey did not seek to examine them. However, secondary information obtained during the interviews relating to the scale and commercial significance of projects corroborated that, with one possible exception, tenders were also handled as suggested by the case studies. Company A and Company G were also illustrative of the fact that, being non-autonomous group establishments, they were required to obtain Group approval for some non-routine projects, including those which exceeded a certain price level, loss leaders, and projects involving high risk factors. This requirement was not observed, however, for any of the specific projects studied in the case studies or the survey.

	Case studies n=6				Survey n=7			
Product Innovation	Group	Exec've group	Senior exec've	Senior mgr	Group	Exec've group	Senior exec've	Senior mgr
Minor		2	4				2	2
Major (E)						1	1	1
Major (P)								
New core								

Table 6.2: Approval of contract projects

Summary: It is evident that major product development projects were approved at an executive level, and usually by an executive group or, in the case of non autonomous establishments, the parent group. Minor improvements (e.g. design change requests) on the other hand were reviewed at a less senior level. Contract projects, which tend to be more routine and usually have less strategic importance than product development projects, and which tend to involve less substantial product innovation, were usually reviewed by an individual executive or senior manager. Responsibility for tender reviews was indicated by the case studies to be conditional on the scale of the tender and commercial considerations associated with it. A greater scale of tender or significant commercial implications implied a more senior level of approval. For the non-autonomous group company there could be an ultimate requirement with certain forms of project to obtain Group approval to authorise a tender or initiate a product development project.

6.3.4 Design Specification

A written brief or specification was produced prior to the start of the main project stages for all case study projects except Company C. At Company C the highly original nature of the project meant that it was only possible to provide a statement of the problem and a fairly basic definition of the objectives and requirements at the outset. Following initial research and feasibility studies, however, a more specific set of requirements and constraints were defined and documented. A written specification was produced for all but two of the survey projects.

6.3.4.1 Internal Inputs to the Specification

The internal inputs into the formulation of the specification in the case studies were frequently limited to the commercial and engineering functions (Table 6.3). The dominance of one or both of these within the process often tended to restrict the scope of inputs from the other functions (production, quality, purchasing, customer service, and so on). Moreover, in one case the product marketing group provided a definitive marketing brief to the development team. Notwithstanding the evidence of less good practice identified in Chapter 5, some case studies suggested that where particular considerations were strongly emphasised, these were reflected in the functional inputs to the specification. These considerations included the managerial complexity of the project and the degree of process innovation involved.

	Case Studies n=14	Survey n=15
Marketing / Sales	13	14
Engineering	12	14
Production	2	5
Quality	1	4
Purchasing	0	4
Other	1	4
Customer	6	9
Suppliers	1	3

Table 6.3: Inputs to formulation of specification

Managerial Complexity

Managerial complexity reflects the degree of integration between functions and/or disciplines involved in a project. Projects may be classed as non integration projects, which are focused on one or two functions or disciplines, or integration projects, which require the integration of several functions or disciplines.

Although, as mentioned above, the inputs to the specification were almost always restricted to the marketing and engineering functions, there were two notable exceptions, both of which were associated with requirements for functional integration. The major enhancement of Company D's product involved a number of systems design considerations which required the integrated inputs from several functions and disciplines. Also, although at Company E, Marketing provided the only input in the project studied, in response to difficulties which arose from this, inputs from the other functions were included for projects subsequently undertaken. The survey also provided some rather limited evidence to support the hypothesis that projects associated with integrational needs would involve more functional inputs than those without integrational needs. As shown in Table 6.4, although integration and non integration projects were equally likely to involve fewer than four functional inputs, only the integrational projects involved five or more functional inputs.

	Number of functional inputs (n=15)		
	1-2	3-4	5-6
Integration project	4	1	3
Non integration project	5	2	0

Table 6.4: Functional inputs into specification according to integrational needs in survey

Production Process Innovation

It was anticipated by the author that inputs into the formulation of the specification by the production functions would be a feature of projects involving more substantial production process changes than those requiring minor or no process changes. Amongst the product development projects in the case studies, production process innovation was only of major significance to two companies (C & F) and of minor significance to four companies (D, E, G and J). Whilst the manufacturing implications in one case (C) could not be foreseen, only two of these (D & F) involved the production functions to any extent when defining the specification. However, under subsequently revised procedures at Company E, the production functions were required to be represented during the specification formulation process of their major development projects. The interview survey found fairly good support for this hypothesis, since, as shown in Table 6.5, in half the projects involving process innovation (new processes or equipment) there were inputs from the production function, whereas there were no production inputs for projects involving no process innovation. Several explanations as to why half of the projects involving production process innovation did not include production inputs may be postulated. Firstly, this may be a case of less good practice. Secondly, this may reflect the procedures of some companies. Thirdly, in some instances manufacturing process changes and their implications may not have been foreseeable at this early stage.

	Input of production functions n=15	
	Yes	No
Process innovation	5	5
No process innovation	0	5

Table 6.5: Inputs of production function into specification according to process innovation in the survey

6.3.4.2 External Inputs to the Specification

As shown by Table 6.3, customers had inputs to the specification in around half of projects, whilst suppliers had inputs in only a few projects. A major distinction was found to arise as a consequence of the type of project.

Project Type

The inputs of customers to the specification in the case study projects is shown in Table 6.6. The noteworthy feature of these was the differences observed for the product development and contract projects. In only one product development project was the customer formally involved and, hence, it was usually the marketing function which acted as the 'voice of the customer'. This was in sharp contrast to the contract projects studied where the customer was involved to varying degrees in all but one case. Indeed, depending upon the terms of the enquiry, this could extend to the customer providing a definitive specification (L). Table 6.6 also shows that the survey strongly supported these findings.

	Product Devel't		Contract	
	Cases n=8	Survey n=10	Cases n=6	Survey n=7
Customers	1	2	5	7

Table 6.6: Customer inputs to the specification according to project type

6.3.4.3 Specification Elements

A feature of best practice, which was discussed in Chapter 5, is that all the relevant requirements and constraints should be considered in the development of the specification and included as appropriate. Hollins and Pugh (1990), for example, provide a fairly exhaustive list of specification elements. Other empirical studies have shown that companies will often only address the performance related elements in their specifications, with the other key elements, particularly those associated with cost and time constraints, being omitted or assumed as given (Walsh et al, 1992). It is apparent from the cases that under specific circumstances the inclusion of some of these elements were inappropriate.

Product Innovation

Details of the intended use of existing design concepts, technologies and design standards were not relevant to the original nature of the development at Company C. This project was unique amongst the projects investigated in both the case studies and the survey, in that being a very low complexity product, the product change concerned the whole product.

Product Complexity

Providing an overview of the system and sub-system requirements was found to be inappropriate to the low complexity products in the case studies (C, E & F). The survey also supported this finding. As shown in Table 6.7, system and sub-system requirements were less frequently included in companies' specifications for low complexity products. Indeed, two companies in the survey stated that this specification element was not applicable to their low complexity products.

	Inclusion of system & sub-system requirements n=15	
Product complexity	Yes	No
Low	1	3
Medium	5	2
High	3	1

Table 6.7: Inclusion of system & sub-system requirements in specification according to product complexity in the survey

Project Type

The specification of production volumes is usually of some importance, since this can have implications for various decisions, including production process and tooling choices, which will themselves influence the product's design. The contract projects in the case studies were usually concerned with the production of a single product and, in some instances, the possibility of repeat orders. With these low production volumes the specification of the production volume was not necessary. This was also found to be the case for all but one project in the survey. However, this was a hybrid form of contract project (see section 6.5.1) whereby the product was developed to a customer contract, but for batch manufacturing in relatively high production volumes.

Process Innovation

Specification of manufacturing process requirements and constraints by the case study companies was found to be of less relevance when use was made of well established production processes i.e. no process innovation (A, H, I & K). Table 6.8 demonstrates some support for this hypothesis. A higher proportion of establishments in the survey where projects involved process innovation (new or modified processes or new equipment) had specified manufacturing requirements or constraints than those whose projects did not involve process innovation. There were projects, however, involving production process changes which did not specify these. Part of the explanation for this may lie in the fact that in some instances manufacturing process changes and their implications may not have been foreseeable at this early stage. Alternatively, these may have been examples of poor practice. When there is no production process innovation it may still be appropriate for manufacturing requirements and constraints to be specified. Indeed, as Table 6.8 shows, this was found to be so with some projects in the survey.

	Inclusion of manufacturing requirements & constraints n=15	
Process innovation	Yes	No
Yes	8	2
No	2	3

Table 6.8: Inclusion of manufacturing requirements & constraints in specification according to process innovation in the survey

There were two other situations in which manufacturing requirements and constraints were not specified:

- The manufacturing processes were to be subcontracted (B).

- A definitive specification was provided by the customer who, in inviting tenders from several companies, was not concerned to specify the detailed manufacturing requirements and constraints (L).

However, these were specific to the companies concerned and were not found to occur in the other case study or survey projects.

Summary: Specifications are an important feature of the project initiation stages. The internal inputs to the formulation of the specification were found to be influenced by the degree of inter-functional integration required and the production process innovation involved. Projects with a need for the integration of several functions, as opposed to those focused on a dominant function, and those which involved production process innovation, were found to involve more functional inputs. With regard to external inputs, suppliers rarely had inputs to the formulation of the specification. Although customers were infrequently involved in product development projects, they were nearly always involved in contract projects.

A good specification should cover all the relevant requirements and constraints. However, factors such as low product complexity, contract-based projects, and low production process innovation, were all found to reduce the relevance and, therefore, inclusion of certain specification elements. In specific cases high product innovation, sub-contracted manufacturing, and the provision of the specification by the customer were also observed to reduce their relevance.

6.4 Project Organisation

6.4.1 Project Organisation Structure

Many different project organisation structures are referred to in the literature. However, as discussed in Chapter 3, these may be regarded as variations of six basic forms, which are referred to in this thesis as the functional, project management, matrix, project team, autonomous team, and multi-project forms of organisational structure. A feature which distinguishes between these is the inter-relationships between the key individuals (project manager, functional manager, team member, etc.) and their inter-relationships.

The type of structure adopted on any given project was found to be influenced by several company characteristics and project specific variables. These include the degree of innovation in the project, the size of the project, the managerial complexity (degree of integration), the competitive criteria, the variability between projects' characteristics, the size of the firm and the technical resource, and the dominant project mode. It was the case, however, that although some of these were found to be particularly influential, the choice of project structure was a consequence of the combined effects of several variables. Consequently, in the following discussion, exceptions to the relationships between individual variables and the type of project structure adopted are explained in terms of the other factors as relevant.

6.4.1.1 Product Innovation

The type of project organisation adopted relative to the degree of product innovation is illustrated in Table 6.9. It is readily apparent that there is a tendency for the data to lie along a diagonal (top left to bottom right), which indicates that, in line with the recommendations of best practice, an increasing level of product innovation was generally associated with a progressive movement from functional through to project team approaches. There are, however, some outlying points shown which warrant some comment. These may be explained as follows. Firstly, two major enhancement projects (Fp & Kp)[1] and one new core product project (Cp) were functionally structured. As these were technical advancement projects, with a strong functional focus, they did not involve significant integration of the functions. It could also be argued that the very small number of individuals involved in the project at Company C ensured that any desirable integrational features were inherently engendered. The degree of interaction also seems to account for the use of matrix structures on minor improvement projects in two of the contract cases (Ic & Lc). As demonstrated by Table 6.10, the survey supported the hypothesised relationship between product

[1] As more than one project type were studied in some cases, subscript p and subscript c are used to denote product development and contract projects respectively in this report.

innovation and the form project organisation in most cases, although, as with the case study projects, there were three notable exceptions. At Company 6, a functional project form was used to develop a new core product. However, this was focused predominantly on the engineering function and, without integrational needs, a functional structure was satisfactory. The multi-project organisational form was used for minor improvement projects at Company 11 and Company 15. The main reason for adopting this type of project structure is because of the need to sub divide a project. Both projects were modular in nature, having a number of distinct technical issues to be resolved and, in the case of Company 15, major parts of the design and manufacture were subcontracted to other companies. Although these findings provide general support for the relationship between project organisation and product innovation, both the occurrence and explanations of those instances of non-adherence must be seen to raise questions of the general recommendations of best practice.

Project Organisation	Product Innovation			
	Minor Improvement	Major Enhancement		New Core Product
		Existing Product	New Platform	
Functional	Dp*, Gp* Fc, Hc	Fp	Kp	Cp
Project Management	Ac, Bc, Gc			
Matrix Organisation	Ic, Lc		Lp	
Project Team		Dp	Bp Ep, Gp, Jp	
Autonomous Team				
Multi-Project				
Key: p - Product developments c - Contracts Note: Dp* & Gp* are secondary information sources				

Table 6.9: Relationship between product innovation and project organisation in the case studies

A feature of the case studies was that all the contract projects studied involved minor improvements and, in the survey, the most substantial product changes were major enhancements to existing products. This feature of contract projects was seen as a reflection of the fact that contracts commonly involve the customisation of existing designs to a customers' specific requirements (i.e. CMTO). Because of this association between contract projects and lower levels of product innovation, and in reflecting the relationship between product innovation and the type of project structure adopted, contract projects were infrequently found to adopt team-based forms of project organisation.

Project Organisation	Product Innovation			
	Minor Improvement	Major Enhancement		New Core Product
		Existing Product	New Platform	
Functional	8, 12	4		6
Project Management	16	13		
Matrix Organisation		17	9	
Project Team		2, 5	1, 3	7, 10
Autonomous Team				
Multi-Project	11, 15	14		
Key: 1-10:- Product developments 11-17: Contracts				

Table 6.10: Relationship between product innovation and project organisation in the survey

6.4.1.2 Production Process and Market Innovation

In addition to product innovation, the degree of market innovation (i.e. targeting existing markets, niche markets or new general markets) and production process innovation (i.e. no process change or new production equipment / processes) were themselves also hypothesised by the author to be relevant factors. Greater innovation in these areas would be similarly expected to increase the integrational needs and therefore the use of team-based structures.

Nearly all the case study projects focused on existing markets so that an objective assessment of the influence of market innovation was not possible. In the survey, however, team-based and non team-based project structures were equally dispersed amongst projects which related to existing markets as for those which related to new niche markets or new general markets.

There was some weak case study evidence which suggested an association between production process innovation and the adoption of team-based structures. The survey projects also provided some limited support for this finding. Its influence was found to be much less than that of product innovation and some of the other dominant factors discussed below.

6.4.1.3 Managerial Complexity

Projects were characterised according to the extent of their inherent need for integration between the different functions and disciplines involved. Integration projects require the close integration and interaction of several functions / disciplines whereas non integration projects do not. Non-integration projects, for example, may primarily focus on a dominant function such as engineering.

The relationship between the type of project organisation and whether or not there is an inherent need for integration between the different functions and disciplines involved in a project is shown in Table 6.11 for the case study projects. This relationship appears to be very strong. Also, as shown in Table 6.12, this finding was also strongly supported by the survey.

Project Organisation	Integration Characteristic	
	Non-integrational	Integrational
Functional	Cp, Dp*, Fp, Gp*, Kp Fc, Hc	
Project Management	Ac, Bc, Gc	
Matrix Organisation		Lp, Lc, Ic
Project Team		Bp, Dp, Ep, Gp, Jp
Autonomous Team		
Key: p - Product developments c - Contracts Note: Dp* & Gp* are secondary information sources		

Table 6.11: Relationship between integration characteristic and project organisation in the case studies

This factor, as indicated above, also explained some of the discrepancies associated with product innovation as a determinant of project structure. The basis for a relationship between product innovation and the form of project organisation used may be explained as follows. Minor innovations are often concerned with a part of the product and therefore with a relatively narrow functional or disciplinary focus, and often on a small scale, so that a functional or project management focus is expected. Alternatively, most major innovations are often concerned with a greater part of a product's systems and therefore typically with the need to integrate functions through team-based structures. However, this may not necessarily be so and, as the case studies and the survey illustrated, minor innovations may impact on several functions whereas major innovations may not. Therefore, when determining the optimal organisational form, it is clearly necessary to anticipate the integrational requirements of the various functions and disciplines by considering the intended scope of the project (product specification, manufacturing and marketing implications, etc.).

Project Organisation	Integration Characteristic	
	Non-integrational	Integrational
Functional	4, 6, 8, 12	
Project Management	13, 16	
Matrix Organisation	17	9
Project Team		1, 2, 3, 5, 7, 10
Autonomous Team		
Multi-project	14, 15	11
Key: 1-10: Product developments 11-17: Contracts		

Table 6.12: Relationship between integration characteristic and project organisation in the survey

6.4.1.4 Establishment Size & Technical Resource

Some of the literature on product development suggests that functional forms of project organisation may be appropriate to small firms, see, for example, Walsh et al (1992). It is also reasonable to hypothesise that this would also apply to a small technical resource. Indeed, in large firms the technical resource may be small and vice versa, which suggests that this may be a more suitable variable than establishment size. The case study projects did not find any association between small establishment size or a small technical resource and the use of functionally based organisational forms rather than team-based organisational forms. The survey, however, did find support for this hypothesis. The small establishments were more inclined to use functionally based project organisations than the larger firms (Table 6.13). Moreover, a particularly strong association was found between establishments with a small technical resource and the use of functionally based projects organisations (Table 6.13). Table 6.13 demonstrate that a feature of the large establishments or those with a large technical resource was that they did not use functional structures. However, this may partly reflect the fact that, unlike some of the case study projects which adopted functional approaches because they did not have integrational requirements, these survey projects all had integrational needs which led to project teams being used.

	Establishment size n=17			Size of technical resource n=17		
Project organisation	Small	Medium	Large	Small	Medium	Large
Functional	3	1		3	1	
Project management	1	1			2	
Matrix	1	1			2	
Project team	1	2	3		2	4
Autonomous						
Multi project		2	1		1	2

Table 6.13: Relationship between establishment size and technical resource, and project organisation in the survey

6.4.1.5 *__Project Size__*

Project size is defined in this thesis as the number of individuals assigned to the project. This was hypothesised to be influenced by product complexity and depth of product structure, and product innovation. The basis for suggesting that these factors were related to project size was that product complexity and product structure would determine the number of activities involved, whereas the degree of product innovation would determine the number of design degrees of freedom (i.e. the number of design options which potentially could be investigated). Table 6.14 and Table 6.15 demonstrate that higher product complexity and deeper product structure were associated with a larger project size. There was also some evidence of a weak relationship between product innovation and project size. Minor product innovations were not associated with large projects.

Product complexity	Case studies n=16 Project size			Survey n=17 Project size		
	Small	Medium	Large	Small	Medium	Large
Low	4			4		1
Medium	5	5		2	3	2
High		2		3	2	
Note: Project size: Small <=10, Med. <=25, Large > 25						

Table 6.14: Relationship between product complexity and project size

Product structure	Case studies n=16 Project size			Survey n=17 Project size		
	Small	Medium	Large	Small	Medium	Large
Low	7	2		4		1
Medium	2	3		4	4	1
High		2		1	1	1
Note: Project size: Small <=10, Med. <=25, Large > 25						

Table 6.15: Relationship between product structure and project size

Project size was found to impact on the types of project organisation adopted. The case study projects were small- or medium-sized so that analysis of the influence of project size on project organisation was limited. Only with the contract projects was there an observable trend from functional (F) through to project management approaches (A, B, G) with increasing project size. However, there were exceptions due to the effects of other factors at Company H and Company I. The low variability between projects at Company H enabled it to retain a functional approach by having a specialist planning function to support the functional management, and the integrational requirements of Company I's project was the reason for it adopting a matrix structure. However, the survey demonstrated that functionally structured projects tended to be associated with small projects, whereas project team structures tended to be a feature of, albeit not exclusive to, the larger projects (Table 6.16).

	Project size n=17		
Project organisation	Small	Medium	Large
Functional	3	1	
Project management	2		
Matrix	2		
Project team	1	2	3
Autonomous			
Multi project	1	2	
Note: Project size: Small <=10, Med. <=25, Large > 25			

Table 6.16: Relationship between project size and project organisation in the survey

6.4.1.6 Lead-time

Lead-time pressures arise because of time-to-market factors with product developments and delivery lead-time factors with contracts. Where the case study projects were subject to lead-time pressures this generally corresponded with the use of team-oriented project structures. This follows logically from the notion that lead-time pressures give rise to greater process concurrency needs and hence the need for integration. High levels of concurrency can of course be achieved without the need for integration and therefore a team structure. Company H, having an inherently modular project characteristic, was such a case. Table 6.17 illustrates the relationship between the presence of lead-time pressures relating to a product's markets and the type of project organisation adopted for projects in the survey. There is a weak indication that those establishments subject to lead-time pressures were less likely to adopt a functional management or project management organisation than team-based organisational forms. However, these time pressures were not specific to the project itself, but indications of the relative importance of these competitive criteria to the product group's market in general. A clearer relationship therefore should be expected between project organisation and lead-time pressures at the project level.

	Lead-time pressures n=17	
Project organisation:	Yes	No
Functional	1	3
Project management	1	1
Matrix	2	
Project team	3	3
Autonomous team		
Multi-project	1	2
Note: Lead-time pressures identified where time-to-market cited for product development projects and delivery lead-time 1st or 2nd ranked for contracts.		

Table 6.17: Relationship between lead-time pressures and project organisation in the survey

A further time-related factor, delivery conformance, is relevant to contract projects. When this is important then an emphasis is placed on schedule control mechanisms. This and the need to control costs, particularly on large projects, were a primary reasons for adopting a project management organisation (Ac, Bc & Gc) or other project-based structures (Ic & Lc). Although both contract projects in the survey where delivery conformance was a first or second ranked competitive criterion used a project-based (i.e. non-functional) form of organisation, a project-based approach was in fact adopted for all but one of the contract projects. This suggests that delivery conformance, if not an order winning criterion, was a necessary qualifying criterion for most firms engaged in contracts.

6.4.1.7 Dominant Project Mode

Chapter 3 discussed how a company's design and development activities will tend to involve particular types of project and, therefore, it will structure itself according to these, and will acquire proficiency in handling such projects. In this way, it develops a dominant mode (Wheelwright and Clark, 1992). It may be important that a firm develops capabilities (resources, skills, training, systems, etc.) that allow it to apply alternative modes when appropriate for different types of project. However, the approach taken on any particular project should be compatible with the dominant mode(s). The focus of the case studies was on individual products and specific projects rather than looking at companies' practices in an holistic sense. Therefore, it was not possible to investigate the effects of project modes on firms' practices in any detail. In a similar way it was not possible to investigate these issues in the interview survey. However, specific cases did provide some useful insights.

Some companies are routinely engaged in different types of project and therefore will possess a broad range of experience and skills in managing these. Company G, for example, had an on-going involvement in both product development and contracting activities. Contracts were usually concerned with minor improvements and a project management project structure was used. Product developments involving minor and major enhancements involved functional and project team approaches respectively. The company therefore had several operating modes.

Alternatively, a company's activities will often be biased towards a particular type of project, and it will be structured towards and have acquired competence in handling such projects. It may from time-to-time need to undertake a project with quite different characteristics from its dominant mode. In these circumstances it may be appropriate to compromise from the theoretically optimal project organisation, and to adopt an approach which is more compatible with its dominant mode. At Company H, for example, contract projects were routinely handled through a functional approach in which planning support was provided by a specialist department. This approach was modified, however, for projects which were different from the routine ones. The company indicated that, in preparing a tender for a contract which would be more complex than usual, it had planned to appoint an individual from the planning function to act as project coordinator (i.e. a matrix structure). Another example was a contract it undertook for a related but different product and market. This raised a number of issues relating to the technical design and production, including a very high specification of quality, and investments in new facilities. Because of the strategic importance of the contract an experienced senior manager was appointed to manage the project. However, despite recognising the need to approach the project in a different way, the project proved to be a salutary lesson for the company in the difficulties associated with making such changes in approach. The project commenced using many of the existing procedures, some of which were inadequate or inappropriate to the project. Much of the project involved redefining these and setting in place more appropriate procedures. Similar experiences were found at Company A. A major part of its business had historically been associated with engineer-to-order markets relating to large turnkey projects. Its organisational structure and many of its systems therefore reflected this mode of project. In recent years it had moved into a new but related technology area which was associated with smaller, but more numerous, customisation projects. Although a project management organisational approach was still appropriate, some aspects of its general organisational characteristics (e.g. a separate support function for project planning) and systems were too cumbersome for the relatively rapid turnover of projects. These were being re-evaluated in order to reduce the number of cross-functional interfaces and improve the responsiveness and control of processes.

Summary: The corresponding section of Chapter 5 indicated that current best practice guidelines are stated too simply. It may be concluded from the thematic analysis that the most appropriate form of project organisation to adopt was found to be determined by the combined influences of several variables and, therefore, it is necessary to consider all of these. Factors which, to varying degrees, were indicated to have some influence were the integrational needs, product innovation, process innovation, project size, time related pressures, establishment and technical resource size, the variability between projects, and the type of project commonly handled (i.e. the dominant modes of operating). However, the degree of integration required between functions and disciplines was particularly influential and it is important to anticipate these needs.

6.4.2 'Team' Features

6.4.2.1 Team Structure

Several projects in the case studies used team-based forms of project structure. A generally held principle of best practice, which was discussed in Chapter 3, is that the organisational dynamics of teams, such as the ability to achieve effective communications, places an upper limit on the size of a single core team of around ten members. Indeed, Company J, where projects would normally have involved a team with a size below this limit, experienced some difficulties during the main development stages when the team's membership reached fourteen (eleven permanent and three temporary). Company G also expressed concerns over the effectiveness of large teams based on the experiences of its largest development projects. Therefore, for larger projects, it has been recommended (McGrath et al, 1992) that an appropriate approach is to adopt an extended team structure in which the core team members interface with individuals assigned to the project from their respective departments. The type of team structure adopted was therefore hypothesised to be related to the project's size. The product development projects at Company D and Company J involved just over ten members. Company D used an extended team structure, however, Company J used a single core team structure. This was not surprising considering that team size would be less than ten for most projects and a transitionary band might be anticipated between the two approaches. In the survey, however, the transition between team structures was strongly supported. As Table 6.18 demonstrates, an extended team was used for all projects in which the team size exceeded ten members, and a core team was used for all but one of the projects in which the team size was ten or less. Indeed, the one exception involved a team size of ten individuals.

	Team structure n=11	
Project size	Core	Extended
10 or less	3	1
More than 10		7

Table 6.18: Relationship between project size and team structure adopted for team-based project structures in the survey

6.4.2.2 Team Membership

With regard to the individuals assigned to a project, those who have responsibility for its management can be distinguished from the other team members. The seniority of those responsible for the routine management of projects was strongly suggested by the case studies to be influenced by the overall type of project organisation used, since, with a functional structure this role was performed by the functional management in all cases. This was also the case for all functionally organised projects in the survey. Usually this role was undertaken by a functional manager(s). However, one case study project (C) and one survey project (6) studied, both of which were concerned with the development of a new core product, also involved a director.

With project-based forms of organisational structure the routine responsibility for a project is assigned to a project manager, project leader, etc. The level of seniority associated with this role was hypothesised to be determined, firstly, by the project's size, and, secondly, by the degree of innovation. On larger contracts in the case studies (A, B, G & L) this role was referred to as project manager or contract manager and was usually undertaken by a manager or someone with equivalent authority. Secondary information obtained during three case studies (A, G & I) suggested that with smaller contracts it was usual for less senior individuals to have responsibility for the project. The exception to this was the small project studied at company I where a contract manager was appointed. However, although the project was small in absolute terms, the fact that it was large relative to those the company would usually handle was cited as the reason for this. As all the contract projects in the case studies were minor improvement projects the influence of product innovation could not be investigated. All contract projects in the survey were found to be the responsibility of someone with managerial status regardless of the size of the project or the product innovation involved. However, although the anticipated relationship between these was not found, consideration of these on a project-by-project basis suggested that these and other factors were nevertheless influential. For medium- and large-sized projects or those involving major product innovation assigning the responsibility to a senior manager appeared to be appropriate. However, at Company 17, where a manager had responsibility for a major enhancement project, it was stated that a senior functional representative rather than a manager would usually be responsible for the minor change projects usually undertaken. There were two small projects which involved minor improvements whose managerial responsibility was assigned to a manager. At Company 16, because the project was relatively large and strategically more important than usual, the Contract Manager took responsibility for it rather than a less senior individual. Alternatively, at Company 11, an Account Manager was responsible for all projects for a major client, suggesting that organisational factors were also a consideration.

Amongst the case study product development projects a manager was usually appointed as project leader. The exception to this was Company G, where a senior functional representative was appointed. However, product development projects in the survey were as likely to be managed by a senior functional representative as a manager. As with the contract projects it was hypothesised that more innovative and larger product development projects would be managed by a more senior individual. Although none of the case study projects involved minor product improvements, and all project-based projects were major enhancements, there was evidence that with highly innovative projects this would become the responsibility of a senior executive

- procedures at Company E stated that this would be so. However, the survey did not support these relationships. Although managers were responsible for most medium- and large-sized and major innovation projects, senior functional representatives were responsible for two major enhancement projects (1 & 3) and one new core product project (10). However, the latter of these was not good practice. Although the projects commonly handled by the company, were often fairly substantial and managed by senior functional representatives, the company was in this case adopting routine procedures for a non-routine project. Again, consideration of the survey projects on an individual basis suggested that there were a number of possible influences, which, in addition to the size of the project and the degree of product innovation, include the size of the technical resource. A medium or large technical resource was suggested to give rise to a greater possibility for delegating responsibility to a senior functional representative.

With regard to the seniority of team members (i.e. excluding individuals who solely had project management responsibilities) the case studies suggested that, whereas managerial levels were usually involved when functional or project management structures where used, this was less common with team-based approaches. However, in the survey managerial levels were almost equally represented on team-based and non team-based projects. Managerial level inputs were also hypothesised to be most commonly found with projects involving major enhancements (platform) and new core product innovations and, in particular, those involving team-based projects. However, the survey only found weak support for this. The lack of support for these hypotheses may partly be explained by the fact that there may have been some inconsistent responses by interviewees in the survey concerning managerial involvement in projects. The case studies also suggested that senior functional representatives were more frequently represented on team-based projects than non team-based projects and, that, junior functional representatives were more frequently represented when an extended team form rather than core team form of team-based structure was adopted. Although all team based projects included senior functional representatives, this was true for all but one non team-based project. However, two thirds of extended teams as opposed to only a third of core teams involved junior functional representatives.

6.4.2.3 Team Commitments

The literature on product development, as discussed in Chapter 3, has generally stressed the importance of permanent and full-time representation of individuals on project teams. The research found that, for both team-based and non team-based project structures, several factors influenced whether individuals' commitments should be permanent or temporary, part-time or full-time.

Lead-time

Certain case studies suggested that permanent and full-time commitments to projects would occur when lead-time minimisation was emphasised (by time-to-market being cited for product development projects and delivery lead-time being cited as a first or second ranked competitive criterion for contracts). This was most pronounced at company J where there were substantial pressures to have a prototype available for its industry's premier international exhibition. Table 6.19 demonstrates that although the case studies suggested a strong relationship between lead-time pressures and the proportion of individuals committed part-time to the project, the survey found no support for this result. Table 6.20 shows that no relationship was identified amongst the case studies between lead-time pressures and the proportion of individuals with permanent commitments to projects. Moreover, the findings of the survey also appeared to contradict the original hypothesis. There was a tendency for lead-time pressures to be associated with a higher proportion of temporary commitments to projects. This result suggests that, rather than commit personnel on a more permanent basis, some establishments were using temporary personnel to complete more quickly subdivisions of their projects. These inconclusive and contradictory findings may reflect differences between the lead-time pressures of the general product market which were used and the actual lead-time requirements of specific projects in the survey, or they may reflect the influence of other factors (see below).

	Cases n=8		Survey n=17	
Lead-time pressures	100% part-time	<100% part-time	100% part-time	<100% part-time
Yes		5	4	4
No	3		4	5

Table 6.19: Proportion of individuals committed part-time to projects according to lead-time pressures

	Cases n=7		Survey n=17	
	Proportion of team committed permanently		Proportion of team committed permanently	
Lead-time pressures	<=median*	>median*	<=median*	>median*
Yes	3	2	5	3
No	1	1	4	5
* Data split into two halves at median value (case studies median = 54%, survey median = 28%).				

Table 6.20: Proportion of individuals committed permanently to projects according to lead-time pressures

Establishment Size & Technical Resource

For the small- or medium-sized case study establishments and those with a small- or medium-sized technical resource, it was found that individuals were more likely to be committed on a part-time basis (Table 6.21 and Table 6.22). Presumably this was because individuals in these establishments were necessarily committed to more than one project or task. Indeed 100% part-time working was not observed for the large establishments or the establishments with a large technical resource. These findings were also supported by the survey (Table 6.21 and Table 6.22). The case studies and the interview survey also indicated a weak relationship between small establishment size or a small technical resource and a tendency for more temporary working.

	Cases n=8		Survey n=17	
Establishment size	100% part-time	<100% part-time	100% part-time	<100% part-time
Small	2	2	4	2
Medium	1	1	3	4
Large		2	1	3

Table 6.21: Proportion of individuals committed part-time to projects according to establishment size

Technical Resource	Cases n=7		Survey n=17	
	100% part-time	<100% part-time	100% part-time	<100% part-time
Small	1	1	2	1
Medium	1	2	5	3
Large		2	1	5

Table 6.22: Proportion of individuals committed part-time to projects according to technical resource

Project Type

All the contract projects in the case studies involved mainly part-time inputs (with the exception of some temporary full-time inputs). The two instances of notable full-time inputs were related to product development projects at Company G and Company J. It was therefore hypothesised that the commitment of individuals to projects was a influenced by project type. Contract projects were anticipated to involve more part-time commitments and more temporary commitments than product development projects. Table 6.23 shows that, although the survey provided some weak support for the relationship between project type and the proportion of part-time commitments, a stronger relationship was found for the proportion of permanent commitments.

	Proportion of team with permanent commitments n=17		Proportion of team with part-time commitments n=17	
Project type	<=median*	>median*	100% part-time	<100% part-time
Product developments	4	6	4	6
Contracts	5	2	4	3

* Data split into two halves at median value (28%).

Table 6.23: Commitment of individuals to projects according to project type in the survey

Product Innovation

Although not evident from the case studies, it was hypothesised that minor levels of product innovation would be associated with a higher proportion of part-time commitments to projects than for more substantial product innovations. This was based on the postulation that minor change projects by their very nature are likely to be less substantial and require only partial involvement for at least some of the project's participants. More substantial product innovations, however, would be expected to require high levels of involvement by the project's participants.

Product Innovation	Proportion of part-time commitments n=17	
	100% part-time	<100% part-time
Minor improvement	4	1
Major (existing)	3	3
Major (platform)	1	2
New core product		3

Table 6.24: Proportion of individuals committed part-time to projects according to product innovation in the survey

The hypothesis was supported by the survey. Table 6.24 reveals that most minor improvement projects involved 100% part-time commitments, whereas increasing product innovation was associated with a progressively higher incidence of full-time commitments. Indeed, all new core product projects involved some full-time commitments.

6.4.2.4 Representation on Projects

The literature on product development discussed in previous chapters emphasises the need for all the main internal functions (marketing, engineering, production, etc.) and relevant external parties (customers, suppliers, etc.) to be formally represented on projects. Representation of the different internal functions, customers and suppliers during projects, as distinct from their involvement which is discussed in Section 6.5.2.2, was found to be influenced by their inherent characteristics. The case study projects categorised as integration projects were in general associated with a larger number of functional inputs (Table 6.25). One particular departure from this concerned the project team at Company J. Although classed as an integration project, the project team was established to integrate several engineering disciplines rather than the different functions. Although Marketing was the only other function represented, delays which arose from not adequately considering the manufacture of the product until late in the development process (resulting in a post-prototype redesign for manufacturing exercise and a delayed market launch) suggested that Manufacturing should have had formal representation on the team. The case study findings were also strongly supported by the survey (Table 6.25).

Table 6.26 demonstrates that Marketing and Sales did not have formal representation on half of the case study projects and, moreover, was more frequently represented on product development projects than contracts. The formal representation of Marketing and Sales was also found to be strongly associated with the form of project organisation adopted, which, as discussed in Section 6.4.1, was found to be influenced by several company and project factors including the integrational requirements (managerial complexity) discussed above. In two thirds of projects involving team-based organisational forms Marketing and Sales was represented, and there was no representation with non team-based organisational forms Table 6.27. These results were also supported by the survey.

	Cases n=14		Survey n=17	
	Functional inputs		Functional inputs	
	1-3	3-8	1-3	3-8
Integration project	3	5	1	7
Non integration project	5	1	8	1

Table 6.25: Functional inputs into project according to integrational needs

	Cases n=13		Survey n=17	
	Marketing inputs		Marketing inputs	
Project type	Yes	No	Yes	No
Product development	5	3	6	4
Contract	1	4	1	6

Table 6.26: Marketing inputs into project according to project type

	Cases n=12		Survey n=17	
	Marketing inputs		Marketing inputs	
Project structure	Yes	No	Yes	No
Team-based	5	3	7	4
Non team-based		4		6

Table 6.27: Marketing inputs into project according to project structure

It was expected that formal production representation on projects would be conditional on the degree of process innovation involved. However, there were production inputs to most case study projects. The major exception, as discussed above, was Company J. Despite a process dimension to the project the Manufacturing Department was only involved during the down-stream stages. The survey provided support for the hypothesis. As revealed by Table 6.28, in only two projects when there were production process implications were there no production inputs, and there were no production inputs in half of the projects which involved no process changes.

	Production inputs n=17	
Process innovation	Yes	No
Yes	9	2
No	3	3

Table 6.28: Production inputs to projects according to project type in the survey

With regard to customers and suppliers a distinction was made between having formal inputs to the project and being formally recognised as part of the project's team. In all the case study and survey projects studied customers were not considered to be a formal part of the team, and in only two survey projects was this found to be the case for suppliers. In the case studies and, also, in the survey, customers were only found to have formal inputs on contract projects, whereas suppliers were represented in similar proportions of contract and product development projects. For suppliers, the existence and the nature of key supply items was found to determine their representation on projects. The comparative analysis for the case studies suggested that the involvement of suppliers was influenced by several supplier dimension factors including the internal span of process, supplier rationalisation, and control over suppliers, and product dimension factors such as product complexity and product innovation. With several variables, however, their complex inter-relationships made it difficult to determine the extent of their influence other than on a company-by-company basis.

Also, variables such as supplier rationalisation and supplier control tended to generate inconsistencies, possibly because these are general rather than project specific factors. The critical factor for key suppliers was the requirement for supplier collaboration. An ordinal supplier collaboration index (0-3) for this was devised. This was based on surrogate variables which included whether or not there were key supply items, was a substantial design content involved, and was the design undertaken by the supplier? Although this was a simple ordinal measure a strong correlation to the formal input of suppliers to projects in the case studies was found (Table 6.29). This was also found to be the case in the survey (Table 6.29).

	Cases n=14		Survey n=17	
Supplier index*	Supplier inputs		Supplier inputs	
	Yes	No	Yes	No
0		1		4
1	1	1		1
2	3	2		2
3	6		7	3
* Key supply item = 1, design content = 2, design by supplier = 3				

Table 6.29: Supplier inputs to projects according to key supplier collaboration index

The nature of the key supply items (as indicated by the supplier collaboration requirement index) was also found to be related to the formal representation of purchasing on projects. Although the case study projects provided no conclusive evidence of such a relationship, Table 6.30 demonstrates that in the survey purchasing was not formally represented on any projects when there were no design implications (supplier index <= 1) for supplier items, whereas purchasing was represented on most projects involving design by the supplier (supplier index = 3).

Supplier index*	Purchasing inputs n=17	
	Yes	No
0		4
1		1
2	1	1
3	7	3

* Key supply item = 1, design content = 2, design by supplier = 3

Table 6.30: Purchasing inputs to projects according to key supplier collaboration index in the survey

Summary: When a team-based form of project organisation was adopted, the structure of the team was found to be strongly influenced by the size of the project. A transition from a single core team to an extended team as the project's size approaches and exceeds 10 participants was found to occur. No single dominant factor was found to determine the level of seniority of those with responsibility for the routine management of projects. Several factors were suggested to be relevant, however, including the type of project structure used, project size and the degree of product innovation involved (absolute and relative to frequently handled projects), size of the technical resource, strategic considerations, and organisational features relating to the handling of projects in general were suggested to be relevant. Although the seniority of other individuals assigned to projects was suggested to be influenced by the type of project structure adopted, only limited support for this was found. However, where relevant, the type of team structure adopted was found to be influential, with junior functional representatives more frequently represented on extended teams than single core teams.

In contrast to the best practice recommendations for permanent and full-time representation on teams, this was not so in most cases, and was found to be conditional on several factors. Smaller establishment size or smaller technical resource was associated with more part-time commitments, and contract projects with more temporary commitments. Product innovation was also a contributory factor, with minor improvements tending to involve 100% part-time commitments and increasing product innovation being associated with more full-time commitments.

The formal representation on the project of the different internal functions was related to the integrational requirements (managerial complexity). Integration projects were associated with more functional inputs than non-integrational projects. Marketing was more frequently represented on product development projects than contracts, and was more frequently represented on projects involving team structures than with functional and project management organisational forms. Production process innovation was an important influence on representation for the production function. No customers, and very rarely suppliers, were represented as a formal part of the team. Customer inputs were a distinct feature of contract projects. Although formal inputs by suppliers were indicated to be influenced by several general factors, the requirement for supplier collaboration at the project level (as indicated by the existence and nature of key supply items) was found to be very influential. The supplier collaboration requirements also influenced the formal representation of purchasing on projects.

6.5 Process and Integration

6.5.1 Principal Processes and Activities

A major element of best practice which was discussed in Chapter 5 is that companies should establish formal definitions of generic processes (i.e. main stages, primary activities and key events) for their main project types. Although a structured process was not always defined this was recognised by most companies (see Section 5.6.1). Moreover, considering the detailed descriptions of the development processes provided and the consistency between the different interviewees in respective establishments in the case studies, and that the interviewees in the survey generally had little difficulty in describing the main stages, activities and events for the projects studied, led to the conclusion that companies generally had a good understanding of their design and development processes.

The number of stages and the terminology used to define their processes varied between companies. Sometimes this was done to reflect the particular emphasis or characteristics of their projects. The number of stages, or phases, used by companies to determine their processes ranged between four and eight in the case studies and, also, in the survey. The case studies suggested that the number of stages cited for contract projects was higher than for product development projects. However, although the mean number of stages for contract projects was found to be higher than product development projects in the survey, the difference in the means was not statistically significant ($t=0.693$, $p>0.1$, one tailed test). Product complexity, as revealed by Table 6.31, was also observed to influence the number of stages cited in the case studies, with products of low complexity being associated with fewer project stages than products of medium and high complexity. Less than 5 stages was not observed for high complexity products and more than six stages was not observed for low complexity products. Table 6.31 also reveals that this was generally supported by the survey. The main exception in the survey was Company 9. It defined seven stages for its low complexity product. However, as these were based on each milestone in the process, rather than more general activities, this gave rise to a more discriminatory definition of the process.

Although there were variations in the number, and definition, of the project stages, by thinking in terms of processes and activities it was possible to identify generic models for the product development process and the contract process based on the case study projects studied. These are shown according to the basic conventions of the Structured Analysis technique (Ross, 1977) in Figure 6.1 and Figure 6.2 respectively. These top level process definitions include the main activities, along with the inputs, outputs and constraints relating to these. These models do not define how the processes should be undertaken (i.e. the resources and mechanisms used). Many of these features - concurrency, methods, decision making mechanisms, project management, etc. - were found to be influenced by company and project factors and, therefore, are dealt with elsewhere in this chapter.

Product complexity	Case studies n=15			Survey n=17		
	Project stages			Project stages		
	3-4	5-6	7-8	3-4	5-6	7-8
Low	2	2		2	2	1
Medium	1	5	3		5	3
High		1	1		2	2

Table 6.31: Relationship between product complexity and the number of project stages

The survey confirmed the existence of these two processes and, notwithstanding the fact that companies recognised different phases (see above), their sequence of activities were generally found to follow the intent of the generic process models. Indeed, most interviewees in the survey stated that this was so. However, the survey also identified three hybrid models which comprised elements of the product development and contract process models:

- At Company 9 a low volume product was developed following a specific request by an end customer, but with the intention of entering the resulting product into the company's standard product catalogue or range in order to exploit a wider market opportunity - this followed the product development process model with some elements of the contract process, such as negotiation on costs, etc., with the customer.

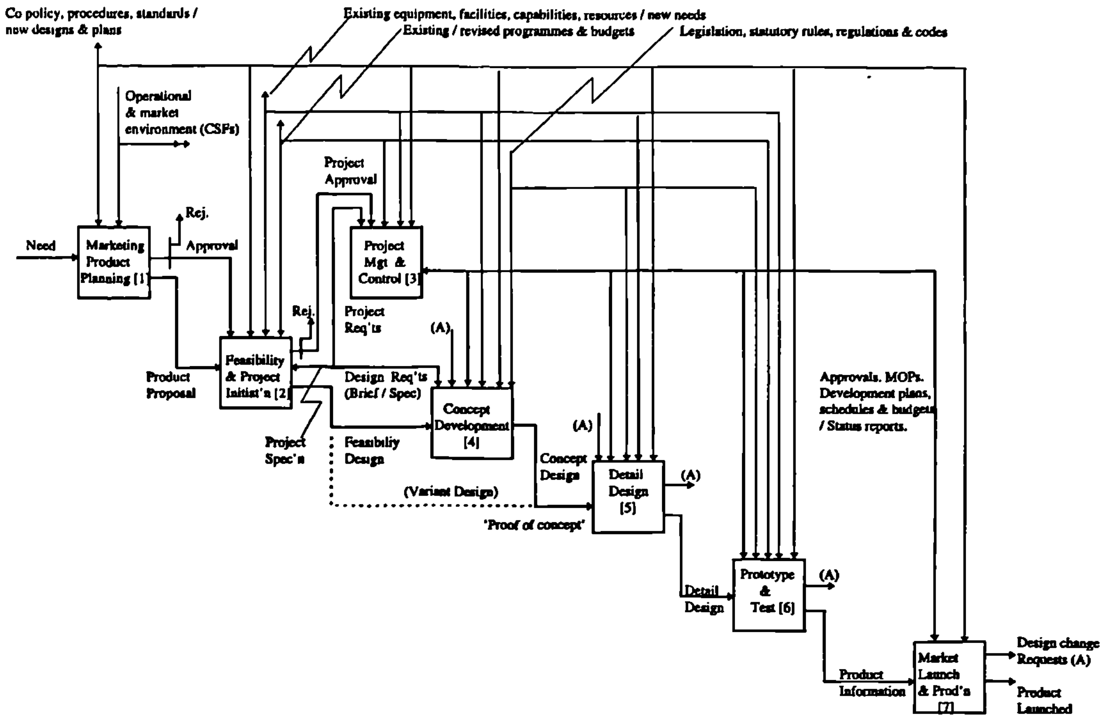


Figure 6.1: Product development process model

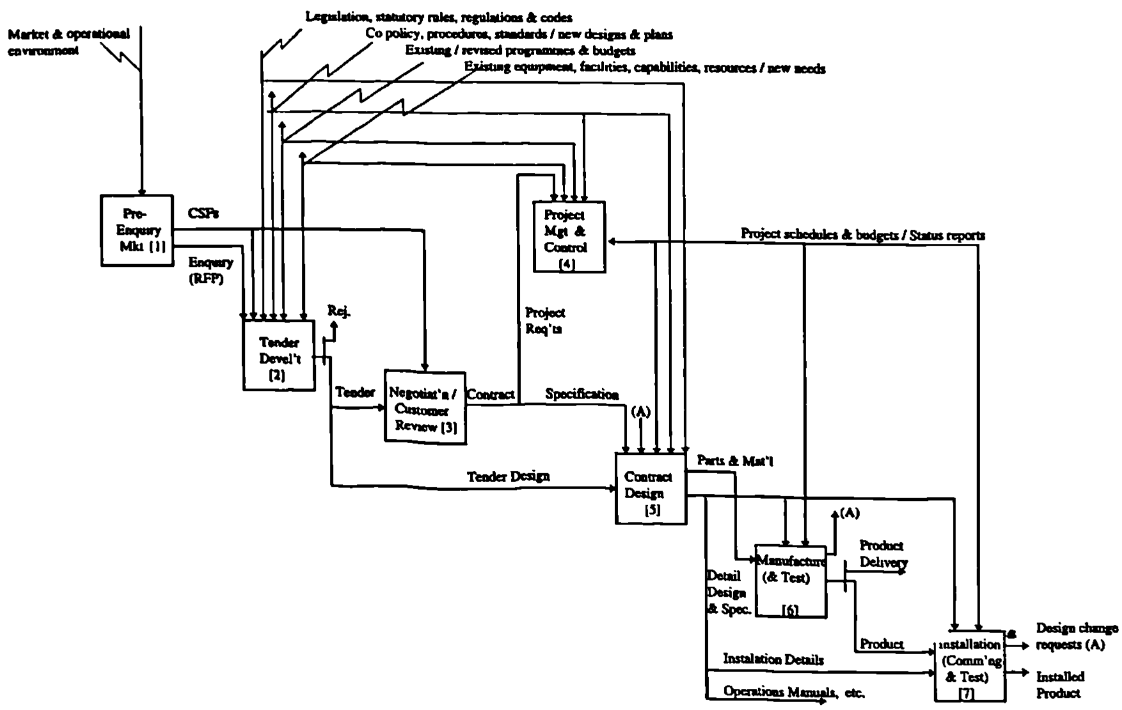


Figure 6.2: Contract process model

- Company 10 initiated the development of a low volume, high complexity product but, owing to the scale of the development, in order to complete it, a contract for sale had to be obtained - the model therefore had a product development front-end followed by a contract.

- At Company 11 a high volume, low complexity product was developed for a specific customer under a negotiated agreement with a view to the company becoming a preferred supplier - the model was essentially a contract, but largely followed a product development model supplemented by customer inputs to the review and testing activities.

Although these generic models were broadly applicable at a relatively abstract level, Figure 6.1 and Figure 6.2 illustrate that particular activities were absent in some cases (e.g. in minor change projects no conceptual design was usually required other than at the feasibility or tender stages), or additional activities were present (e.g. in contracts concerning complex products or systems with distinct installation and commissioning phases). Moreover, at a more detailed level, activities were found to be conditioned by a number of company and project specific factors. Product factors were inevitably influential in determining the nature of the design and development processes. Two critical and related factors were product complexity and product structure, and differences were observed in the case studies between the development of products having low complexity and/or shallow product structure through to products of high complexity and deep product structure. In the engineering design literature the core design activities have been generally represented by two phases (concept and detail) or three phases (concept, embodiment and detail). In most case study companies two phases were referred to, their products being of low or moderate complexity. Companies involved in contract work often referred to three stages; but the second stage, which followed the award of contract, was in essence a completion of the tender design work done at the tender phase, and should therefore be interpreted in the context of a two stage design model. For all types of product innovation and project types, higher complexity and deepening product structure was associated with an increasingly distinct embodiment stage. The survey did not seek to test these findings and, as companies described their processes from a product development rather than an engineering design perspective, the findings could not be verified without an unacceptable degree of interpretation.

As might be expected factors such as the type of project, product complexity and product structure, and the degree of product innovation were found to influence the time scales of projects. The overall duration of contract projects (enquiry to delivery / installation) in the case studies were in the range of six to eighteen months. The product development projects all had overall durations (product idea to first production for sale) in excess of this, varying between two and ten years, which suggested that the overall duration of product developments will be greater than contracts. In the survey product development projects (excluding Company 9 which appeared dubious) with overall durations of between 7 and 42 months and a median of 24 months, compared with overall durations for contracts of between 10 and 30 months and a median of 18 months. Therefore, the survey appeared to support the finding of the case studies in so far as the overall time scales for product developments were longer than contracts on average, but they were not always of greater duration than the contracts. Moreover, the difference in their means were not found to be statistically significant ($t=1.166$, $p>0.1$, one tailed test). This contradiction of the case studies may reflect the influence of other factors. A notable feature of the case studies was that all the contracts involved minor improvements and all the product developments involved major innovations or new core product innovations. Alternatively, the survey (in which all establishments were pre-selected) included a mix of degrees of product innovation for both the product development and contract projects. It was hypothesised that other factors relating to the scale of projects (product complexity, product structure and product innovation) were influential. The basis for suggesting that these factors were relevant was that product complexity and product structure would influence the size of a project and hence the number of activities to be undertaken, and that project innovation would impact on the design degrees of freedom (i.e. the number of design options which could potentially be investigated) and hence the types of activities and methods involved. Product complexity and depth of product structure were not found to have any influence.

However, as shown in Table 6.32 product innovation was observed to be very influential in the case studies, with minor improvement projects having shorter durations than those with higher product innovation . The only exception to this relationship was the contract project at Company H. Although a minor improvement project it had a duration above the median. The project's duration, however, was only marginally above the median. The survey generally supported this finding (Table 6.32). However, there were three exceptions. As with the exception for the case studies, the minor improvement project at Company 15 had a duration which was marginally in excess of the median. Nevertheless, there were two new core product innovations with relatively short durations, and in particular, the project at Company 6. This exception is accounted for by the fact that the product was launched in the market in parallel with, rather than after, field testing (undertaken over a 12 month period), thereby reducing the effective time scale for the project.

Product innovation	Cases n=11		Survey n=16**	
	Overall project duration		Overall project duration	
	< median*	>= median*	< median*	>= median*
Minor improvement	4	1	4	1
Major (existing)		1	2	3
Major (platform)		4		3
New core product		1	2	1

* Cases median = 20 months, survey median = 21 months.
** Company 9 excluded as outlier.

Table 6.32: Overall duration of projects according to product innovation.

The durations of the sub-stages were also investigated. The front-end stages for the case study contracts (customer enquiry to contract award) at up to six months compared with product developments (product idea to project launch) at up to two years. This feature of product development projects has been referred to by Smith and Reinertsen (1991) as the 'fuzzy front-end' since projects are often held up due to ineffective decision making. They have observed that it is not uncommon for up to 50% of a project's cycle-time to be consumed during this period. Indeed, this was found to occur at Company J. However, constraints on the available resources and the need to fit a project into the development programme, were cited by some establishments as necessary reasons for product development projects being delayed (Company D in the case studies and Company 5 in the survey). In the survey, however, only small differences were observed between product development and contract projects. The time scale for translation from product idea to product launch in the market of between 1 and 30 months (6 months in over 50% of development projects) and a median of 6 months, compared with periods for customer enquiry to contract award of between 2 and 12 months, and a median of around 7 months. A more detailed examination revealed that, whilst the tender submission typically took around two-to-three months, contracts were awarded anywhere between 1 and 9 months after the submission of the tender, suggesting that the customer response / negotiating period was a critical determinant of the duration of the front-end of contracts.

Project scale factors (product complexity, product structure and product innovation), discussed above in relation to the overall project durations, were hypothesised to be of some importance to the duration of the design related activities (project launch to completion of the detailed design definition). In the case studies, the period from a project's launch through to completion of the detailed design varied between two and twelve months. Product complexity, product structure and product innovation were suggested to be only weakly related to this. However, as demonstrated in Table 6.33, a composite index of product complexity and product innovation suggested a much stronger relationship so that, in general, the greater a project's scale index the longer the time taken to complete the design definition. The survey, however, found only limited support for this finding (Table 6.33). This was partly to be anticipated, since, the number of individuals assigned to a project was also found to be related to its scale (see Section 6.4.1.5), and would be expected to offset the impact of a project's scale on the required durations to some degree.

Project scale index**	Cases n=8		Survey n=17	
	Design duration		Design duration	
	< median*	>= median*	< median*	>= median*
2-3	4		3	3
4-6		4	4	7

* Cases median = 6.5 months, survey median = 4 months.
** Product complexity: low=1, med=2, high=3.
Product innovation: minor=1, major=2, new core product=3.

Table 6.33: Project launch to completion of detail design according to project scale index.

Summary: Project type (although not statistically supported) and, in particular, product complexity were found to impact the number of stages used by establishments to define their process. Higher product complexity was associated with more process stages. Generic models for the product development and contract processes were identified on the basis of the case studies. The survey found support for these, but also identified three hybrid processes. However, the characteristics of specific companies and the attributes of individual projects, restricted the detail of these generic process models to a relatively abstract level. Furthermore, within these, product complexity and product structure were observed in the case studies to determine features of the core design stages. In contrast to products of low or moderate product complexity and depth of product structure, higher product complexity and deepening product structure were associated with an increasingly distinct embodiment design activity. Factors such as the type of project, product complexity and product structure, and the degree of product innovation were suggested to influence a project's duration. Product innovation was found to be a strong determinant of the overall duration of projects, with minor product improvements being associated with shorter time scales than more substantial product innovations. The front-end of contracts (enquiry to contract) were frequently found to be shorter in duration than product developments (product idea to project launch). However, the fact that some contracts were the subject of protracted customer review / negotiation meant that, in the survey, there was no overall difference between the two types of project. Although the period between project launch and completion of the detail design work was suggested to be longer for large scale projects (reflected by product complexity and product innovation), this relationship was offset by the fact that the number of individuals assigned to a project was also found to be higher.

6.5.2 Internal and External Interfaces

6.5.2.1 Staffing and Skills

Staffing and skills issues were hypothesised to be related to the strategic role assigned to design and product development in the business. The staffing and skills provisions of a company should therefore reflect the business strategy and product development strategy along with the company's policy on the internalisation and externalisation of skills.

The overall skills requirements (specialists, generalists, multi-skilling, and reliance on experience) are largely related to the inherent features of a company's products. An essential concern, therefore, is how these should be provided, particularly for generalist and/or specialist skills. Amongst the case studies, when generalist skills were needed these were invariably internalised. Alternatively, specialist skills were externalised in some cases. The large firms which had specialist requirements (A, G & K) were more able and likely to internalise these. The small companies and/or those with a relatively small technical resource, for which there were specialist needs, were more likely to have generally skilled engineers, relying on external specialists (HEIs, consultants, suppliers, etc.) as necessary (B, H & I). Being part of a group also provided access to wider resources in some cases. The factors which were found to be indicative of an emphasis on generalists by the case study establishments included generally lower rates of innovation, establishments being predominantly associated with minor improvement projects, and a low strategic importance for design and product development. The survey also investigated some of these relationships. The nature, and source, of design skills was only measured crudely in the survey, and it was not surprising to find that the particular variables used provided only limited discrimination. Notwithstanding this, however, Table 6.34 demonstrates that a preponderance for generalists and/or specialists was strongly related to establishments' strategic emphasis on product leadership. When product leadership was ranked first (relative to market focus and operational excellence) then generalists were less likely and specialists were more likely. Generalists were always cited when product leadership was second or third ranked.

Product leadership	Generalist skills n=16		Specialist skills n=16	
	Yes	No	Yes	No
1	2	5	6	1
2	4		2	2
3	5		1	4

Table 6.34: Relationship between ranking for product leadership and the provision of generalist and specialist skills in the survey.

Relative to companies' general policies the use of external resources by the case study establishments was then found to be determined by requirements which applied on a project-by-project basis. In Company H's industry it was not economic or practical to perform certain specialist forms of modelling and analysis. Several providers of specialist technical services therefore existed whose services were used as necessary. Also, although classed as minor improvement projects, several specialist technical aspects, which were beyond what was normally encountered, required the use of technical consultants by Company B and Company I. Most marked though was company C whose activities were routinely concerned with design customisations for specific customers. It had a predominance of general mechanical engineering skills. For its new core product it subcontracted the initial concept generation work to a local university, and much of the laboratory test work was also contracted out. External specialists were also used in around half of the survey projects. Most of these related to the general policies on the outsourcing of certain skills in the establishments concerned, and included laboratory testing, rapid prototyping, finite element analysis, and data modelling. However, there were three projects in which the specialist skills were project specific, and included the use of product design consultants and specialist technical design consultants.

6.5.2.2 Concurrency and Integration

Section 5.6.2 in the previous chapter outlined that, for the purposes of this thesis, concurrency has been defined as the degree of simultaneous involvement of the primary internal functions and external organisations over the course of the development process. This was measured as follows for each project. Firstly, the involvement of the marketing & sales, engineering, production and purchasing functions, as well as suppliers and customers was assessed (on a scale of zero to two) for each project stage, using a concurrency evaluation matrix (see Appendix C) and, secondly, these were analysed to calculate measures of overall concurrency (all internal functions, suppliers and customers), core concurrency (marketing, engineering and production), and the involvement of the individual functions, customers and suppliers. These are shown for the case study projects and the survey projects in Table 6.35 and Table 6.36 respectively.

	Primary Projects												Secondary Projects					Best
Company	Ac	Bc	Cp	Dp	Ep	Fp	Gp	Hc	Ic	Jp	Kp	Lc	Bp	Fc	Gc	Ip	Lp	Pract.
Overall concurrency (%)	50	46	43	61	56	-	60	63	48	51	41	46	-	-	45	48	-	86
Core concurrency (%)	50	47	50	80	70	-	77	69	56	69	61	52	-	-	56	60	-	94
Involvement of disciplines (%):																		
Sales & Marketing	42	42	50	83	87	-	83	66	60	83	50	58	-	-	60	70	-	100
Engineering	58	50	83	83	62	88	83	83	70	83	92	58			60	60		92
Production	50	50	25	75	62	83	66	58	40	41	41	41	-	-	41	50	-	92
Purchasing	42	33	16	42	37	-	40	42	20	25	25	25			30	30		75
Suppliers	33	41	33	33	25	50	60	58	30	25	25	33	80	-	10	30	-	83
Customers	75	66	58	50	62	-	33	75	70	50	42	58	-	-	60	50	-	75

Table 6.35: Summary of project concurrency ratings for case studies

Company	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Best Pract.
Overall concurrency (%)	54	54	76	36	69	51	68	33	43	53	68	42	48	44	54	45	49	86
Core concurrency (%)	64	64	83	50	83	58	75	61	50	53	70	50	55	33	50	63	53	94
Involvement of disciplines (%):																		
Sales & Marketing	66	42	83	50	75	33	83	33	42	17	70	37	66	42	50	30	58	100
Engineering	83	83	92	66	92	100	83	83	66	83	60	87	66	58	66	90	75	92
Production	42	66	75	33	83	42	58	66	42	58	80	25	33	0	33	70	25	92
Purchasing	33	25	83	33	42	50	75	0	33	25	40	37	25	33	25	20	25	75
Suppliers	25	83	75	17	58	50	58	17	17	66	80	0	33	42	83	0	17	83
Customers	75	25	50	17	66	33	50	0	58	66	80	62	66	92	66	60	92	75

Table 6.36: Summary of project concurrency ratings for survey

Overall Concurrency and Core Concurrency

The concurrency for the core internal functions (marketing & sales, engineering and production) was found to be equivalent to, or higher than, the overall level of concurrency for all the case study projects (Table 6.35), and in only two survey projects were the core concurrency values less than the overall concurrency values (Table 6.36). This feature of the majority of projects arose from the low involvement on the part of purchasing, key suppliers and customers relative to marketing, engineering and production. The two exceptions in the survey were Company 14 and Company 15. These occurred largely as a consequence of their low core concurrency ratings. At Company 15, for example, the manufacture of its product was subcontracted out, and this resulted in very low inputs by the Production Department and, at Company 14, the moderate core concurrency was contrasted by fairly high involvement of its customer and suppliers.

Analysis of the case studies (both collectively and individually) led to the postulation of relationships between several project variables and the levels of concurrency observed. The project variables which were suggested to be influential included the type of project, competitive criteria (delivery lead-time, time-to-market, and quality and reliability), product and process innovation, and the requirements for integration of the different functions. The type of project organisation, and whether team-working was used were also indicated to be relevant. Many of the organisational issues discussed in Section 6.4 in terms of the integrational characteristics of projects are clearly relevant to degree of concurrency observed and, therefore, it was not surprising that higher levels of concurrency were observed for integration projects, when lead-time pressures were indicated, with higher levels of product innovation, and when team-based forms of project organisation were adopted. The basis for establishing these hypotheses and the findings of the survey in relation to each of the relevant factors are outlined below.

- Product innovation: The levels of concurrency were indicated by the case studies to be higher for major product innovations than minor product innovations. In the survey the mean overall concurrency for minor improvement, major enhancement and new core product innovations were 48.5%, 52.5% and 57.3% respectively, and the corresponding core concurrency ratings were 58.8%, 59.4% and 62.0%. These were further divided by grouping minor improvement with major enhancements to existing products and major platform enhancements with new core product innovations to enable a t-test of the difference in means. The corresponding mean ratings for overall concurrency were 49.3% and 57.5% and the difference between these was statistically significant ($t=-1.38$, $P<0.1$, one tailed test). The corresponding mean ratings for core concurrency were 57.4% and 63.8%, however, the difference between these was not found to be significant ($t=-0.969$, $P>0.1$, one tailed test).

- Process innovation: As the involvement of production was found to be determined by the degree of process innovation associated with a project (see below), it was hypothesised that this would be reflected in the core concurrency and possibly the overall concurrency observed for projects. The case studies suggested that this was so and, in the survey, differences in the mean levels of concurrency between projects involving no process innovation and those involving process innovation (new processes or equipment) were observed for both the overall inputs and core functional inputs. For overall concurrency, process innovation was associated with a higher mean (55.7%) than when there was no process innovation (45.7%), and this was statistically significant (t=1.746, P<0.1, one tailed test). Similarly, for core concurrency, a higher mean (65.8%) was found for process changes than when no process changes were involved (48.5%), and these were again statistically significant (t=3.396, P<0.1, one tailed test). This was in fact significant at a probability of under 1%.

- Project type: The levels of overall concurrency and core concurrency in the case studies were in most cases lower for firms engaged in contracts than those engaged in product developments. The only, but nevertheless notable, exception was Company H. Its contract project achieved the highest overall level of concurrency, mainly due to the fairly high involvement of its customer and key suppliers. In the survey, the mean overall concurrency for contracts (50.0%) was below that for product developments (53.7%), but this was not statistically significant (t=-0.610, P>0.1, one tailed test). This result was not as anticipated because of the confounding influence of customers, their involvement being higher in most of the contracts and lower in most of the product development projects in the survey than in the case studies. Consequently, the core concurrency was found to be a more appropriate measure. The mean core concurrency for contracts (53.4%) was notably lower than for product developments (64.1%), and this was found to be statistically significant (t=-2.33, P<0.1, one tailed test).

- Integration requirements (managerial complexity): Case study projects characterised as being integrational were found to both have higher overall and core concurrency values than projects which focused predominantly on one or two functions. The interview survey projects also supported this finding. The mean overall concurrency for integration projects (60.6%) was higher than non-integration projects (44.6%), and the difference between these was found to be significant (t=3.60, P<0.1, one tailed test). Similarly, the mean core concurrency for integration projects (67.7%) was higher than with non-integration projects (52.5%), and was also a significant result

($t=2.93$, $P<0.1$, one tailed test). These results were in fact significant at the 1% level.

- Lead-time pressures: Higher levels of concurrency were generally observed in the case studies for product development projects when time-to-market was cited as a competitive criterion and for contract projects when delivery lead-time was important (1st or 2nd ranked amongst all criteria). Although, in the survey, the mean values for overall and core concurrency were found to be higher, these were not however significantly different (overall concurrency: $t=0.73$, $P>0.1$, one tailed test; and core concurrency: $t=0.71$, $P>0.1$, one tailed test). This result may reflect the fact that lead-time pressures were based on the general competitive situation in relation to the product and not the particular project studied.

- Project organisation: Because of the association between integrational requirements and project organisation (see Section 6.4.1.3), and the association between integrational requirements and concurrency (see above), then a relationship was also postulated to exist between project organisation and the degree of concurrency. The survey found support for this hypothesis. The mean overall concurrency for team-based project structures (autonomous team, project team, and matrix and multi-project when a team structure was used) were found to be higher (57.4%) than for non team-based project structure (42.5%). This result was also statistically significant ($t=2.99$, $P<0.1$, one tailed test). For the corresponding core concurrency ratings at 61.6% and 56.1% respectively, the difference in means (based on a separate variance estimate due to differences in the two variances) was not found to be significant ($t'=1.05$, $P<0.1$, one tailed test).

- Team working: The hypothesis that team working was associated with higher levels of concurrency arose from the above relationship between project organisation and concurrency. It was not surprising, therefore, that team working (which, in addition to the use of a team-based project structure, includes non team-based approaches where the individuals are constituted as a team either collectively or within their functions) was found to be associated with a higher mean overall concurrency (57.4%) than projects which did not involve team working (42.5%), and that the difference between these was a significant result ($t=2.82$, $P<0.1$, one tailed test). The corresponding mean core concurrency at 61.4% and 54.0% respectively, did not provide a significant result ($t=1.01$, $P>0.1$, one tailed test).

- Technical criteria (quality, reliability, performance and technical): It was hypothesised that a competitive emphasis on issues such as quality, reliability and technical excellence would require more interfunctional and interdisciplinary cooperation, and that this would be reflected in higher levels of concurrency. A comparison of case study projects in establishments where these issues were collectively ranked 1st relative to other primary criteria (see Table 4.4) against those where a lower ranking was assigned did not suggest this to be a plausible relationship. However, the survey did find some support for this, with significantly different mean overall and core concurrency ratings being observed (overall concurrency: $t=1.43$, $P<0.1$, one tailed test; and core concurrency: $t=1.84$, $P<0.1$, one tailed test) between projects in establishments where technical issues were ranked highly (see Table 4.7).

The ratings for overall concurrency and core concurrency were a result of the involvement of the individual functions, key suppliers and customers. These were also found to be conditioned by a number of factors and are discussed below. In order to enable the concurrency matrix to be used with some ease in the survey a degree of sensitivity had to be forfeited. This did not appear to have a negative influence on the relationships identified in relation to the levels of overall and core concurrency. However, although a number of the relationships which were postulated in connection with the individual functions, customers and suppliers were observed to be in the anticipated direction, this may have been a factor in significant results not being found in some instances.

Engineering

The average involvement of engineering functions during projects in the case studies and the survey was very high and, relative to the peripheral functions, customers and suppliers, was associated with low variability. Despite the low variation between projects for the involvement of engineering, the type of project and the degree of product innovation involved were postulated to be influential factors.

The involvement of engineering during the case study projects was usually found to be higher for product development projects than contract projects. This occurred because although engineering tended to have a substantial involvement during the main stages for both types of project, and it tended to have some involvement during the product proposal and market launch stages of product developments, it was frequently not involved during one or more of the pre-enquiry, negotiation (if applicable), and manufacturing and installation stages of contracts. There were only two product development projects (Company E and Company I) where the engineering involvement was lower than the highest level of involvement for the contract projects. Both of these were distinctly marketing led projects in which engineering had only very limited inputs early in the development process. However, this was identified as a less good feature of the project at Company E, and revisions to its procedures following the project studied required a more substantial engineering input prior to the commencement of a project. The relationship between project type and the degree of involvement of the engineering functions was also supported by the survey. The mean level of engineering involvement for product developments (83.1%) was higher than for contracts (71.7%) and this was a significant result ($t=2.00$, $P<0.1$, one tailed test).

It was also postulated that product innovation would have some influence, with minor improvement projects giving rise to less involvement of engineering during projects (e.g. the traditional over-the-wall approach to projects). In the case studies all contracts involved minor product improvements and all product developments involved major product innovations and, therefore, although a relationship was indicated this may have been due to the sole influence of project type (see above), or a compounding of the influences of project type and product innovation. There was also an element of bias between project characteristics in the survey (minor improvements tended to be associated with contract projects and major platform and new core product innovation projects were a feature of the product development projects). Consequently, although a marginally significant difference in the means was observed ($t=1.51$, $P<0.1$, one tailed test) when improvement and major enhancement to existing product projects were compared with major platform and new core product projects, the concern for bias cast doubt on the result.

Production

Amongst the case studies, the extent of production involvement over the course of a project related well to the amount of process innovation involved. In most cases involving innovation in production processes or equipment the concurrency exceeded that when there was no such innovation. Two exceptions were Company C where manufacturing of the product was subcontracted, and Company J where there was an element of less good practice and a greater degree of concurrency should have been expected. Also, at Company H, where there was no production process change, the very high product complexity and deep product structure created significant design for assembly implications and, therefore, a high level of involvement. The survey found strong support for this relationship. The mean involvement of production when there were process changes (60.4%) was notably higher than when there were no process changes (27.7%), and this was also a highly significant result ($t=3.83$, $P<0.1$, one tailed test). Indeed, this was significant at the 1% level.

The case studies also suggested that product innovation would influence Production's involvement. Product and process innovation frequently went hand in hand with each other, but even when there was little or no process change per se, major product innovation gave rise to design for production considerations in some instances. At

Company D and Company G, for example, where there were only minor process changes, consideration of design for manufacture and assembly, process testing, quality procedures, and so on, were required by their product development projects. The survey did not however find support for this hypothesis.

As the case study contracts were one-off projects, they invariably related to the use of existing production processes, and this was reflected in a relatively low production involvement. The production input was most substantial at Company H. This was a consequence of the very deep product structure (i.e. modularity). It necessitated fairly significant production engineering considerations to be incorporated with respect to the different product breakdown and assembly options which arose from the customised design arrangement. Product development projects were more likely to involve substantial process innovation and, therefore, production involvement was generally lower during contract projects than product development projects. In the survey production involvement was also found to be lower for contracts (38.0%) than product developments (55.2%). As some contracts involved production process innovation and some product developments did not, it was not surprising that, whilst the result was significant ($t=-1.62$, $P<0.1$, one tailed test), it did not yield a relationship as strong as that for production process innovation (see above).

It had been anticipated that a strategic emphasis on manufacturing issues would have been associated with increased production involvement. However, manufacturing excellence was not identified as a dominant strategic factor in any of the case studies, and any strategic impacts could not therefore be adduced. The survey, however, did not find such a relationship. In fact, if anything, this was opposite to that anticipated.

Marketing and Sales

Marketing was found generally to have less involvement on contract projects than product development projects in the case studies. There were two product development projects (Company C and Company K) whose marketing involvement was less than the highest level of involvement observed amongst the contract projects.

The notable feature of these two projects was that they were distinctly engineering led. However, the survey found no difference between the two types of project (mean involvement for contracts was 50.4% and the mean involvement for product developments was 52.4%). This result can be contrasted with the finding that six of the ten product development projects in the survey had formal marketing representation compared to only one of the seven contract projects. The apparent contradiction may reflect the fact that with the contract projects it was common for most of the marketing activity to occur before the award of the contract, whereas marketing involvement was often distributed throughout the process for product development projects.

It was postulated that when lead-time reduction was important this would impact most significantly on the peripheral functional activities, so that the major time compression would occur through the increased concurrency of marketing and production activities with respect to the engineering activities. Indeed, two of the case study companies stated that compression of the peripheral activities were an important means to achieve lead-time reduction. Marketing involvement was indicated by the case study projects to be higher when there was an emphasis on lead-time. The product development project at Company E was noteworthy, however, having the highest marketing involvement of all the projects studied despite their being no lead-time pressures. This appeared to be a reflection of the fact that the product development process was marketing led and that the project had a distinct integrational characteristic. The survey did not support the hypothesised relationship. Although the mean involvement when there were lead-time pressures in the market (time-to-market for product development or delivery lead-time 1st or 2nd ranked amongst all competitive criteria for contracts) was higher (56.5%) than when lead-time was a lesser consideration (47.2%), this was not a significant difference ($t=0.97$, $P>0.1$, one tailed test). Again this result may be a consequence of general market pressures not being replicated at the project level.

Product innovation, marketing innovation, and a strategic emphasis on market focus were also expected to be relevant variables. In the case studies and, also, in the survey, marketing involvement was generally lower for minor improvement projects than for major innovation projects. However, a striking feature of all the new core product projects studied (Company C in the case studies and Companies 6, 7 & 10 in the survey) was the fairly moderate involvement of marketing and sales. Market innovation was a feature of only one of the case study projects, which reflects the fact that most product development and contract projects are concerned with existing markets and, because of this, it was not possible to consider its influence on the degree of marketing involvement. The survey projects, however, were selected to include several projects associated with new niche markets or new general markets. No difference in the mean marketing involvement during projects associated with existing markets and those with some market change was found. As market focus was highly ranked as a strategic factor (relative to product leadership and operational excellence) for all the case study establishments its influence could not be assessed. Moreover, no relationship was found in the interview survey.

Customer

The degree of customer involvement found amongst the case study projects was found to be conditioned mainly by the type of project. For most of the contract projects this was higher or equivalent to the product development projects. Moreover, some of the contracts were evaluated as equivalent to or higher than the best practice model (see Table 6.35). This was a reflection of the fact that the contract projects were driven by specific customer requirements and the customer was often involved throughout the process, including discussions prior to and during tender development, and during negotiations, design review and approval, performance tests, and so on. In contrast the product developments studied were not collaborative to any great extent. The customer involvement was therefore mainly limited to front-end marketing, field testing, and launch activities. In the survey the difference in mean customer involvement between contracts (74.0%) and product developments (44.0%) was significant ($t=2.926$, $P<0.1$, one tailed test). In fact this was significant at the 1% level. The minor improvement of Company 8's product was notable for there being no customer involvement at any stage in the project. This was an internally driven project involving a fairly minor change which was transparent to the market and which did not require field testing. Even if this project were to be considered as an outlier, the result was still significant at the 2.5% level.

The degree of market innovation was also postulated to have an influence on the degree of marketing involvement. As discussed above under Marketing and Sales, market innovation was a feature of only one of the case study projects and, because of this, it was not possible to consider its influence on the degree of marketing involvement. A difference in the mean marketing involvement was observed in the survey. However, although this was observed to be lower when projects were concerned with existing markets (52.1%) than when they were concerned with new niche or new general markets (66.4%), the finding was not a significant one ($t=-1.02$, $P>0.1$, one tailed test). Whilst the relationship was in the anticipated direction, its weakness may reflect the confounding influence of other factors (e.g. project type) and, as discussed earlier in this section, the moderate degree of sensitivity possible when the concurrency matrix was used in the survey is a possible factor.

Key Suppliers

The highest levels of supplier integration in the case studies were below that implied by best practice (see Table 6.35). Indeed, although opportunities existed for some firms to enhance the degree of supplier integration, managing the balance between such opportunities and risk exposure were key strategic issues in many cases. The generally moderate levels of supplier integration appeared to reflect the position of most of the case study firms towards multi-sourcing on the supplier rationalisation dimension. A low or moderate internal span of process (and hence a greater proportion of supply items) was also suggested to be partially related to higher supplier involvement. There were however some significant exceptions (H, D & B), principally because this factor did not capture the degree of significance of the key supply items.

It was postulated that the involvement of suppliers was conditional upon several supplier dimension factors including the internal span of process, supplier rationalisation, and the degree of control over suppliers, as well as product complexity factors and product innovation. Notwithstanding the foregoing, the inter-relationships between variables made it difficult to determine the extent of their influence other than on a company-by-company basis. These variables tended to generate inconsistencies, possibly because these were mostly general, rather than project specific. The critical issue was whether there was a supplier collaboration requirement. An ordinal (0-3) indicator for this was devised based on surrogate variables for the supplier and product dimension factors. These were, whether or not there were key supply items, was substantial design content involved, and was the design undertaken by the supplier? Although this was a simple ordinal measure the indicator, Table 6.37 shows that it did provide a good correlation to the degree of supplier involvement during the project. When there were no key supply items or when there was no design content, then a low supplier involvement was involved. When there was a substantial design element and this was undertaken by the supplier this was associated with a higher level of supplier involvement. Table 6.37 also indicates that when there was a substantial design content involved and this was not undertaken by the supplier (supplier collaboration requirement index=2) there was a higher supplier involvement. However, the case study projects did include three such projects with a degree of supplier involvement equivalent to the median and, therefore, their location within the columns of the table is affected by the split about the median. A strong relationship was also found in the interview survey. Table 6.37 demonstrates a clear dichotomy between projects which involved suppliers in the design of key supply items (index=3) and when there were no such inputs. Moreover, the average values for these were found to be 62.6% and 13.28% respectively. This was a highly significant result ($t=6.43$, $P<0.1$, one tailed test).

It was also observed in the case studies that the involvement of suppliers was generally lower for contracts than product developments. This may have been a reflection of the constraints to collaboration with suppliers faced by many ETO / CMTO firms. Although the mean level of involvement in contracts was also found to be lower than product developments in the survey both were associated with high variances, and the result was not significant (t=-0.64, P>0.1, one tailed test).

Supplier index**	Cases n=14		Survey n=17	
	Supplier involvement		Supplier involvement	
	<median*	>=median*	<median*	>=median*
0	2		4	
1	1		1	
2	1	4	2	
3	1	5	1	9
* Cases median = 33%, survey median = 42%.				
** Key supply item = 1, design content = 2, design by supplier = 3				

Table 6.37: Supplier involvement according to key supplier collaboration index

Purchasing

The case studies suggested that the involvement of purchasing and how this was distributed amongst the process stages mirrored that of the supplier activities. When there were key supply items associated with significant design content then a greater purchasing involvement tended to occur than when there were no key supply items or they were of less significance. When there were no key supply items or they were less significant, the role of purchasing would usually be limited to administering purchase requisitions during the detail design stages. The mean involvement of purchasing in the survey projects was also found to be higher for key supply items involving some design content (42.3%) than when there was no design content or no key supply items (25.8%). This was also a statistically significant result (t=1.59, P<0.1, one tailed test).

In Section 6.4.2.4 it was found that the formal representation of purchasing on projects was related to the nature and extent of the key supply items (supplier index). Based on this finding it was also hypothesised that the involvement of purchasing would be related to whether or not purchasing was represented formally on projects. The case studies did not suggest that this was the case. However, the survey did support the hypothesis. The mean involvement of purchasing when not formally represented (27.5%) was lower than when formally represented (44.5%) and this difference was significant ($t=-1.92$, $P<0.1$, one tailed test).

Summary: Staffing and skills issues were found to be influenced by establishments' strategic or general policies and, also, the requirements of individual projects. The case studies indicated that factors such as small establishment size, lower rates of innovation in the product, establishments being predominantly associated with minor improvement projects, and a low strategic importance for design and product development were associated with an emphasis on general skills. The survey also demonstrated that a preponderance of either generalists or specialists was strongly related to the extent that establishments' placed a strategic emphasis on product leadership. When product leadership was ranked first (relative to market focus and operational excellence) then generalists were less likely and specialists were more likely. Relative to establishments' general policies the use of external resources was found to be determined by the requirements which applied on a project-by-project basis.

Relative to the high levels of concurrency implied by the general assumptions of best practice, several characteristics of the individual companies and their specific projects limited the involvement of the internal functions, customers and suppliers. Consequently, the overall levels of concurrency realised were usually below best practice. The degree of concurrency was inter-related to the organisational issues of projects and, hence, the overall levels of concurrency were generally highest for integration projects, with higher levels of product innovation and process innovation, and when team-based approaches were adopted. Higher levels of overall concurrency were also observed when technical issues were a primary competitive criterion and when lead-time pressures were important, however, the relationship with lead-time pressures was not found to be a significant result. Similar relationships were observed for levels of core concurrency, but those relating to product innovation and project organisation were not significant. Lower levels of core concurrency were also found for contracts than product developments. The individual functions, key suppliers and customers were also found to be affected by several variables. Whilst the involvement of engineering was found to be fairly consistent, this was higher on average for product development projects than contract projects. Production involvement varied according to the level of process innovation and was higher for product development projects. The involvement of marketing and sales was less for contracts than product developments (but not a significant result). In contrast, customer involvement was found to be more substantial for contracts than product developments. The case studies suggested that the degree of collaboration with suppliers was broadly influenced by the general characteristics and strategic policies associated with the supplier environment. At the project level, however, the extent of supplier involvement was determined by the characteristics and nature of the key supply items (i.e. their existence, the design content, and whether the company and/or supplier are responsible for the design work). The involvement of purchasing was also found to be influenced by the nature of the key supply items, and it was not surprising that this often replicated the degree of supplier involvement. Purchasing's involvement was also higher when purchasing was formally represented on projects. A number of other relationships were hypothesised in relation to the involvement of the internal functions, suppliers and customers and, although these were found to be in the anticipated direction, they were not found to be statistically significant.

6.6 Design Methods, Modelling and Analysis

6.6.1 Marketing Techniques

The case studies demonstrated that the distinction between product development and contract projects had a pronounced influence on the use of marketing techniques. There were a number of common methods and techniques associated with the analysis of competitors, suppliers, and customer requirements. These included:

- Monitoring trade literature, press, etc.
- Attending conferences and exhibitions.
- Assessment of field problems.
- Sales presentations.
- Eliciting customer feedback.
- Requesting information on lost orders.
- Maintaining market requirements and intelligence databases.
- Legislative and political monitoring.
- Identifying preliminary project scope / market brief.

Forms of personal contact were found to be important to both product development and contract projects, but particularly for contracts with regard to intelligence gathering and influencing customers. Indeed, as Section 5.4.1 highlighted, less systematic and less structured mechanisms for collating and analysing market information were inclined to be used by companies who were predominantly engaged in contract projects. In addition, companies engaged in product development projects were more inclined to make substantial use of a number of additional methods. These included:

- More extensive market surveys.
- Competitor analysis and product analysis - trade literature, promotional material, etc., and reverse engineering.
- Market analysis - market statistical data, market studies.
- Technology Monitoring - patent searching.

These issues were not investigated by the interview survey.

6.6.2 Modelling and Analysis Tools

6.6.2.1 General Application

A number of design tools for modelling and analysis are available. These include empirical methods, rig testing, physical models, CAE modelling and analysis tools, and rapid prototyping. The use of these in projects was measured by means of a simple tally score. Their application during the case study projects was indicated to be higher when there were lead-time pressures, for more complex and deeply structured products, and higher design capability was required by products. Product innovation and project type were also suggested to be influential factors. It was inferred that these tools were less common amongst minor improvement projects and, by association, contract projects. An emphasis on reliability and / or technical performance factors was also hypothesised as a possible reason for using these tools. However, in general, the significance of reliability and technical performance did not correlate particularly well with their use. More commonly it was when in association with other factors such as product complexity and lead-time pressures that these factors were relevant.

The design capability required by establishments' products was not addressed by the interview survey. The distribution of some of the data groups relating to the other relationships were indicated to be non normal and, therefore, the significance of these was examined by using the non parametric Wilcoxon Rank Sum Test (an alternative form of this which is frequently referred to in statistical texts is the Mann-Whitney U Test). The findings of the survey in relation to these are outlined below:

- Technical emphasis: The use of these tools was found to be higher when technical criteria (quality, reliability, functional performance, and technical) were collectively ranked 1st (median = 4) than when ranked lower (median = 1.5). This was found to be just significant at the 5% level, however, with the presence of several tied scores, it would be inappropriate to postulate such a level of significance ($U=16$ & 15, $P<0.1$, one tailed test).

- Product innovation: Minor improvement and major enhancement to existing product projects (median = 2) were found to involve a lower use of these tools than major enhancements to develop a new platform and new core product projects (median = 4). This result was also found to be just significant at the 5% level (U=15 & 51, P<0.1, one tailed test).

- Project type: A significant difference was found in the number modelling and analysis tools used (U=17.5 & 52.5, P<0.1, one tailed test), being less frequent amongst contracts (median = 1.5) than product developments (median = 4). This result may partly reflect the association between project type and product innovation.

- Product complexity: No relationship was found for product complexity or product structure.

- Lead-time: No significant difference was found to occur because of lead-time pressures (U=30 & 42, P>0.1, one tailed test). Although this may have reflected the fact that time-to-market and delivery lead-time were measured with regard to projects in general, this result was not unexpected as it was postulated that lead-time pressures would be more likely to be related to the use of these tools for the front-end activities (see Section 6.5.2.2 below).

6.6.2.2 Front-end Application

The modelling and analysis tools defined above (i.e. empirical methods, rig testing, physical models, CAE modelling and analysis tools, and rapid prototyping) are often cited in the literature on best practice as being associated with the front-end of the design process. Their application during the case study projects prior to 'proof of concept' was found to occur only slightly less frequently than their more general use on projects. Therefore, their use was higher when there were lead-time pressures, for more complex and deeply structured products, when higher design capability was required by products, for major product innovation and product development projects. Again an emphasis on reliability, technical performance, and so on, was postulated to be relevant. The logic in an early application of these tools is apparent if one considers, for example, that higher product complexity (which could lead to higher costs and / or constraints on prototyping), a technical emphasis and lead-time pressures emphasise the need to be able to adequately predict product performance early in the design process in order to reduce down-stream iterations. Such factors were stated by Company G and Company K as being reasons for applying these modelling and analysis tools at an early stage.

The design capability required by establishments' products was not addressed by the interview survey. The findings of the survey in relation to the other factors are outlined below:

- Technical emphasis: Although the use of the tools was indicated to be higher when technical criteria (quality, reliability, performance, and technical) were collectively ranked 1st (median = 2.5) in comparison to a lower ranking (median = 1), the difference between the two ranking groups was not significant (U=28.5 & 37.5, P>0.1, one tailed test).

- Product innovation: Although minor improvement and major enhancement to existing product projects (median = 1) were indicated to involve a lower use of these tools on average than major platform and new core product projects (median = 3), the difference between the two was not quite significant (U=22 & 44, P>0.1, one tailed test).

- Project type: The median number of techniques for contract projects (median = 1) was less than that found for product development projects (median = 2). However, the difference in the use of these design tools between contracts and product developments was not significant (U=27 & 43, P>0.1, one tailed test).

- Product complexity: Most low complexity products were not associated with the use of front-end design tools (median=0) whereas most medium and high complexity products involved one or more tools (median = 2). The difference between the use of these tools for low complexity products and medium and high complexity products was also significant (U=15 and 45, P<0.1, one tailed test). This result was nearly significant at the 5% level, however, with the presence of several tied scores, it would be inappropriate to postulate such a level of significance.

- Lead-time: No significant difference was found to occur as a consequence of lead-time pressures being cited (U=35.5 & 36.5, P>0.1, one tailed test). This may be a reflection of lead-time pressures being defined as general rather than project specific factors in the survey.

Although most of the hypothesised relationships were not supported by the survey, it is possible that the findings were adversely affected by some less good practices. Indeed, it is also worth recalling from the corresponding section of the previous chapter (Section 5.7.1) that the achievable ratings assigned for the front-end use of design and modelling tools indicated fairly strong relationships with design capability, product complexity, and lead-time pressures.

6.6.3 CAE Tools for Design and Development

The general use of CAE design and development tools, which, for example, includes tools for mechanical and electrical design, 3D modelling and analysis, software development tools, electronic PCB design, and so on, was dealt with in Chapter 5 (Section 5.7.2). It is worth noting that, although there were some differences between the actual and achievable scores, and that the strongest thematic relationships existed with the achievable ratings, the actual usage of these tools was nevertheless strongly correlated to design capability and lead-time pressures. Notably, the degree of product innovation was not found to be particularly influential, suggesting that the use of these tools was primarily related to the inherent characteristics of products, including design capability and product complexity factors. The use of this broad group of tools was not investigated in the survey. The survey did however focus on a subset of these (and also those for modelling and analysis discussed above), namely the CAE modelling and analysis tools. The findings were found to replicate the use of the broader group of modelling and analysis tools (Section 4.5.2.1) in that no relationship was found between the use of these tools and product complexity or the presence of lead-time pressures. However, as demonstrated by Table 6.38, a fairly strong relationship was found with product innovation. CAE modelling and analysis tools were infrequently used for minor improvement projects, but were invariably used for the more substantial product innovations.

	CAE modelling & analysis n=17	
Product innovation:	Yes	No
Minor improvement	1	4
Major (existing)	3	3
Major (platform)	2	1
New core product	3	

Table 6.38: Relationship between product innovation and application of CAE modelling and analysis tools in the survey

6.6.4 Mutually Supportable Techniques

The relationships between factors such as product innovation, project type and the integrational requirements of projects and the application of techniques such as value engineering, quality function deployment, failure mode effect analysis, brainstorming, robust design and so on, were discussed in Section 5.7.3 of the previous chapter in relation to achievable practice for the case study establishments. Greater managerial complexity (integrational characteristic) in projects, major product changes and product development projects were associated with these techniques being used more frequently. Although the actual use of these techniques was fairly low in the case studies, a comparison of these projects also suggested these relationships. Most integrational projects involved some use of these techniques and, of the non integrational projects, only at Company C were any such techniques used. At Company C brainstorming was used in relation to its new core product project. This finding was also supported by the survey. A significant difference between integrational (median = 3.5) and non integrational (median = 2) projects was found using the Wilcoxon Ranked Sum Test at the 5% level ($U=9.5$ & 62.5, $P<0.1$, one tailed test). With regard to product innovation, it was found that all but one of the minor improvement projects in the case studies used none of these techniques and that all the major enhancement and new core product projects used at least one technique. The survey also found that the techniques were less frequently applied for minor improvement projects (median = 1) than for more substantial product changes (median = 2.5) and that the difference in the incidence of application was significant at the 5% level ($U=8$ & 23, $P<0.1$, one tailed test). These techniques were also found to be more frequently applied on product development projects than contract projects. In the survey, although a difference was found at just less than the 5% significance level, the number of tied scores suggests that it would be inappropriate to claim such a level of significance. This result was considered to be a consequence of the association between the type of project and product innovation rather than a direct consequence of the type of project.

Some additional observations on the use of the value engineering technique are worth stating since price was an important competitive criterion which created cost reduction pressures for most of the companies. Although used in only four of the projects studied, it was claimed to have more general use in the majority of companies. This was, as would be anticipated, most common for product developments and post-development improvements. However, value engineering was used on more than half of the survey projects and, this was a distinct feature of the product development projects, being used in seven of these in contrast to only two contract projects.

6.6.5 Design Methods

The use of several generic design methods (functional decomposition, concept generation matrices, brainstorming, design evaluation matrices, and patent searching) are frequently recommended in the engineering design literature (see Chapter 2) for the generation and evaluation of potential design solutions. Amongst the case study projects, their application was found to be strongly determined by the degree of product innovation. On minor improvement projects, with the exception of Company L, none of these methods were used, whereas on the more innovative projects, with the exception of Company E, use was made of one or more of these methods. The survey also found strong support for this finding. By using a simple tally score of their application, it was found that the number of methods used was higher for major platform and new core product projects (median = 3) than for minor improvement and major enhancement to existing products (median = 1). Moreover, the difference in the number of methods used was also significant at the 5% level ($U=9.5$ & 56.5, $P>0.1$, one tailed test).

Design rules, codes and standards are often concerned with existing design concepts. They were frequently used in the case study projects, being applied to both minor and major product innovations although, as might be expected from their association with existing concepts, they were most frequently used on minor product innovation projects. However, this difference was not borne out by the survey. Design rules, codes and standards were used in all but two projects and, therefore, their use was inferred to be independent of the degree of product innovation. This may be because such rules and standards often only apply to some aspect of a product's design and may apply even though, at the overall product level, major product changes are involved. Also, because design rules and standards sometimes only state general requirements and do not place substantial constraints on the choices available to the designer, then in these circumstances their use may be related to all types of product change.

Design methods are closely tied to the form of design strategy adopted on projects. The use of design methods will be discussed further in Section 6.7 in relation to design strategy.

6.6.6 Prototyping and Testing

The case study projects suggested that the production of a product prototype and any subsequent internal testing was very much dependent on the level of product innovation and project type. In contrast to all contracts / minor improvement projects where no prototype was manufactured, all product developments / major change projects produced and internally tested a product prototype. Internal testing of the manufactured product was however undertaken for most contracts, either due to contractual or regulatory requirements. The interview survey also found this to be so. As Table 6.39 shows, the high proportion of product development projects which involved the production of a prototype, contrasts with the low proportion produced for contract projects. Although the survey also found a relationship between product innovation and the production of a prototype this was not a strong relationship. Equal proportions of minor improvement and major enhancement to existing product projects produced a prototype as those that did not, whilst most major platform and new core product projects did. This suggests that project type is the overriding factor which determines whether prototyping occurs. Product complexity and depth of product structure were also hypothesised to influence the cost of prototyping and, therefore, the likelihood of one being produced. Although some companies cited these as a relevant factors no general relationship was found amongst the case studies and, although a fairly strong relationship was found in the interview survey, a closer examination suggested that project type may well have been a related consideration. At company 10, for example, in order to develop its new core product within the scope of its resources, the high complexity and deep product structure demanded that it be undertaken on the back of a contract.

	Product prototyping n=17	
Project type	Yes	No
Product development	8	2
Contract	2	5

Table 6.39: Production of product prototype according to project type in the survey

Field trials (product development) or site testing (contracts) were undertaken during most of the case study and interview survey projects studied. Site testing amongst the case study contract projects was usually related to contractual or regulatory requirements. There was some evidence to suggest that for product developments, field tests were dependent on the level of product innovation. At Company E, for example, field trials were particularly important for major product changes as it was not possible to adequately simulate the operating environment during internal testing. It was stated, however, that for minor changes field testing would not normally be required. Notable, also, was the fact that in the survey, the three product development projects which did not involve field trials were minor improvement or major enhancement to existing product projects. All the major platform and new core product projects involved field trials.

Data concerning testing durations were not extensively gathered during the case studies and, therefore, it was not possible to draw any general conclusions. However, individual cases allowed some inferences to be made. For both internal and external testing the evidence suggested that their durations were a consequence of project type, the degree of product innovation, product complexity and product structure, the importance of quality and reliability, and the extent to which regulatory requirements, when applicable, were onerous. For example, quality and reliability (with regard to a demanding operating profile) were most significant criteria to Company K. Coupled with the very high complexity of the product it was necessary to test both internally and externally for over two years on development projects. Company D had to allow three months during internal prototype testing for regulatory certification tests, and technical performance and reliability factors also necessitated three months field testing. In contrast, the kinds of factors mentioned above were of relatively minor significance to Company L, so that only several days testing were required on contracts. With regard to the duration of internal testing for the prototype and/or product, the survey supported most of these hypotheses. The total duration of internal testing was longer on average for product developments (mean = 1.83 months) than contracts (mean = 0.7 months), for medium and high complexity products (mean = 0.62 months) than low complexity products (mean = 1.75 months), and for major platform and new core product projects (mean = 2.35 months) than minor improvement and major enhancement to existing product projects (mean = 0.69 months). Moreover the difference in the means was significant (Project type: $t=1.52$; product complexity: $t'=1.97$; product innovation: $t=2.95$; $P<0.1$, one tailed test) and, in particular, the difference for product innovation was significant at the 1% level. However, the difference between instances where technical issues (quality, reliability, etc.) were collectively ranked first in comparison with a lower ranking was not found by a Wilcoxon Rank Sum Test (for non normal data) to be significantly different ($U=8.5$ & 18.5, $P>0.1$, one tailed test). With regard to external testing a significant result was only found between the duration of field trials on product development projects and site testing on contracts ($U=6$ & 24, $P<0.1$, one tailed test). The differences for product complexity ($U=12.5$ & 22, $P>0.1$, one tailed test) and technical emphasis ($U=6.5$ & 17.5, $P>0.1$, one tailed test) were not significant. A satisfactory test on the influence of product innovation could not be made because a bias was introduced through the loss of projects which did not involve external testing. As a consequence of this all the less substantial product changes related to contracts and all the substantial changes related to product developments.

Summary: With regard to the application of design methods, and modelling and analysis tools, a number of observations may be made. Firstly, the case study projects found that establishments associated with contract-based markets tended to use less systematic and less structured mechanisms for collating and analysing market information than those engaged in product developments. Forms of personal contact were particularly important with regard to intelligence gathering and influencing customers. Secondly, a higher incidence of use of several design modelling and analysis tools (empirical methods, rig testing, physical models, CAE modelling and analysis, and rapid prototyping) during the development process was suggested by the case studies for the presence lead-time pressures, more complex and deeply structured products, product development projects, more substantial product changes, an emphasis on technical issues, and a higher design capability requirement. The survey found significant support for the relationship between the application of these tools and technical emphasis, product innovation and project type, but not for lead-time and product complexity factors. The use of these tools during the initial design stages of the case study projects also were frequently associated with lead-time pressures, high product complexity and deep product structure, design capability and, in association with these, an emphasis on reliability and technical performance. These were reflected by the need to be able to adequately predict product performance early in the design process. Although similar relationships were observed in the survey, a significant result was only found for the influence of product complexity. It was suggested that the weakness of the other relationships may be a feature of less good practice on the part of some establishments. Thirdly, the use of computer-based tools for design and development was suggested by the case studies to be higher in the presence of lead-time pressures and where there was a higher design capability requirement. The survey also found that CAE modelling and analysis tools were infrequently used for minor improvement projects, but were invariably used for more substantial product innovations. Fourthly, in the case studies and, in the survey, techniques to assist cross-functional activities (such as value engineering, quality function deployment, failure mode effect analysis, robust design, and brainstorming) were significantly more likely to be applied on projects when there was a greater requirement for integration of the functions and disciplines, with product development projects rather than contracts, and for more substantial product innovations. Fifthly, the application of several generic design techniques (functional decomposition, concept generation matrices, brainstorming, design evaluation matrices, and patent searching) were found to be strongly related to higher levels of product innovation. Finally, the proportion of projects which involved the production and internal testing of a product prototype was found to be primarily determined by project type (being more common to product developments) and to a lesser extent product innovation and product complexity factors. Individual projects in both the case studies and the survey, indicated that, for major product developments it would usually be necessary to undertake field trials, whereas for minor product changes this may not be so. However, the case studies indicated that the influence of regulatory requirements, or contractual requirements, were important factors in determining both the internal and external testing requirements. The duration of internal testing on projects for both the case study and survey projects was higher for product developments than for contracts, for more substantial product innovations and for more complex products. An emphasis on quality, reliability and technical issues was inferred from the case studies to be associated with longer testing, however, this was not borne out by the survey. With regard to external testing, field testing on product development projects was found to be significantly longer on average than site testing on contract projects.

6.7 Design Strategy

A design strategy represents the particular design approach adopted for a project or part of a project and, may be characterised by the sequence in which the design stages, activities, methods and techniques are planned or executed. Chapter 2 discussed how previous descriptive research studies have identified a dichotomy between the type of design strategy proposed by the engineering design models and how design is usually performed in industry. The engineering design models, in attempting to promote improved ways of working by design practitioners, have mostly proposed an approach which concentrates initially on analysis of the problem (i.e. problem-focused), followed by a systematic concretisation process during which a number of possible solutions are generated and progressively evaluated and refined in order to converge on a best solution. However, the descriptive research studies mentioned above have identified that, in practice, designers usually adopt an alternative approach which emphasises analysis of the product concept, and makes use of solution conjectures to generate a solution concept and to gain further insights and an improved definition of the problem, and promotes the notion of the solution and problem specification being developed simultaneously (i.e. product-focused). This process is characteristically heuristic in nature, drawing on previous experience, general guidelines and rules of thumb. This is then followed by further analysis and evaluation steps to refine and develop the proposed solution.

The case studies and the survey demonstrated that aspects of both design approaches were applied. Aspects of the engineering design models' approach were used under certain conditions and, although it could be argued that there were specific instances where these activities and methods associated with this approach could have been more widely applied, a number of factors and constraints were found to legitimise the product-focused approach.

The form of design strategy adopted during projects was characterised on the basis of several indicators. The first of these concerned the initial problem definition stages. This established whether or not existing products or design concepts were used as conjecture mechanisms to understand and refine the definition of design requirements. It was most significant that in the case study projects only one project was identified where existing designs and concepts were not used. Significantly, the exception mentioned was Company C's development of a new core product. The use of existing concepts was cited for all projects in the survey. Design practice in industry is clearly in sharp contrast with the abstract definition of requirements implied by most of the engineering design models. Whilst the problem-focused approach recommended by the engineering design models has theoretical attractions, its application insofar as the problem definition stages appears to be of limited relevance to the context in which most design projects occur. Many projects do not involve substantial design changes and they invariably relate to the development of existing products. Companies have vested interests in maintaining and developing their core technologies. Managing risks is also a critical need for businesses and, therefore, constraining the scope of product change and making use of existing technologies and solutions are frequently necessary requirements. However, whilst in overall terms this may be the overriding approach, concerns as fundamental as those of the problem-focused approach are likely to be relevant, and appropriate, to some aspects of the problem definition process.

The second aspect of design strategy to be considered concerned the approach taken and the methods used during the main design stages. The design strategy adopted on projects was classified as either Type A or Type B according to the following descriptions:

> Type A: An initial solution was generated, developed and evaluated. If this proved inadequate in some way it was either modified or another solution was sought.
>
> Type B: Several solution ideas were generated and, through progressive development, analysis and evaluation, a preferred solution was selected (i.e. the approach recommended by most of the engineering design models).

A distinction was also made between the design strategy adopted (i.e. Type A or Type B) at the overall product level and at the sub-system and component levels. It was therefore possible to characterise projects as being wholly Type A, using a combination of Type A and Type B, and being wholly Type B.

A strong relationship was established between product innovation and the type of strategy adopted. As shown in Table 6.40, major platform and new core product projects in the case studies were likely to be based on a divergent (Type B) strategy, whereas minor improvements were inclined to be focused on developing an individual concept according to the Type A strategy. No major innovation projects involved a wholly Type A strategy and no minor change projects involved a wholly Type B strategy. Table 6.40 also illustrates that a similar, albeit less distinctive, result was found in the survey.

Product innovation	Cases (n=10) Design strategy			Survey (n=17) Design strategy		
	A	A/B	B	A	A/B	B
Minor improvement	3	2		3	1	1
Major (existing)		1		4	1	1
Major (platform)		3		1	1	1
New core product			1		1	2

Table 6.40: Design strategy adopted on projects according to product innovation.

The Type A and Type B approaches were suggested by the case studies to be associated with contract projects and product development projects respectively (Table 6.41). Moderate support for this relationship was also provided by the interview survey (Table 6.41). However, it appears that this relationship arises from an association with product innovation. The fact that no contract project in either the case studies or the survey used a Type B strategy reflected the general tendency for contracts to involve modifications to existing concepts (i.e. CMTO). Moreover, the apparent difference in the strength of this relationship may be explained by the fact that in the case studies the contracts were all minor improvement projects and the product developments were major enhancement of new core product projects, whereas in the survey this effect was reduced by the pre-selection of projects.

Project Type	Cases (n=10) Design strategy			Survey (n=17) Design strategy		
	A	A/B	B	A	A/B	B
Product development		4	1	3	2	5
Contract	3	2		5	2	

Table 6.41: Design strategy adopted on projects according to project type.

There were some less conclusive indications that the Type A design strategy was more common when reference to existing concepts had been made within the specification. However, no support for this was found in the survey.

Section 6.6.5 discussed how a selection of several generic design methods (functional decomposition, concept generation matrices, brainstorming, design evaluation matrices, and patent searching), which have been widely recommended in the engineering design literature for the purposes of generating and evaluating potential design solutions, was associated with higher levels of product innovation. These methods are essentially intended to support the divergent type of design strategy (i.e. Type B) recommended by the literature. It was hypothesised that the use of these techniques would be determined by the type of design strategy adopted. The use of brainstorming was not included in this part of the analysis as it was commonly cited by the survey companies and would therefore conflate the results. The high incidence of brainstorming may have occurred because it was used for non design related purposes, for example, seeking solutions to production problems. It may also have been cited when not applied in a truly formal and structured manner. None of the case study projects which involved a wholly Type A approach used any of these methods. In contrast, several of the projects associated with at least some aspect of a Type B design strategy did involve the use of these methods. Notwithstanding the possibilities of some less good practices, the survey also supported the hypothesis. The difference in the number of methods used on projects which adopted a wholly Type A design strategy (median = 0) in contrast to projects which used either a Type A and Type B or wholly Type B design strategy (median = 2) was found to be significant using the Wilcoxon Rank Sum Test ($U=21.5$ & 50.5, $P<0.1$, one tailed test).

The case study and survey projects highlighted the importance of distinguishing between the overall product and its sub-systems and components. Although the design strategy adopted in terms of the overall problem was frequently also found to predominate at the sub system and component levels, this was not so in a number of projects. With some projects, having established the best design configuration in overall terms, there was a policy of using standard assemblies and components (i.e. a

Type A strategy). This was most prominent at Company J. It had to have a working prototype available for exhibition at a major international trade fair. Faced with this lead-time pressure, then, having reviewed the various technical options, the approach was aimed at quickly establishing a working concept. Consequently, the proposed arrangement was decomposed into different functional mechanisms and proven in-house solutions were then modified and combined together to provide a robust design. Alternatively, when the product design concept was already established in overall terms, then the opportunities to consider different options was restricted to the subsystem and component levels. This was so with the contract project at Company L which concerned the customisation of its standard product design.

The hierarchical nature of design problems was discussed in Chapter 2. In this research a distinction was made between the overall product and the sub systems and components (see above). Although this distinction was a simple one, it did illustrate the importance of understanding the hierarchical nature of design problems and, in particular, how it is necessary when determining the design strategy to be adopted in respect of any part of a design project, to take cognisance of the various influential factors. There may however be constraints which limit the choice of approach, including those relating to time, costs, and the designers' capabilities. For example, several establishments were not familiar with techniques such as functional decomposition, concept generation and concept evaluation matrices.

The decision making hierarchy, as discussed in Chapter 2, extends up beyond the individual design problem, to include broad project management and, ultimately, strategic considerations. Therefore, although the relationships described above in relation to design strategy are strongly associated with the characteristics of projects, these will themselves be influenced ultimately by strategic issues relating to the role of design, and the elements and features of the product development strategy (types of products, technology to be developed and used, etc.).

An issue which has some relevance to design strategy is the form of considerations which need to be given to production engineering issues during the design process.

The concerns of best practice for concurrent engineering are particularly relevant. Best practice places much emphasis on the 'simultaneous design of the product and process'. Many projects do not however involve significant process innovation (i.e. new production equipment or processes) and it is therefore appropriate to view production engineering considerations at two levels. The first of these concern the design of the product to enable its effective manufacture. The second is a concern for more substantive issues relating to the design of the production process and its impact on the product's design. A very strong association was found to exist between the occurrence or not of significant process changes and the extent of these production considerations. In the case study projects, when there was no process change involved, production considerations were usually limited to the product's design features, whilst for process changes concerns for the product - process dimension were additionally introduced. The two notable exceptions to this were the product development project at Company J and the contract project at Company H. Although process design changes were involved at Company J only minimal consideration was given to these during the product design process. However, the fact that the failure to address these issues gave rise to a number of downstream problems and the need for a post prototype redesign exercise, indicates that this was a case of less good practice. Company H's project involved no process design changes, but, due to the high complexity and deep structure of its product, there were a number of design implications relating to the

	Design considerations n=17	
Process innovation	Effective production	Process Design
Existing equipment / processes	6	
New equipment / processes	1	10

Table 6.42: Design (production engineering) considerations according to process innovation in the survey

product's manufacture and assembly. The relationship between the type of design consideration and the process innovation involved was also very strongly supported by the survey (Table 6. 42).

Summary: Other than for highly original design projects, the form of design strategy adopted during the early problem specification stages was predominantly based on the use of existing design product concepts (i.e. product-focused) rather than the problem-focused approaches recommended by much of the engineering design literature. This may be a reflection of the characteristics of, and constraints on, projects in industrial contexts. However, even if this is the predominant approach, there will be circumstances when there are opportunities to adopt a problem-focused approach, either as the predominant approach or with regard to some aspects of the problem definition process.

During the main project stages, companies were very discerning in their approach (activities and methods) relative to the characteristics of their projects. A strong association between major product innovation and the generation and refinement of several concepts, and minor improvements and a focus on a single concept was observed. Moreover, the use of several generic design techniques (functional decomposition, concept generation and concept evaluation matrices, and patent searching) for the generation and evaluation of potential product concepts was found to be strongly related to the type of design approach adopted. Whereas they were rarely used when the focus was on the development of a single concept, they were more commonly used when a divergent strategy was adopted. Notwithstanding these findings, however, the case studies also demonstrated how the design approach and the resulting choice of methods could be influenced by other factors such as policies on the use of design standards, and the designer's skills. In addition, the extent and nature of the production engineering considerations were found to be strongly correlated to the degree of production process innovation.

6.8 Project Management and Decision Making

6.8.1 Project Planning

In all the case study projects and all but one of the survey projects a formal project plan was developed. The level of detail (overall plan, work package, and detailed activities) to be ultimately realised over the course of a project was found to be broadly related to product complexity and product structure. Although there were some instances of less good practises identified amongst the case studies (see Section 5.8.2 in Chapter 5), projects involving low complexity and shallow structured products were usually planned in no more detail than an overall plan or work package level, whereas with medium / high complexity and deeper structured products projeccts were planned down to the work package or detailed activity levels in most cases. Table 6.43, which illustrates the relationship between product complexity and the degree of planning detail realised during the survey projects, also demonstrates support for this finding. A very similar result was found for the relationship between the depth of product structure and the level of planning detail.

	Level of planning detail n=16		
Product complexity	Overall	Work Package	Detailed activity
Low	2	1	1
Medium		3	5
High			4

Table 6.43: Project planning detail according to product complexity in the survey

Relative to the level of planning detail to be ultimately defined, the planning detail defined prior to the project launch was suggested by the case studies to be conditional upon the degree of uncertainty. This was clearly evident amongst the product developments. These were all major developments and in most instances planning was limited to the overall plan. Even with the enhancement to an existing product at company D where some work package planning was undertaken this could only be done with respect to the immediate phase of the project. Similarly, at Company G, the development of work package and detailed plans were conditional on the outcome of the conceptual design work. Moreover, at Company C (new core product) and Company J (major platform enhancement) this was limited to a definition of the key milestones and activities of the project. In these cases developing the overall plan was dependent on some project work having been undertaken. The contracts, however, all of which were minor improvements and hence had a greater degree of certainty regarding the project activities and presumably a greater propensity for more detailed planning at this stage, were not planned beyond the overall project level. One possible explanation for this is that factors such as tender hit-rates, and changes to requirements prior to the award of contracts, could have given rise to wasted effort, which, coupled with a relatively high degree of certainty of projects' activities and their outcomes, mitigated the need for more detailed plans. Of the sixteen projects in the survey in which a plan was developed, thirteen developed a plan prior to the project's launch and, of these, only one was developed beyond the overall plan. Significantly, this was the product development project at Company 8 which involved a minor product change. This was associated with a greater degree of certainty, so that more planning could be undertaken.

The gantt chart or bar chart was the most widely used project planning tool amongst the case study projects, being used in all cases for which data was available. Task lists were also frequently used for work package and / or detailed plans. Of the survey projects for which a formal plan was developed only one did not involve the use of bar charts and only four did not make use of task lists. Computer-based project management tools were a distinct feature of the case study contract projects. However, more product development projects in the survey used computer-based project management tools. Indeed, if the case study and survey data is treated collectively, the use of these tools was equally probable with product developments as with contracts, suggesting that project type was not an influential factor. It was postulated that their use would be related to the need to maintain controls on schedule and costs. This was examined by comparing the emphasis on lead-time and price as competitive factors. However, no relationship was established. Their use, however, was found to be associated with the need for more detailed levels of planning in general. Table 6.44 shows that, in the case studies and in the survey, no projects where planning was restricted to an overall plan involved computer-based project management tools, whereas most projects where planning was done in some detail used these tools. Moreover, when they were used, it was found that critical path methods / networks were used for just under two-thirds of the case study projects and a similar proportion of the survey projects. The case studies also suggested that the use of networks was usually constrained to the overall project plans.

Planning detail	Cases n=11		Survey n=16	
	Yes	No	Yes	No
Overall plan		3		2
Work packages	3	1	2	2
Detailed activities	4		7	3

Table 6.44: Use of computer-based project management tools according to required planning detail

The responsibility for project planning and budget development was to a large extent dependent upon the type of project organisation. In the case studies it was found that with all project management or team-based structures this was undertaken by the individual assigned to the role of project manager or team leader. In all cases where functional structures were used this was the responsibility of either a lead functional manager(s) or, as was the case at Company H, a support function. This finding was also strongly supported by the survey. With all functionally organised projects, project planning was the responsibility of a functional manager, and with most projects where a project management or team-based organisational structure was used the project manager or team leader had responsibility for planning the project. Again the only exceptions occurred when there was a specialist planning resource for this activity (Companies 2, 13 & 15).

Summary: Variations were observed in the characteristics of project plans and how they were developed. The level of detail to which project plans were developed was determined by the degree of product complexity and product structure, such that more complex and deeply structured products generally required more detailed planning. For product developments, project planning prior to project launch was dependent upon the degree of innovation (certainty) associated with the project. Higher innovation and, therefore, uncertainty, limited the level of planning detail possible. For contracts, however, involving minor innovation, any planning below the overall project plan was deferred until the award of contract, presumably reflecting uncertainties associated with the award of the contract and the need to minimise unnecessary effort. Gantt charts and task lists were the most widely used project planning tools. Computer-based project management tools were found to be used frequently when projects were required to be planned in more detail than an overall plan. The responsibility for project planning and budget development was to a large extent dependent upon the project organisation. Usually a project manager or team leader was responsible when a project management or team-based structure was used, and a functional manager was responsible when a functional structure was used. In a small number of establishments there was a separate planning resource responsible for this.

6.8.2 General Procedures

Section 5.6.1 of the previous chapter highlighted that written procedures were usually defined for projects, although this did not necessarily include the definition of a standard process structure. The case studies did suggest however that some aspects of companies' procedures were conditioned by their respective attributes. Company size, and the cultural influences associated with it, was one such factor. A general observation was that the smaller firms had both less formal and less detailed procedures, reflecting the benefits they derived from their informal communication mechanisms. Company C was a particularly good exemplar. Having experienced a 50% reduction in employment during the 1990's, it had recently rewritten many of its product development procedures as a consequence. The amount of resource required to implement the original procedures was no longer appropriate to the down-sized organisation. There were however exceptions to this general characteristic of smaller firms. Company I, for example, is a small firm operating in a project-based industry in which exacting procedural requirements have been established. Although it had its own internal procedures for projects, it was most often necessary for the company to operate fairly formalised procedures which were not a reflection of its internal activities, but of contractual obligations typically imposed by clients.

6.8.3 Project Reviews

Project reviews were undertaken by all the case study and survey firms. The number of different types of project review was found to range between one and three. Although the types and characteristics of project reviews used by companies varied, it was possible to distinguish three main types of review: Group reviews, senior management reviews, and project / team reviews. For the non-autonomous group establishment there was the possibility for project reviews to be undertaken at group level or for group management to be represented at the main project reviews. However, this only occurred during two projects in the survey.

For all the case study and survey projects, the main internal project reviews were either senior management reviews or project reviews at which senior management was represented. In most of the case study projects and all but one of the survey projects these reviews were pre-defined (i.e. undertaken at key project milestones or on a regular basis). Ad-hoc project reviews occurred where companies felt it appropriate to initiate them at the project manager's discretion or because the key milestones at which they would be undertaken could not be defined initially. Also, in contrast to the product development literature's recommendations, the main project reviews were less likely to be undertaken at key project milestones than on a regular (monthly but sometimes weekly) basis. The case studies suggested that when project reviews were undertaken at key project milestones these would tend to be a feature of product development projects and the use of team-based forms of project organisation, rather than contract projects and those involving functional and project management structures. This occurred because the senior management of some companies operating in contract-based markets often needed to review a number of projects and, therefore, it was not practical to review each project at its respective milestones. The need to maintain an on-going review of progress and budget adherence was also suggested to prompt the use of regular reviews. It was for these reasons that the contract projects at Company A and Company H were reviewed at regular intervals. The two exceptions were the functionally organised product development projects at Company F and Company K which were reviewed at monthly intervals rather than at their key project milestones. At Company F, the large number of contracts being handled and the limited technical resources, meant that product development projects had to be reviewed with the contract projects at the monthly management meeting. However, although contracts were reviewed on a monthly basis at Company K, it is surprising that major milestone reviews were not used for the product development project studied given its scale and strategic importance. The survey also found that most of the reviews which were undertaken at key project milestones were product development or hybrid projects. The only exception was the contract project at Company 17 in which project reviews occurred at key milestones. However, this was a major project for the company. Also, although regular reviews were undertaken when team based project structures were used, in all of the projects in which project reviews were undertaken at key project milestones a team-based project organisational structure rather than a functional or project management structure was adopted.

Other project reviews which served to routinely review progress on projects were also undertaken in more than half of the projects studied. With both the case studies and the survey projects these were usually project specific and, although monthly and fortnightly meetings were used, these were most commonly undertaken on a weekly basis. Alternatively, ad-hoc meetings were held at the discretion of the team leader or functional manager. It was found that when undertaken these project / team reviews were a distinct feature of product development projects and matrix team and project team structures, enabling the team leader and team to discuss progress and specific project issues independently of the main project reviews. They were rarely used with contracts and functionally-based project structures because the senior management reviews (see above), which tended to be done at regular intervals, were usually sufficient. In the survey, for example, only one functionally organised project and only two contract projects held such reviews.

The case studies suggested that, as a consequence of the organisational characteristics of projects described above, establishments adopting matrix or project teams would have more review mechanisms on average than those adopting functional or project management structures. This finding was also strongly supported by the survey. The difference in the number of project reviews used for matrix or project team structures (median = 2) in contrast to functional or project management structures (median = 1) was found to be significant using the Wilcoxon Rank Sum Test ($U=5.5$ and 60.5, $P<0.1$, one tailed test). Also, the number of review mechanisms used for product development projects (median = 2.5) was more than contract projects (median = 1) and this was a significant result ($U=9.5$ and 60.5, $P<0.1$, one tailed test).

Projects were sometimes reviewed by external parties. Review by the customer or client was an important part of the project review process for some of the projects studied. As would be expected this was common amongst the contract projects. However, customer reviews also formed part of the hybrid projects which were identified in the survey. No product development projects involved review by the customer. However, the product development project at Company C was funded by an industry grant and the company was required to provide progress reports to the funding body.

Summary: For the non-autonomous group establishment there was the possibility for project reviews to be undertaken at group level or for group management to be represented at the main project reviews. The main internal project reviews involving senior management were usually pre-defined rather than ad-hoc. Project type and project organisation were found to be the major determinants of whether or not these were undertaken at key project milestones or at regular intervals during the project. Projects in which reviews were undertaken at the key milestones tended to be a feature of product development projects or hybrid projects and the adoption of team-based project structures. Other related factors which were found to be relevant were the number of projects to be reviewed, the size of the technical resource, the need to monitor progress and budgets, and the scale or degree significance of the project. Additional project / team reviews which enabled the team leader and team to discuss progress and specific project issues independently of the main project reviews were found to be a distinct feature of product development projects and matrix team and project team structures and, consequently, establishments operating in this way had more formal project review mechanisms on average. Customer specific project reviews were also undertaken. These were found to be unique to the contract and hybrid projects

6.8.4 Design Reviews

Major design reviews were undertaken in all but one of the case study projects and in all of the survey projects. They were usually undertaken at key design milestones and were generally conducted in a formal manner. This was found both for the case study projects and, as demonstrated by Table 6.45, the survey projects. One of the ways in which design reviews were characterised was whether they were pre-defined or instigated on an ad-hoc basis. The case studies indicated that the organisation of design reviews either on the basis of ad-hoc or a combination of pre-defined and ad-hoc meetings was a reflection of higher levels of project innovation. With the exception of Company B's contract which involved a minor product improvement, ad-hoc design reviews were associated with major enhancement or new core product projects. Around half of the major design reviews in the survey were ad-hoc. However, no relationship between the degree of innovation and the initiation of major design reviews was found. Major innovation was however found to be indicative of the use of a peer group for major design reviews. The known exceptions to this in the case studies were Company E and Company J. Their design reviews were not undertaken separately from the project reviews (see below). Conversely, there was a tendency with minor innovation projects for reviews to be constrained to the immediate technical group. Although individuals not involved in the project usually participated in the design reviews of the survey projects, it was found that, in those instances when there was no peer input, minor improvement or major enhancement to existing product innovation projects were involved.

	n=17
Major design reviews	17
Ad-hoc	9
Undertaken at key design milestones	12*
Formal procedure	13
Separate from project reviews	15
Formal review criteria	6
Intermediate design reviews	11
Ad-hoc	10
Undertaken at key design milestones	5
Formal procedure	3
Separate from project reviews	9
Formal review criteria	4
* Data available for 16 projects	

Table 6.45: Conduct of design reviews in survey projects

Intermediate design reviews (for subsystem and component issues) were undertaken less frequently than major design reviews for both the case study and survey projects. A strong association was found between products of low complexity and intermediate design reviews not having been undertaken. The three case study projects which did not involve intermediate design reviews (Cp, Ep and Fp) were all associated with low complexity and shallow structured products. This result was also supported by the survey in which there were five projects which did not involve intermediate design reviews. Three of these were concerned with low complexity and shallow structured products. There were two exceptions at Company 8 and Company 16 which related to more complex products. However, the project at Company 8 was a very minor change project relating to a particular part of the product, and the project at Company 16 was less substantial than the projects usually handled (which would involve intermediate reviews). The case study projects indicated that intermediate design reviews were more inclined to be ad-hoc and informal. This appeared to be a reflection of the concern for detailed design issues on minor innovation projects, and elements of uncertainty on major innovation projects. Table 6.45 demonstrates that this was also supported by the survey.

Best practice emphasises the need to handle design reviews separately from project reviews (see Section 5.8.8). This is due to their different concerns and the types of individuals who are required to be involved. Major project reviews are concerned with progress and need to involve the senior management, whereas design reviews are concerned with product attributes and need to involve a peer group which does not necessarily imply superiors. The case study projects and, as shown in Table 6.45, the survey projects usually involved separate reviewing mechanisms. However, the case studies indicated that with the small firm / small technical resource it was sometimes necessary or acceptable to undertake design reviews in conjunction with project reviews, provided that the distinction between them was clearly maintained. This is because the individuals who are required to be involved will often be one and the same in small firms. Design reviews were known to be addressed at project meetings by two small companies (B & E), but also at one large company (J). However, it may be argued that, with a project team, intermediate design reviews could be adequately dealt with in this way. The critical shortcoming of this approach, however, is that external and impartial individuals are excluded from the review process.

Projects were sometimes reviewed by external parties. In some industries, regulations require third party certification of a product's design, manufacture and testing. Several of the case study and survey companies were subject to these requirements. A further requirement which was cited by a number of the establishments was the need for their products to comply with the European CE mark.

Summary: Individuals not associated with a project were usually involved to provide an impartial input to the design review process. When this did not occur then this was likely to be associated with less substantial product changes. Major design reviews were usually undertaken at key design milestones and were generally conducted in a formal manner. Intermediate reviews concerning more detailed design issues or problems were more inclined to be ad-hoc and informal. When intermediate design reviews were not undertaken this was invariably associated with low product complexity and shallow product structure. Although it is widely considered good practice to handle design reviews and project reviews separately, under certain conditions (small technical resource and team structures) it may be necessary or feasible to address these together. Third part certification was an important consideration for a number of companies.

6.9 Summary

This chapter has described the findings of the thematic analysis of companies' practices. This was undertaken to determine what form the implementation of the areas of best practice, as identified from the literature on engineering design and product development and the best practice evaluation, should take in general and specific terms. The research found that whilst many aspects of companies' engineering design and product development practices were common to the companies studied, others were determined by the characteristics of companies, their strategic policies and specific projects. In particular, the specific project's characteristics, such as the project type, integrational requirement, innovation involved, and so on, were found to be very influential. These findings and those of the best practice evaluation are drawn together in the next chapter.

Chapter 7

Findings of the Research

7.1 Introduction

The previous two chapters presented the analyses of the best practice evaluation and the cross comparative analysis for the case study and interview survey companies. The main findings of these analyses are drawn together in this chapter. The style of the discussion is to outline existing best practice as revealed in the literature, to discuss this in terms of its general applicability to the case study and survey establishments, and to indicate those aspects of companies' practices which were found to be determined by the characteristics of companies and their projects.

7.2 Competitive Environment and Company Characteristics

The characteristics of the case study and the survey companies are shown in Table 4.4. and Table 4.7 (see chapter 4). The general assertion of the best practice literature on product development is that companies are operating under similar competitive pressures for higher quality products, under shorter and more predictable lead-times, and at lower prices. The case studies and the survey identified the existence of these competitive criteria in many cases, however, there was some variability in the relative emphasis assigned to these by different establishments. Price was cited in nearly every case and was most commonly top ranked, followed by quality and reliability, performance, and delivery lead-time and conformance issues. However, the lower ranked competitive criteria were often important order qualifying criteria. These findings are consistent with those of a study by Walsh et al (1992) in three industry sectors - electronic business and computing equipment, office furniture, and heating equipment - which also observed that UK firms tend to compete on the basis of price and, that this contrasted with their Nordic counterparts, who placed greater emphasis on other competitive factors such as product design and quality. The best practice literature also suggests that time considerations are an increasingly important competitive weapon for manufacturing companies. Time-to-market was not, however, frequently cited as a competitive weapon, although when it was a consideration, it tended to be an important one.

In terms of their overall business strategy orientation, as expressed by their relative prioritisation between operational excellence, market focus, and product leadership, the case study and survey companies were found to place a generally low emphasis on manufacturing. Market focus and product leadership were the dominant strategic positions adopted. This is quite striking, particularly if one considers the emphasis placed on manufacturing issues (just-in-time, manufacturing resources planning, flexible manufacturing, etc.) during the 1980s, although it is not possible to conclude from the current evidence whether the shift in the focus of debate towards design and product development has been reflected in changes to the strategic focus of companies.

7.3 Strategy and Technology Management

Companies are concerned to defend and improve their competitive positions. In responding to their changing business environments, the strategic policies pursued by companies, and the mechanisms they use to inform their decisions, are important considerations. In the context of product design and development, best practice suggests that the development of a comprehensive product development strategy, a competitive approach based on a knowledge of the important competitive criteria, a focus on customers, developing collaborative approaches to suppliers, and technology management activities are important considerations.

Apart from aspects of companies' approach to suppliers and technology management, the above requirements of best practice were found to have general applicability to the case study companies. All of the case study companies, but particularly those engaged in contract-based activities, were found to have limited opportunities to adopt collaborative approaches to suppliers, suggesting that best practice is too simply stated, and that it is more appropriate for companies to take a strategic view of procurement, whereby the most appropriate types of relationship with different suppliers are carefully considered. In addition, aspects of companies' technology development policies on licensing, acquisition, and links with universities etc., and analysis mechanisms such as patent searching, legislative monitoring, technology auditing, and so on, were likely to be less relevant or less frequently used in small or independent companies, those involved in contract projects, and those with a low innovation rate.

Having a product development strategy which defines the types of product, markets to be targeted, features and differentiating factors, technology to be used, research areas, prioritisation for developments, resources required, and so on, is an important area of best practice, being widely considered to be a contributory factor to improving companies' performance. In general, the case study and survey companies had a good overall perception of the main strategic issues concerning product development. Most establishments' product development strategies referred to the markets to be targeted, types of product to be developed, key research areas, and resourcing requirements. It was observed, however, that issues such as the types of technology to be used and how it should be introduced, the critical product features, differentiating factors, and customer benefits, and the means for prioritising between prospective developments, were less frequently specified. Most significant, however, was that although approximately two thirds of establishments had a formally written product development strategy, of these, only a third were separate from the overall business plan. This may partially reflect the fact that for some group establishments the product development strategy resided with the parent company and not at the establishment level. Indeed, formal product development strategies tended to be a feature of the larger establishments. It may also reflect the fact that incremental change was the dominant form of innovation in the companies studied, and they may not have perceived the need for a formal product development strategy. However, considering the strategic emphasis on market focus and product leadership expressed by many companies in the survey, this gap between actual and recommended practice should perhaps still be of concern.

7.4 Marketing and Project Initiation

The 'front end' of projects is the stage at which product developments are assessed for their feasibility, or tenders for contracts are developed. Important marketing and project initiation activities are market, customer and competitor analysis mechanisms, the evaluation of product proposals or tender enquiries, their subsequent development, specification formulation, and project approval. With only minor exceptions, the general recommendations of best practice were found to be applicable to the case study companies. However, these front end activities have been cited in the literature as being unsatisfactorily managed by companies (see Chapter 3). This was also borne out by the analysis of actual practices for the case study and survey projects, for which a number of shortcomings were identified in specific areas. The striking feature of these is that most were concerned with easily implemented procedures. A further finding was that their implementation (particularly the product proposal or enquiry review mechanisms, responsibility for, and organisation of, the tendering process and the subsequent project approval decision) was found to be dependent on the characteristics of companies and projects.

7.4.1 Systematic Market Analysis Mechanisms and Marketing Techniques

The best practice literature emphasises the requirement for systematic market analysis mechanisms, including market studies, market feedback mechanisms, competitor analysis, and the search for new product ideas. There was a limited use of detailed market studies and the lack of a systematic search for product ideas in most of the case study establishments. However, the distinction between general product markets and contract-based markets had a pronounced influence on the specific techniques used. Although there were a number of marketing techniques (monitoring trade press, assessment of field problems, sales presentations, requests on lost orders, and so on) which were common to both types of market, case study establishments engaged in contract-based projects were inclined to use less systematic approaches for these, and less likely to use other systematic and structured mechanisms for collating and analysing market and competitor information (market surveys, competitor analysis and product analysis, market analysis, and so on). Moreover, in contract-based markets, personal contacts were frequently more important where intelligence gathering and influencing customers were concerned.

7.4.2 Project Initiation Procedures

In accordance with best practice, most of the case study and all of the survey projects went through a two-stage screening process: product proposal or enquiry review and project approval or tender review. However, although a purpose of the initial product proposal or enquiry review should be to determine what further activities need to be undertaken to enable the second stage project approval or tender review to proceed, and should usually involve a go / no-go decision, these activities were not always undertaken. In the survey, for example, these did not occur for a quarter of the initial product proposal reviews. Best practice also recommends that the screening of product proposals should be undertaken on a regular (<= quarterly) basis. However, the case studies and the interview survey found that ad-hoc and less frequent reviews were often undertaken. Notwithstanding the possibilities for some less good practices, fewer product proposals (which was partly a reflection of a low rate of innovation in the product) was indicated to reduce the required frequency of product proposal reviews or enable them to be initiated on an ad-hoc basis.

Due to the strategic importance of product developments, product proposals tended to be reviewed by an executive group and, in the case of the group establishment, by the parent group. Tender enquiries were handled according to the organisational characteristics of the respective companies (e.g. the presence of a dominant commercial department or business manager), and the strategic importance and scale of potential contracts influenced the level of seniority at which decisions were made. Larger contracts or those of some strategic importance were more likely to be reviewed at a senior level by a company executive or an executive group. The non-autonomous group company could also be required to gain group approval to commence the tender.

In line with the requirements of best practice, it was concluded that the feasibility or tender development stages should include assessments of the market, financial, commercial, technical and manufacturing implications of projects as appropriate and broad assessments of the potential sources of risk. However, a rather narrow focus was frequently adopted amongst the case studies. Projects tended to focus on the technical and marketing issues and many important aspects of risk evaluation were often omitted.

The case studies identified inter-departmental cooperation to be very common during the feasibility stage of product development projects and during the tender development stage of contract projects. Alternatively, other inter-disciplinary mechanisms (i.e. multi-functional project teams or departments) were used. The scope and scale of tenders, which were hypothesised to be determined by several factors such as product complexity, technical content, and the enquiry requirements, was found to influence how tenders were developed. With a small tender proposal, an individual or department usually wrote the proposal drawing on other functional inputs as necessary. With a larger proposal and/or one having specific technical implications an individual or department coordinated the inputs of other disciplines and functions in its preparation.

The importance of evaluating projects on the basis of a broad range of criteria is also stressed by best practice and was found to be relevant to the case study companies. These criteria should include both those relating to assumptions of successful outcomes (i.e. forecasts for sales, market size and market share, profitability, etc.), and those concerned with delivering these outcomes or which may influence their realisation (i.e. resources, capital and revenue requirements, risks and probability of success, product need, compatibility with the company's strategic policies and objectives, competitor position, compatibility and effect on other company products, etc.). However, whilst a basic evaluation against key marketing (i.e. sales) and financial (i.e. cost and profitability) variables was undertaken by all the case study firms, the vast majority made limited use of the wider variables and factors, including those indicated above, so that, in nearly all cases, the need for more comprehensive procedures was identified.

Major product development projects, because of their strategic importance, were approved at an executive level amongst the case study and interview survey projects. This was usually done by an executive group or, in the case of some non autonomous establishments, the parent group. Minor improvements (e.g. design change requests) on the other hand were reviewed at a less senior level. Contract projects were usually reviewed by an individual executive or senior manager. These usually were more routine, had less strategic importance than product development projects, and involved less substantial product innovation. Responsibility for tender reviews was indicated by the case studies to be conditional on the scale of the tender and commercial considerations associated with it. A greater scale of tender or significant commercial implications implied a more senior level of approval. Specific projects also demonstrated how, for the non-autonomous group company, there could be an ultimate requirement with certain forms of project to obtain Group approval to authorise a tender.

7.4.3 Design Specification

An important feature of the project initiation stages concerns the development of a written brief or specification of the project and design requirements prior to commencing the main project stages. A written specification was produced for nearly all the case study and survey projects. A good specification should cover all the relevant requirements and constraints. However, factors such as low product complexity, contract-based projects, and low production process innovation, were all found to reduce the relevance and, therefore, inclusion of certain specification elements, notably system and sub-system requirements, manufacturing requirements and constraints and production volume. In specific cases high product innovation, subcontracted manufacturing, and the provision of the specification by the customer were also observed to reduce their relevance. It was therefore not always necessary to include these elements in specifications. Notwithstanding this finding, the case studies and the interview survey supported the findings of other empirical research (see, for example, Hollins and Pugh (1990) and Walsh et al (1992)) which has criticised the adequacy of specifications used in industry. Although specifications usually included most of the requirements, constraints and issues relevant to their projects, some of these were frequently omitted when it was reasonable to include them.

In taking account of all the relevant considerations during the feasibility / tender development activities, including the formulation of the specification, the literature recommends that this should be a multi-disciplinary activity. The case studies and the survey confirmed that inputs generally, although not always, included the engineering and marketing functions, but that the inputs of the other internal functions and those of suppliers and customers were dependent on several factors. The internal inputs to the formulation of the specification was found to be influenced by the degree of inter-functional integration required and the production process innovation involved. Projects with a need for the integration of several functions, as opposed to those focused on a dominant function, involved more functional inputs, and those which involved production process innovation were more likely to include production inputs. However, the fact that production departments were sometimes not involved in the preparation of specifications when there were in fact manufacturing change implications, or were involved when there were no manufacturing change implications, suggested that production involvement was to some extent a reflection of companies' general procedures rather than concerns within a specific project. With regard to external inputs, although key supply items were common, suppliers rarely had inputs to the formulation of the specification. Although customers were infrequently involved in product development projects, they were nearly always involved in contract projects. Therefore, although in some circumstances aspects of specifications may not be relevant and some inputs may not be required, it was found that specifications were often not formulated in accordance with good practice. This is a concern given that they have been shown by the literature to be a critical factor in the successful completion of projects.

7.5 Project Organisation

The issues covered here are concerned with the most appropriate choice of project organisation structure (and the form of team structure when a team-based structure is used) during the main project stages, the application of team working principles, and the form of representation and commitment of individuals during projects. The research found that the general recommendations of the literature in relation to these issues often were not appropriate. Several company and project variables were found to be influential on companies' practices. Although some of these were found to be particularly influential, the case studies demonstrated that the appropriate choice was often the result of the combined and complex interaction of several factors.

7.5.1 Project Organisation Structure

The research findings found that the best practice literature's recommendations as to which type of project organisation (functional, project management, matrix team, project team, autonomous team, and multi-project) to adopt are too simply stated. Contrary to these recommendations, which tend to be favourable to the use of project team or autonomous team forms of project organisation, a number of different organisational forms were observed amongst the case study and survey projects. Moreover, the choice of project organisation was generally found to be appropriate to the context of the company and project. In particular, it was notable that there were instances when a matrix project structure was used, but no autonomous team forms were observed amongst either the case study or interview survey projects. Many of the characteristics for which the matrix team form is criticised in the literature, such as the involvement of the functional management and the limited influence of the project leader, often appeared to be positive, or inconsequential, features. It offered the benefits of team working whilst not constraining companies in the flexible use of limited resources. In addition, the need to handle several projects simultaneously and the high proportion of temporary or part-time inputs were also cited by some establishments to have prompted the use of a matrix team structure.

The most appropriate form of project organisation to adopt was found to be determined by the combined influence of several variables and, therefore, it is necessary to consider all of these. Whereas team-based forms of project organisation were typically large, associated with new platform or new core product projects, and more common amongst larger establishments or those having a larger technical resource, the functional form of project organisation tended to be associated with small projects, minor changes, and smaller establishments and technical resources. Additionally, the case studies suggested that functional forms were possible when there was a little variation between the characteristics of successive projects and, that, the type of project commonly handled would also have a bearing on the type and form of organisation adopted. However, the degree of integration required between functions and disciplines was found to be a very significant factor, with low integration needs being associated with functional and project management structures, and higher integration needs being associated with team-based structures. Surprisingly, only limited evidence of an association between the presence of lead-time pressures and the use of team-based organisational structures was found. Notwithstanding the possibility of less good practices by some establishments, this result may reflect the fact that the indicators of lead-time pressures used in the analysis related to the general market situation, rather than being project specific.

A generally held principle of best practice is that the organisational dynamics of teams, such as the ability to achieve effective communications, places an upper limit on the size of a single team to around ten members and, that, with increasing team size, a transition to a team which extends into the functions is more appropriate. On the basis of the difficulties experienced by some of the case study firms with the use of larger teams this seemed appropriate. Moreover, all larger teams in the survey were extended into the functions.

Employing team-working principles and co-locating individuals assigned to a project, either collectively or within their respective functions, are widely cited components of best practice. Indeed, three quarters of the case study and survey projects involved some form of team characteristic. Team-working was found to be a distinct feature of the larger establishments or those with a large technical resource: Amongst the case studies and survey projects, all the large establishments and all establishments with a large technical resource, used some form of team working. The case studies also indicated that characteristics such as small firm size and operating in contract-based markets, were associated with less relevance and application of co-location.

7.5.2 Team Representation and Commitments

No single dominant factor was found to determine the level of seniority of those with responsibility for the routine management of projects. A case-by-case analysis of the case study and survey projects, however, suggested that several factors were relevant. These include the type of project structure used, project size and the degree of product innovation (absolute and relative to frequently handled projects) involved, size of the technical resource, strategic considerations, and organisational features relating to the handling of projects in general. Although the seniority of other individuals assigned to projects was suggested by the case studies to be influenced by the type of project structure adopted, the survey found only limited support for this. However, when a team-based structure was adopted, the type of team structure was found to be influential, with junior functional representatives more frequently represented when an extended team structure was used than when a single core team was used.

The literature on product development generally stresses the importance of permanent and full-time representation of individuals on project teams. In contrast, however, the research found that, for both team-based and non team-based project structures, several factors influenced the formal representation of individuals on projects, and whether their commitment should be permanent or temporary, part-time or full-time.

The formal representation on the project of the different internal functions was generally related to the integrational requirements (managerial complexity) of projects. Integration projects were strongly associated with more functional inputs than non-integrational projects. Not surprisingly, Engineering was formally represented in all the projects studied. Marketing had no formal membership in more than half of the case study and survey projects and was more frequently represented on product development projects than contract projects, and when team-based organisational structures were used rather than functional and project management organisational forms. Production process innovation was an important influence on representation for the production function. With regard to customers and suppliers a distinction was made between their formal inputs and being a formal part of the project's team. In contrast to the literature's recommendations, no customers, and very rarely suppliers, were represented as a formal part of the project team. Formal customer inputs were a distinct feature of contract projects. Indeed, there were no formal inputs to product development projects. Although formal inputs by suppliers were indicated to be influenced by several general factors, the requirement for supplier collaboration at the project level (as indicated by the existence and nature of key supply items) was found to be very influential. The supplier collaboration requirements also influenced the formal representation of purchasing on projects.

The levels of permanent and full-time representation on projects were generally low. For example, nearly half of projects in the survey involved 100% part-time commitments. Smaller establishment size or smaller technical resource was associated with more part-time commitments, and contract projects with more temporary commitments. Product innovation was also a contributory factor, with minor improvements tending to involve 100% part-time commitments and increasing product innovation being associated with more full-time commitments.

7.6 Process and Integration

7.6.1 Principal Processes and Activities

A major element of best practice is that companies should establish formal definitions of generic process structures for their main project types. These should be in sufficient detail to provide an overall framework to accommodate flexibility between projects, and enable process improvements to be realised. Also related to this are the inputs to the process (see Section 7.5.2) and the levels of involvement of the different internal disciplines, customers and suppliers over the course of the development process (referred to here as concurrency).

The establishment of formal definitions of generic process structures is a best practice factor which was found to have general applicability to the companies studied. Indeed, companies generally had a good understanding of their design and development processes. All the case study and three quarters of the survey establishments claimed to have procedures governing projects, with nearly all of these specifying the major stages, activities and milestones. The number of stages, or phases, used by companies to define their processes ranged between four and eight, with fewer stages being associated with lower product complexity. Generic models for the product development and contract processes were identified on the basis of the case studies (see Figure 6.1 and Figure 6.2). The survey found support for these, but also identified three hybrid processes which comprised elements of the product development and contract process models:

- A low volume product was developed following a specific request by an end customer, but with the intention of entering the resulting product into the company's standard product catalogue or range in order to exploit a wider market opportunity - this followed the product development process model with some elements of the contract process, such as negotiation on costs, etc., with the customer.

- The development of a low volume, high complexity product was initiated but, owing to the scale of the development, in order to complete it, a contract for sale had to be obtained - the model therefore had a product development front-end followed by a contract.

- A high volume, low complexity product was developed for a specific customer under a negotiated agreement with a view to the company becoming a preferred supplier - the model was essentially a contract, but largely followed a product development model supplemented by customer inputs to the review and testing activities.

However, the influence of company and product characteristics, and the attributes of individual projects, meant that it was only possible to define these at an abstract level of detail. Although at their abstract level of detail these process models were broadly applicable, companies recognised different phases to projects and sometimes there were additional or absent phases (e.g. in some minor change projects where no conceptual design is required). Furthermore, within these, product complexity and product structure were observed in the case studies to determine features of the core design stages. In contrast to products of low or moderate product complexity and depth of product structure, higher product complexity and deepening product structure were associated with an increasingly distinct embodiment design activity.

Factors such as the type of project, product complexity and product structure, and the degree of product innovation were suggested to influence projects' durations. Product innovation was found to be a strong determinant of the overall duration of projects, with minor product improvements being associated with shorter time scales than more substantial product innovations. Although the front-end of contracts (enquiry to contract) were frequently found to have shorter durations than product developments (product idea to project launch), the fact that some contracts were the subject of protracted customer review and negotiation meant that, in the survey, there was no overall difference between the two types of project. Similarly, although the period between project launch and completion of the detail design work was suggested to be longer for large scale projects (reflecting higher product complexity and greater product innovation), this relationship was offset by the fact that the number of individuals assigned to a project was also found to be higher.

7.6.2 Staffing and Skills

Staffing and skills issues were found to be influenced by establishments' strategic or general policies and, also, the requirements of individual projects. The case studies indicated that factors such as small establishment size, lower rates of innovation in the product, establishments being predominantly associated with minor improvement projects, and a low strategic importance for design and product development were associated with an emphasis on general skills. The survey also demonstrated that a preponderance of either generalists or specialists was strongly related to the extent that establishments' placed a strategic emphasis on product leadership. When product leadership was ranked first (relative to market focus and operational excellence) then generalists were less likely and specialists were more likely. Relative to establishments' general policies the use of external resources was found to be determined by the requirements which applied on a project-by-project basis.

7.6.3 Concurrency and Integration

Best practice is predicated on the basis of significant involvement from all the main internal functions, the customer and suppliers, throughout the process. Concurrency, as defined in this thesis, measures the degree of simultaneous involvement of the primary internal functions and external organisations over the course of the development process. The disciplines of engineering, marketing and sales, and production comprise the measure of core concurrency, whilst overall concurrency includes the additional internal discipline of purchasing, together with customers and suppliers. Several characteristics of companies and their specific projects were found to condition the involvement of the internal functions, customers and suppliers and, consequently, the levels of concurrency which should be realised. Not only were the case study and interview survey companies' actual levels of concurrency invariably below best practice, but the case studies implied that, relative to what should be regarded as their appropriate levels of concurrency, there was scope for improvement by some companies.

The degree of concurrency was inter-related to the organisational issues of projects and, hence, the overall levels of concurrency were generally highest for integration projects, with higher levels of product innovation and process innovation, and when team-based approaches were adopted. Higher levels of overall concurrency were also observed when technical issues were a primary competitive criterion. The case studies also suggested that concurrenncy would be higher when lead-time pressures existed, although the wider survey of companies did not find support for this. Similar relationships were observed for levels of core concurrency, but those relating to product innovation and project organisation were not significant. Lower levels of core concurrency were also found for contracts than product developments.

The individual internal functions, key suppliers and customers were also found to be affected by several variables. Whilst the involvement of engineering was found to be consistently high, this was higher on average for product development projects than contract projects. Production involvement throughout the project was greater for product development projects than contract projects, and when process innovation was involved. The involvement of marketing and sales was less for contracts than product developments. In contrast, customer involvement was found to be more substantial for contracts than product developments. The extent of supplier involvement varied considerably. The case studies suggested that this was broadly influenced by the general characteristics and strategic policies associated with the supplier environment. At the project level, however, the extent of supplier involvement was determined by the characteristics and nature of the key supply items (i.e. their existence, the design content, and whether the company and/or supplier are responsible for the design work). The involvement of purchasing was also found to be influenced by the nature of the key supply items, and it was not surprising that this often replicated the degree of supplier involvement. Purchasing's involvement was also higher when purchasing was formally represented on projects.

7.7 Design Methods, Modelling and Analysis

Many design activities may be most effectively performed by the selective use of design methods and techniques, and modelling and analysis tools, as appropriate to the particular situation. In particular, a distinction may be made between design modelling and analysis tools, techniques which facilitate cross-functional activities, and generic design methods. Additional considerations are product prototyping, and well planned and executed performance testing and field testing activities.

7.7.1 Modelling and Analysis Tools

Best practice in this context tends to be driven by the enabling technologies. The research demonstrated that the use of design modelling and analysis tools (empirical methods, rig testing, physical models, CAE modelling and analysis, and rapid prototyping) is particularly important under certain conditions. The case studies indicated that these tools were more frequently used during the development process for more complex and deeply structured products, product development projects rather than contracts, more substantial product changes, an emphasis on technical issues, a higher design capability requirement, and when there were lead-time pressures. The survey also found significant support for the relationship between the application of these tools and technical emphasis, product innovation and project type, but not for lead-time and product complexity factors. The use of these tools during the initial design stages of the case study projects also were frequently associated with lead-time pressures, high product complexity and deep product structure, a high design capability requirement and, in association with these, an emphasis on reliability and technical performance. This reflected the need for companies to be able to adequately predict product performance early in the design process. Although similar relationships were observed in the survey, a significant result was only found for the influence of product complexity. However, this may be a feature of less good practice on the part of some establishments.

The general use of computer-based tools for design and development was suggested by the case studies to be higher in the presence of lead-time pressures and where there was a higher design capability requirement. A specific subset of this group of tools are those for CAE modelling and analysis. The survey found their use to be strongly related to the degree of product innovation, being infrequently used for minor improvement projects, but widely used for more substantial product innovations.

7.7.2 Methods and Techniques

The literature strongly encourages the use of a number of techniques to assist cross-functional activities (such as value engineering, quality function deployment, failure mode effect analysis, robust design, and brainstorming). In the case studies and, in the survey, these techniques were significantly more likely to be applied on projects when there was a greater requirement for integration of the functions and disciplines, with product development projects rather than contracts, and for more substantial product innovations.

The application of several generic design techniques (functional decomposition, concept generation matrices, brainstorming, design evaluation matrices, and patent searching) amongst the case study and survey projects was strongly correlated with higher levels of product innovation, and also reflected the type of design strategy adopted (see Section 7.8). It was also notable that methods associated with the use of existing design concepts, such as design rules, codes and standards, and empirical methods, dominated.

Of the formal methods and techniques recommended by the best practice literature, it was notable that despite the considerable emphasis placed on these, a number were not widely used by either the case study or survey companies. Significantly, some of these, including quality function deployment, robust design, functional decomposition, concept generation and evaluation matrices, were not widely known, let alone applied. This may reflect the fact that few companies had a clearly defined role for consideration of enabling technologies and methods (see Section 7.10). However, some companies indicated that they had found techniques such as quality function deployment to be too demanding on time and resources.

7.7.3 Prototyping and Testing

The production of a product prototype was a distinct feature of product development projects rather than contract projects (contracts often involve one-off products and / or the customisation of a basic design) and, to a lesser extent, was associated with major product innovations and less complex products (higher complexity often being associated with prohibitive costs). The case studies indicated that the influence of regulatory requirements, or contractual requirements, were often important factors in determining both the internal testing and external testing requirements. Although field trials or site testing were undertaken during most of the case study and interview survey projects studied, specific projects indicated that, for product development projects involving major product innovations it would usually be necessary to undertake field trials, whereas for minor product changes this may not be so.

The duration of internal testing on projects for both the case study and survey projects was higher for product developments than contracts, for more substantial product innovations and for more complex products. The perception of quality, reliability and technical issues as highly ranked competitive factors was inferred from the case studies to be associated with more comprehensive testing programmes, however, this was not borne out by the survey. With regard to external testing, field testing on product development projects was found to be significantly longer on average than site testing on contract projects.

7.8 Design Strategy

A design strategy represents the particular design approach adopted on a project or part of a project. It may be characterised by the sequence in which the design stages, activities, methods and techniques are planned or executed.

The form of design strategy adopted during the early problem specification stages was predominantly product-focused, being based on the use of existing product design concepts, rather than the problem-focused approaches advocated by much of the engineering design literature. Only one project, which involved a highly original design problem, adopted a problem-focused approach. Although the use of a product-focused approach was usually a legitimate reflection of the characteristics of, and constraints on, projects in industry, this was rarely the result of a conscious choice as to the most appropriate approach to adopt. Few companies were aware of the problem-focused approach, nor when it might be adopted, either as the predominant approach or with regard to some aspects of the problem definition process.

During the main project stages the design approach adopted by companies reflected closely the characteristics of their projects and, in particular, differences which occurred between the overall product and its systems, subsystems and components. A strong association between major product innovation and the generation and refinement of several concepts, and minor improvements and a focus on a single concept was observed. Moreover, the use of several generic design techniques (functional decomposition, concept generation and concept evaluation matrices, and patent searching) for the generation and evaluation of potential product concepts was found to be strongly related to the type of design approach adopted. Whereas they were rarely used when the focus was on the development of a single concept, they were more commonly used when a divergent strategy was used. Notwithstanding these findings, however, the case studies also demonstrated how the design approach and the resulting choice of methods could be influenced by other factors such as policies on the use of design standards, and the designer's skills.

The extent and nature of the production engineering considerations were found to be strongly correlated with the degree of production process innovation involved in the project. When production process changes (new equipment or new processes) were involved considerations tended to focus on the design of the production process itself, rather than simply considering the design of the product to enable it to be effectively manufactured within the existing production systems.

7.9 Project Management and Decision Making

Project management and decision making is concerned with the mechanisms for planning and controlling development projects. Best practice recommendations include the provision of a clear definition of the project's objectives and terms of reference, effective project planning and budgeting, having organised systems and procedures for the management of records, undertaking project reviews and design reviews at the appropriate project milestones, and clearly distinguishing senior management's role in relation to these.

With few exceptions, this area of best practice was found to have general applicability to companies, such that a non-application of these principles reflected opportunities for improvement. Instances of less good practices concerned inadequate project planning, not clearly distinguishing top management's and project level responsibilities, and the inappropriate application of project and design reviews, including narrowly defined review criteria for these.

7.9.1 Project Planning

Although a project plan was produced for all but one of the case study and survey projects studied, the characteristics of these and how they were developed varied. The level of detail to which project plans were developed (i.e. overall plan, work packages or detailed activities) was found to be determined by the degree of product complexity and product structure, such that more complex and deeply structured products generally required more detailed planning. For product developments, the amount of project planning undertaken prior to project launch was found to be dependent upon the degree of innovation associated with the project and the corresponding level of certainty as to the project activities. Consequently, higher innovation and, therefore, greater uncertainty, limited the level of planning detail possible. For contracts involving minor innovation, however, any planning below the overall project plan was deferred until the award of contract, presumably reflecting uncertainties associated with the award of the contract and the need to minimise unnecessary effort. Gantt charts and task lists were the most widely used project planning tools. Computer-based project management tools were found to be used frequently when projects were required to be planned in more detail than an overall plan. The responsibility for project planning and budget development was to a large extent found to be dependent upon the project organisation. Usually a project manager or team leader was responsible when a project management or team-based structure was used, and a functional manager was responsible when a functional structure was used. Alternatively, in a small number of establishments, there was a separate planning resource responsible for this.

7.9.2 Project Reviews

Regular or ad-hoc project reviews, as opposed to the literature's preference for pre-defined key milestone project reviews, were used for the main project reviews in a number of the case study and survey projects. Notwithstanding the fact that less good practices were being adopted in some instances, the adoption of these approaches to project reviews were found to be equally applicable in certain situations. The main internal project reviews involving senior management were usually pre-defined rather than ad-hoc. Project type and project organisation were found to be the major determinants of whether or not these were undertaken at key project milestones or at regular intervals during the project. Projects in which reviews were undertaken at the key milestones tended to be a feature of product development projects or hybrid projects and the adoption of team-based project structures. Other related factors which were found to be relevant were the number of projects to be reviewed, the size of the technical resource, the need to monitor progress and budgets, and the scale or degree significance of the project. Additional project / team reviews which enabled the team leader and team to discuss progress and specific project issues independently of the main project reviews were found to be a distinct feature of product development projects and matrix team and project team structures and, consequently, establishments operating in this way had more formal project review mechanisms on average. For the non-autonomous group establishment there was the possibility for project reviews to be undertaken at group level or for group management to be represented at the main project reviews. Customer specific project reviews were also undertaken during some projects. These were found to be unique to the contract and hybrid projects

The research also found that, for product development projects of any significance, the main project reviews should involve a go / no-go decision on the continuation and resourcing of the project. The case studies demonstrated that this usually only occurred at the project approval stage. With the contract projects studied the company usually became fully committed to the completion of the project with the award of the contract and, therefore, this type of decision was not relevant to the main project stages.

7.9.3 Design Reviews

Major design reviews were undertaken in all but one of the case study projects and in all of the survey projects. Also, as recommended by best practice, they were usually undertaken at key design milestones and were generally conducted in a formal manner. The case studies suggested that major design reviews were more likely to be instigated on an ad-hoc basis, rather than pre-planned, when higher levels of product innovation were involved. However, although the survey found no general evidence to support this, it was found that whilst some establishments undertook design reviews according to a specific project's requirements, others tended to follow a particular procedure for all projects.

Intermediate reviews concerning more detailed design issues or problems were more inclined to be ad-hoc and informal. When intermediate design reviews were not undertaken this was invariably associated with low product complexity and shallow product structure. These findings suggest that the literature's recommendations are inappropriate for purposes of these more detailed design reviews.

Although, in line with the recommendations of best practice, peers not associated with a project were usually involved to provide an impartial input to the design review process, their involvement was found to be determined by the degree of product innovation. Individuals not associated with the project were more likely to be involved on major innovation projects than when there were less substantial product changes.

It is widely considered good practice to handle design reviews and project reviews separately. However, several projects indicated that, under certain conditions, such as when there is a small technical resource, it may be necessary or feasible to undertake these in conjunction provided that the distinction between them is clearly maintained.

7.10 Performance Measurement and Process Improvement

The issue of performance measurement and process improvement is receiving increasing attention in the literature. This is concerned with monitoring the progress of projects and a strategic emphasis on continuous improvement. Important aspects of this include the appointment of a process champion, undertaking post project audits, and applying suitable performance metrics.

The assignment of a process champion to facilitate support for development activities and to ensure their continued improvement through revised procedures, improved IT support systems, training in new techniques, and so on, is most relevant but not exclusive to product development processes. The case studies demonstrated that this role, when undertaken, usually took place in an ad-hoc and informal manner, and was not clearly defined.

Upon completion of a project it is good practice to undertake an audit of both the product and the project's management. Although post project audits were undertaken by around three quarters of survey establishments, half of these audits were limited to product related issues. Moreover, when issues relating to the project and its management were addressed this was not necessarily part of a formal procedure for process improvement, but a response to a particular problem.

Performance measurement criteria are relevant to all companies. Overall measures of performance should be related to the business (e.g. market share, profits, etc.) and market (e.g. customer satisfaction, price, delivery adherence). Measures for project monitoring and improving the effectiveness of the product design and development processes (e.g. relating to cost, quality, time, etc.) need to be consistent with the overall measures of success. In general, few performance metrics were defined by companies, and invariably they only addressed a narrow set of issues (i.e. project schedule and budget adherence), and most were not aware of what others might be used, particularly as a strategic tool for process improvement. This was consistent with the limited application of post-project audits discussed above.

These mechanisms are an important way for companies to learn from, and improve, their procedures and processes. The findings of this research suggest that this should be an area of general concern.

Chapter 8

Conclusions

8.1 General Conclusions

This research has addressed the need for a framework that provides a way of analysing and understanding the engineering design and product development processes within the context of a commercial manufacturing organisation. Such a framework has been developed and tested. This framework comprises factors that classify a company (in terms of its organisation, markets, products, production processes, suppliers, and the local and global environment), and its strategic policies and key project variables that impinge on the process. Using this framework it was found to be possible to distinguish between generic and company specific features of the processes of engineering design and product development and to identify which elements of best practice were appropriate and achievable for the companies studied.

A number of areas of best practice were identified from a review of the engineering design and product development literature. These were found to be generally applicable to a group of medium and large sized UK engineering establishments. These best practice features included product development strategy, generic process structures, performance measurement and process improvement, and most of the requirements for marketing and project initiation, and project management and decision making. However, the research investigations identified a number of shortcomings. Firstly, because the characteristics of the types of industries, companies, and projects on which much of the literature is predicated are different from those of the companies studied, a number of elements of best practice were found not to be appropriate in specific circumstances. Table 8.1 shows that these included aspects of companies' approach to suppliers, technology management, project organisation and team working, integration and concurrency, modelling and analysis, and design strategy. In particular, some aspects of best practice were found

Best Practice Area	Major Deviations from Best Practice
Competitive Environment	Type and prioritisation of competitive drivers more variable than the assumption of a simultaneous need for higher quality products, in shorter lead-times and at lower cost (e.g. price frequently very important, but lead-time often not a significant factor).
Strategy	Collaborative approach to suppliers often difficult or inappropriate. More discriminatory and strategic view of procurement required, whereby appropriate relationship (e.g. partnership sourcing, multi-sourcing, etc.) is carefully considered.
Technology Management	Systematic analysis mechanisms and technology development policies not universally relevant. Less relevant to some small firms or independent firms, those involved in contract projects, and a low innovation rate.
Marketing and Project Initiation	Systematic market analysis mechanisms less widespread in contract markets. Fewer functional inputs to specification may be necessary due to project characteristics (e.g. low integrational requirement, no process innovation and contract projects).
Organisation	Alternatives to project team and autonomous team forms of project organisation are appropriate for different project contexts. Co-location may be problematic for small firms and with contracts. Project owner less relevant to contracts. Often fewer formal representatives on projects from functions, customers and suppliers due to project context. Permanent and full-time commitments usually inappropriate, particularly for small establishments / technical resource, contract projects and minor product innovation.
Integrated Process	Often lower involvement / concurrency of functions, customers and suppliers due to project context.
Modelling and Analysis	CAE modelling and analysis tools, design methods, cross-functional techniques not universally required and determined by project context.
Management & Decision Making	Project reviews not always at pre-defined milestones, particularly with contract projects and non-team forms of project organisation. Detailed design reviews not always at pre-defined milestones and formal. Inputs by peers to design reviews less common in minor change projects
Design Strategy	A wider variety of approaches are appropriate to suit different problem and sub problem characteristics.

Table 8.1: Major deviations from the assumptions and recommendations of the literature

not to be applicable with regard to small companies and companies engaged in contract-based activities. A failure to recognise these differences could lead to companies attempting to apply models which are inappropriate to their needs. Secondly, the literature was revealed to have a narrow focus. The development of products may be realised either through 'product development projects' or 'contract projects'. The guidance currently provided to companies tends to focus on product development projects and largely ignores contract projects. Thirdly, best practice deals with generally applicable principles but, in many respects does not deal with how they should be implemented. Significantly, many aspects of how projects were implemented were also found to be determined by a variety of company and project characteristics. Collectively, these considerations place a considerable onus on companies to interpret best practice and develop approaches which are suitable to their particular characteristics and the types of project they undertake.

An important distinction concerning the way in which projects were initiated and undertaken was found between product development projects and contract projects. The principal distinction between them was in terms of their respective processes (see Figure 6.1 and Figure 6.2). Differences were also observed for marketing techniques, customer and marketing inputs during projects, commitment of individuals to projects, project durations, and the degree of pre-project planning. Project variables (e.g. product innovation) were to some extent related to the type of project and, therefore, by association, project type was reflected in other aspects of companies practices - project organisation, design strategy, and so on.

Relative to achievable practice, the practices observed for the companies studied suggested varying degrees of scope for improvement, particularly in relation to product development strategy, marketing and project initiation, management and decision making, and project management. Notably these were areas where the literature's recommendations were found to be generally applicable. This should be a concern given that aspects of these, including properly considered and formulated product development strategies and design specifications, have been shown to be related to project success and hence company performance. These less good practices were suggested to be, in part, a consequence of working to a particular procedure and not taking full account of the characteristics of particular projects. Essentially this arose through a lack of awareness of the more subtle influences of the project context. The limited knowledge of the different engineering design approaches and the available methods possessed by some firms was a notable example of this. Working to a particular procedure meant that the effectiveness of the process was less than it could have been. A particular concern was that a majority of companies did not have appropriate resources and mechanisms in place to identify and implement opportunities for process improvement. It is also worth noting that difficulties encountered by companies during projects, were frequently not technical, but managerial in origin. Technical difficulties tended to occur at a more general level, for example, in relation to the selection and implementation of CAE support tools. Notwithstanding the shortcomings highlighted in companies' practices, it should be stressed that there was a considerable amount of good practice being implemented within the companies studied, and that many of the instances when best practice was not applied reflected genuine constraints on its application rather than poor practice on the part of the companies.

The research has shown that, as a result of the complex and diverse nature of companies and their competitive environments, good practice for any one company is dependent on its own unique attributes. Moreover, project specific factors, such as the degree of innovation envisaged, whether a contract was involved or not, the integrational requirements, or the presence of key supply items, were found to be particularly influential. These were found to determine aspects of project organisation, processes and activities, the degree of concurrency between disciplines, design strategy, design methods, tools and techniques, and project management and decision making procedures.

Therefore, the principal conclusion from the research was that, in seeking to model the engineering design and product development processes, it is inappropriate to think in terms of a single general model or models for particular types of company. Instead it is better to think in terms of a framework that enables the engineering design and product development processes to be assessed and interpreted in the context of a particular company. This conclusion runs counter to previous (and acclaimed) research in the field which has sought to develop and promote generic models having a broad applicability.

8.2 Implications for Research and Industry

Many of the recommendations of the existing literature have been criticised in this thesis, not least for being prescriptive. These are not criticisms of the particular models and approaches, which have been proposed as efficient and effective ways of performing design and development activities, but of their intended application to some companies and situations.

The first criticism relates to attempts to generalise the models' applicability beyond the context in which they were developed. The generality which has often been claimed by many of the models' authors and proponents was often not supported by this research. For example, the best practice evaluation described in Chapter 5 demonstrated that many features of the product development models, which have been predicated on the basis of particular industries and companies, were not applicable to the companies studied.

The second criticism concerns the emergence of preferred or consensus models. For example, Chapter 2 discussed the support accorded in the engineering design literature to problem-focused strategies (see, for example, Pahl and Beitz (1984)). A consensual view of design is desirable in the sense that it might lead to improved and consistent standards of design practice. However, being systematic and consistent does not mean that this should be a narrow view based on a single approach. Frequently a number of alternative models, and variation of these, exist. It could be argued that a designer with an holistic view of design and an awareness of several approaches would be better equipped to undertake a design problem than one adopting the same approach to all problems. However, few of the key engineering design texts consider or discuss the relative merits of these different models.

The third criticism concerns the failure of the proponents of particular models to consider the true industrial context (for an exception, see Hales (1993)) and, therefore, the constraints on their use. For example, this research has supported previous studies in finding that many design practitioners do not adopt the approach prescribed by most of the engineering design models. Moreover, it identified that a variety of constraints faced by design practitioners (e.g. product development policies, time and resource constraints, the designers skills, etc.) influenced their chosen method.

These criticisms, coupled with the findings of this research, suggest that future research in the field of engineering design and product development should adopt a more holistic approach which takes account of, and reflects on, the company context. This does not preclude the development of new models which enrich our knowledge of the field. This should be welcomed. However, it is important that they are developed with a greater focus on, and awareness of, their intended purpose. Essentially this requires researchers to contemplate models for interpretation rather than pure prescription. This represents a major challenge to researchers.

Given that there is a need to ultimately consider the context in which engineering design and product development takes place, the research also raises important methodological implications for future conduct of research in the field. The research methodology adopted for this research arose from the need to be able to capture the complexity of manufacturing organisations and the causal relationships between their characteristics and their engineering design and product development practices. This involved a partial rejection of the approach commonly adopted by engineering scientists, based on the postulation of a model and its subsequent testing, in favour of a more exploratory, but nevertheless structured and systematic method. This required the use of research skills (questionnaire design, case study and interviewing skills, etc.) which traditionally have been associated with the social sciences. Engineering design and product development are fundamentally social processes. Therefore, if engineering researchers are to develop effective models and methods, and be able to apply the enabling technologies they develop, then it is essential that they should be equipped with more than a superficial understanding of these research methods and skills. To do otherwise would be myopic. This does not preclude research from being carried out according to the traditional methods of engineering science. Moreover, in the context of engineering design, Fulcher and Hills (1996) have postulated the possibility of developing a hybrid form of applied research. Certainly a broader set of research methods and skills are implied. Developing these and identifying when it will be appropriate to use them represents another major challenge for researchers, but one which the author believes is an important and necessary requirement for the continued development of engineering design and product development methodologies.

This research has been undertaken because of a concern for the difficulties companies face in managing the complex processes of engineering design and product development and the considerable onus placed on companies when developing design and product development procedures appropriate to their specific circumstances. However, despite the complex nature of the issues to be considered, for a given company and, notwithstanding the fact that changes will occur over time, many of its defining characteristics may be assumed to be relatively constant. Examples of these are the size and structure of a company, the products it makes and the markets it targets, and the types of project it undertakes. The implication of this is that, having identified the necessary design and product development requirements, standard procedures may be established within broadly similar product and market areas for the basic types of project undertaken, provided sufficient flexibility is incorporated to accommodate variations between projects.

Whilst this research has developed and demonstrated a contextual framework which allows an understanding of a company and its development practices to be captured the implementation issues also need to be considered. What is required, therefore, is a framework that allows companies to analyse their processes and the key factors they need to take into account. This would enable companies to define themselves in terms of their critical attributes (firstly, at the level of the company as a whole, and secondly, in terms of its products and markets), ascertain their strategic policies, and then relate these to the general and company specific features of product development practices. In this way, rather than attempting to implement an inappropriate generic model, or best practice recommendations predicated on conditions that do not exist within the company, the product development process can be defined to meet the inherent needs of the company. A particular development would be to provide an implementation tool (e.g. in the form of a workbook) which may be used by industry or the national and regional support agencies (DTI, TECs, Business Links, etc.). The findings of the research should therefore be of interest to those involved in the development of policies to support industry and the providers of this support.

Chapter 9

Areas for Further Research

This research has demonstrated the importance of developing an understanding of the context of companies and projects and how this influences the engineering design and product development processes. There are a number of areas, however, where further research would be beneficial.

The contextual framework is a new approach and some further work is required to refine the framework and to establish its wider applicability. Firstly, with the resources available it was not possible to investigate thoroughly the influence of all aspects of the contextual framework. These areas warrant further study. Secondly, although the framework takes a holistic view, it is not comprehensive and, therefore, there is a need for further development and refinement of the framework, including the addition of other factors as appropriate. For example, the contextual framework includes a number of factors which capture the companies strategic policies. There is considerable scope to develop this further in order to provide a greater appreciation and discrimination of the broad strategic context. Most companies operate within a product value system (PVS) involving many different types of organisation engaged in various roles and relationships (Alderman, 1996). The requirements and demands on the design and development function of an organisation ultimately will be determined by the organisations strategic positioning and its policies for acquiring competitive advantage, what this means for the value to be delivered to the customer, and how this should be provided through the assembly of the various elements of design, manufacture, finance, project management, and so on, which may be both internal and external (i.e. customers, suppliers, suppliers' suppliers, consultants, regulators, financiers, etc.) to the organisation. Understanding the role of design and the implications for the design processes in this wider system context, including where and how it levers competitive advantage, is an important consideration. In addition, the framework as it currently stands includes what may be termed the hard organisational factors. There is scope to extend this to include the important human, cultural and political influences which exist within and beyond establishments. Thirdly, the competitive environment and the characteristics and practices of companies are themselves undergoing a process of continuous evolution. For many manufacturers of capital goods, for example, increasing attention is being given to the strategic importance of procurement and the make / buy decision (Venkatesan, 1992). In some cases this is resulting in externalised manufacture and supply with companies focusing their capabilities on design and project management and through life support services. New forms of contracting relationship are also emerging which allow for shared risks between customers and suppliers, see, for example, ICE (1993). A consequence of such changes is that the contextual framework proposed by this research and the causal relationships which have been associated with it also must be regarded as being subject to change.

The research has looked at establishments of varying size. However, this did not extend down to those employing much less than a hundred employees. The economic importance of such companies to the UK economy is frequently stressed by government and academia. There has been very limited research focused exclusively on the engineering design and product development practices of small firms. This may reflect the difficulties of engaging small firms with their limited resources in academic research. However, an appropriate research methodology could overcome this.

The research focused on the mechanical engineering sector of UK manufacturing industry. This was necessary to provide sufficient focus to the research. A useful study would be to undertake further investigations in other industry sectors, the automotive, electronic, construction, pharmaceutical and chemical process industries, for example. In particular, it would be worthwhile applying the research framework's ability to discriminate between company characteristics to the electronic and automotive industries. These sectors were the source of many of the general recommendations of the literature on best practice. A key research question is whether the competitive environment and company practices do in fact apply generally across these sectors as has been claimed.

A further consideration would be to consider regional variations in company practices. Secondary analysis of the full interview survey data (as yet unpublished) indicated differences in practices between different northern UK regions. Undertaking a more extensive study across different UK regions in order to identify and explain such regional variations would provide valuable information to both national and regional policy makers. Studies also could be undertaken on an international scale. The European Union (EU) has funded a considerable amount of fundamental research into the development of advanced technologies through a number of programmes such as ESPRIT (European Strategic Programme for Research and Development in Information Technology), BRITE (Basic Research in Industrial Technologies for Europe, EUREKA, and so on. A major issue for the EU is how successfully these technologies are being adopted and brought to market as new products by companies in the various member nations. The framework could provide a basis for a comparative study of different European countries to enable differences between the characteristics of companies and their practices in these countries to be identified and considered. Similarly wider international studies could involve companies in established industrial nations such as America and Japan as well as companies in some of the newly industrialised countries.

This research has focused on the engineering design and product development processes. The research framework in its broadest sense may also have application to other research fields which deal with problems relating to the management of organisations.

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Appendices

Appendix A - Introductory Interview Aide-memoire

Appendix B - Case Study Interview Schedule (Aide-memoire)

Appendix C - Interview Survey Questionnaire

Appendix D - Performance Measures

Appendix A

Introductory Interview Aide-memoire

Section 1 - Introduction and Company Classification

Introduction*

- Background to the project
- Outline methodology
- Cooperation and benefits
- Project deliverables.

The Company, Products and Markets

- Company (Corporate) Structure*
  Size (employment)
  Ownership: Independent or Group

- Markets*
  ETO/CMTO/MTO/ATO/MTS
  Size/Share
  Home/Export
  Europe
  Globalisation

- Products*
  Complexity
  Product Groups/Range
  Technological Content

- Competition*
  Number/Size
  Competitive Criteria

- Processes
  Complexity
  Flexibility
  Internal Span of Process

- Supplier Environment
  Degree of Control Over Suppliers
  Supplier Rationalisation
  Collaboration/Partnership
  Location
  JIT Delivery

What are the change characteristics with regard to the above?

Section 2 - Strategy, Organisation and Product Development

Summary Sheet

- Strategies

    Areas Covered
        Business
        Marketing
        Product Development
        Manufacturing
        Information
    Formulation Process
    Integration/Interaction of Areas
    Communication

- Organisation*

    Overall Structure
        Organisation Chart (Corporate and establishment)
        Type of Structure

    Organisation of Product Development
        Type of Structure
        Responsibilities
        Functions/Specialists Involved
        Key Individuals

- Product for Study*

    Type/Description
    Nature of Change
    Reason for Change
    Past/Current Project

- Product Development*

    Description of Process
    Top Management's Involvement
    Performance Assessment

- Supplementary Questions

* Indicates priority areas in the event of time constraints

Section 2 - Strategy, Organisation and Product Development

Strategies

"We would like to gain an impression of the strategic thinking of the business and how product development fits into this."

What is the company focusing on to be successful in its markets?

Are there strategies covering the following areas, and are they formally documented?

Business
Marketing
Product development
Manufacturing
Information

How has the strategy development process been organised?
- Strategy integration & interaction of strategy areas?

Does the product development strategy define:
- Types of market?
- The sorts of products to be developed?
  e.g. new/improved
- Areas for research?
- Key technologies
- Resources required?

Is the product development strategy communicated to all?

Who is responsible for information strategy/systems development?

Internal Organisation

"We would like to discuss the organisational structure of the establishment and nature of the product development process"

Can you provide (or describe) an organisational chart?

Type of organisational structure overall?
- Functional, matrix, business?
- Teamworking?

What type of organisational structures are used to implement the product development activities?
- Functional, project management, matrix, project teams?
- Teamworking?

Are clear lines of responsibility laid down for product development, and is it clear who is ultimately responsible for different types of product development?
- Who is ultimately responsible?
  e.g. Director, senior manager.
- Who manages product development on an on-going basis?
  e.g. Product manager, design manager, R & D manger.
- What is their background?
  e.g. Marketing, Design.
- Who leads individual development projects?
  i.e. team leader.

Which functions/specialisms are involved in the product development process?

Market & Product Planning
Design
R & D
Finance
Cost Estimating
Purchasing
Planning
Production
Quality
External Partners / Alliances
Others

How are they organised?

Who are the key individuals?

Do you distinguish between the management of R & D and product development?

Products for Study

"We would now like to turn to the subject of the product(s) which would be most appropriate for study"

Product development options for study?
- Product type and description?
- Nature of the change?
- Reason for the change?
- Past/current project?

Product Development Process - Top Management

"We would now like to discuss some general aspects of the product design process."

Would you please describe the product development process in detail? You may wish to consider the particular product/project identified for study. We would like you to indicate the main stages and events as you think they occur, describing what takes place and elaborating where possible on the relationships between those involved in the process.

How are you (Top Management) involved in the product development process and at what stage is your involvement greatest?

How do you assess the performance of the product development process?

Supplementary Questions

Are there any aspects of the product development process which cause difficulties, or which you consider unsatisfactory?
What changes could/should be made?

Are there any aspects about product design and development you think are important but have not been covered in this discussion?

Have the following been determined:

Company suitability and commitment?
Product / project for study?
Key individuals for interviewing?

Appendix B

Case Study Interview Schedule (Aide-memoire)

Question Module No.1.

Verification of Product to be Studied

- Product description - Functionality, key systems and technologies.

- What was the reason for the product change/development?
  e.g. business strategy, market need, technology opportunity, production process.

- What was the nature of the product change?

How is the overall product change best described?

New core product
Major enhancement to develop a new product platform
Major enhancement to an existing product
Minor improvement

Does the product change represent a substitution for an existing product or model, or an addition to the firms total product/model range?

How is the change best described at the subsystem and component levels?

Which attributes of the product have changed and how?

Function	Mechanical (hydraulic, fluidic, etc.)
Electrical/electronic	Software (e.g. control systems)
Materials	Standards
Dimensions (e.g. size, shape, etc.)	Complexity (BOM, parts count)
Spares (e.g. % serviceable parts)	Packaging
Price	Etc.

- What are the benefits of the changes to the firm?

Improve product performance	More competitive price
Improved quality	More applications
Greater product range	More market opportunities
Increased profitability	Increased sales
Reduced inventory	Change in bought-out parts
Easier assembly	Improved labour utilisation
Improved productivity	Reduced lead-times
Parts reduction	Modularisation
Standardisation	Parts commonality
Etc.	

- Marketing

What % of sales market share and size is accounted/forecast by the product?
What is the anticipated life of the product?

What criteria determine the total offering?
What are the order-winning and order-qualifying criteria?

Price	Time-to-market (product development)
Delivery lead time	Delivery conformance
Quality / reliability	Performance
Technical	Warranty / guarantees
Service & support	Etc.

Has the nature of required customer service and support changed?

Question Module No.2.

Strategy Formulation Module

"We would like to gain an impression of the strategic thinking of the business and how product development fits into this."

- Are there strategies covering the following areas, and are they formally documented?

  Business
  Marketing
  Product development
  Manufacturing
  Information

- How has the strategy development process been organised?
  - Strategy integration & interaction of strategy areas?

- What is the company focusing on to be successful in its markets?
  - CSF's, goals and objectives, and strategies of the business?
  - Present / future product development strategy / plans and relation to the business strategy?

- Does the product development strategy define:
  - Types of market?
  - The sorts of products to be developed (e.g. new/improved products)
  - Areas for research?
  - Key technologies?
  - Resources required?

Is the product development strategy communicated to all?

- Who is responsible for information strategy/systems development?

- Is design / technology represented at a senior level in the organisation?
  - Group?
  - Company director, senior manager?

Question Module No.3.

Product Development Process (Common Module)

The aim of this module is to obtain from the key individuals identified at the introductory interview stage a *description* of the product development process, the development project for study, and their role within it. It will also allow the degree of shared understanding of the product development process across functions and at differing levels to be ascertained. The aim should be to obtain responses from at least marketing, design and production specialists. *The particular product / project selected for study should be used as the basis for discussion.*

- Description of Process

"We would now like to discuss some general aspects of the product development process."

Would you please describe the product development process for the product / project? We would like you to indicate the main stages, activities and events as you think they occurred, describing what took place and elaborating where possible on the relationships between those involved in the process.

- Roles and Interactions

"We would like to clarify your role within the product development process."

How were you involved in the product development process?
- At each stage what was your role?
- What is the degree of your involvement (e.g. % of your time was involved)?

Who inside/outside the project team did you need to collaborate with, and what was the nature of the collaboration?

Customer	Suppliers
Sub-contractors	Universities
Research Organisations	Regulatory Bodies
Support agencies	Competitors
Etc.	

- Information

What were the key sources and outputs of information (documents etc.) at each stage of the development process?

(Use the guidance checklist - Design Information Records and Documentation).

Which were internal / external?

- What were the major problems, challenges and difficulties you encountered during the project?

What changes could / should be made?

Question Module No.4.

Engineering Design Process

Design Models

Are you aware of any models of the engineering design process?

Do you have any texts on engineering design? (See guidance list - Design Texts)

Do you organise product design and development to a particular model(s)?

Design process

"We would like to ask you a few questions specific to the stages of the design process."

- Problem definition / specification

By what process was the design problem understood and the design requirements specified?

a) a definitive design brief / specification was provided from which the design proposal was developed.

b) an appraisal of the design problem / requirements was undertaken either by:

Analysis and clarification of the problem (i.e. problem focused)

Using existing design concepts and developing potential solutions to the problem in order to verify the customer requirements / understand problem prior to fixing the specification (i.e. product focused)

- Conceptual / detail design

What approach (design strategy) was adopted to develop the design proposal(s)?

(A) An initial solution was generated, developed and evaluated. If this proved inadequate in some way it was either modified or another solution was sought.

(B) Several solution ideas were generated, and through progressive development analysis and evaluation a preferred solution was selected.

By what means did you evaluate the possible solutions?
(See guidance list - Design Methods and Techniques)

What were the evaluation criteria?
e.g. customer requirements, elements of PDS, etc.

How many alternatives were considered before the concept was fixed?

At what point was the concept fixed?

At what stage(s) were the embodiment (layout, form, shape, and material) issues considered?

- Methods

Can you describe the methods/techniques applied during the development process?
(See guidance list - Design Methods and Techniques)

When and for what purpose were they used?

- Design for's

At what stage and how were material and production techniques (i.e. producibility engineering) identified?

What other 'design for' considerations were there?

Performance	Reliability
Maintenance and support	Environment
Product withdrawal	Safety
Etc.	

When and how were these issues addressed?

- Models, mockups and prototypes

When and for what purpose were models, mockups or prototypes used during the development process for the product, assemblies, or components?

Was the customer involved?

What were the implications for the design process?

- Costing

When, how and for or what purpose were cost evaluations produced?

Question Module No.5.

Research and Development

The introductory interview stage should have identified; how R & D is organised within the firm e.g. Separate function, or within design; and whether there is a distinction between the management of R & D and product development. If not, then these should be determined here.

"We would like to discuss the specific role and organisation of R & D"

- How are research needs identified?
  e.g. existing product or process failures, product development support, long term basic research.

Who identifies the need?
e.g. marketing, R & D, production, customer.

- What is the proposal procedure?
  - written proposal
  - standard format

- What is the screening procedure?

Is it formal and documented?

Who screens and authorises projects (e.g. single person/committee)?

Is it a strategic decision (i.e. proactive or reactive)?

What are the evaluation criteria? (See guidance sheet - R & D Project Evaluation Criteria)

- Is there an R & D budget?

On what basis is it established?
- comparison with other firms
- % T/O or % profit
- reference to previous budget

What is the basis for allocation of R & D resources?
- categories of activity e.g. basic development
- to broad areas of firms activity e.g. division
- general objective areas
- particular projects

Are R & D / design staff allowed time to monitor / develop ideas?

- Were there any R & D requirements for the product(s) to be studied?

How were they organised?

Note: 'New & Improved Technology Management' in Organisation, Planing and Control (Module 8) may be relevant here.

Question Module No.6.

Market & Product Planning

- What specific marketing techniques do you use?
  (See separate guidance sheet - Design Methods and Techniques)

- Are there formal procedures for collecting ideas?
  - Product proposal forms?
  - Regular product planning meetings/committees?
    e.g. Product council?
  - Specific item on agenda of meetings?
  - How often does this occur and at what levels?

What are the internal/external sources of ideas?

Customer enquiries	Customer suggestions & complaints
Senior management	Suppliers
Market survey analysis	Sales force feedback
Competitors' products	In-house R & D
Outside consultants	Universities
Patent searches	Standards, codes and regulations
Literature reviews	Manufacturing
Suggestion scheme	Brainstorming sessions
Technology forecasting	Etc.

- Is there a formal evaluation and selection process?
  e.g. feasibility study and investment appraisal?

How does it operate?

How often does this occur and who is involved?

Are there clear screening criteria and are they documented?

What are the evaluation criteria?

- Is an initial brief of the market requirements produced?

Who is involved in its preparation?

Is it possible to have/see a copy of the brief?

How is it organised and what does it cover?
  - product title?
  - purpose it will perform?
  - competing products?
  - markets served?
  - what it is to do?
  - anticipated performance?
  - competitors?
  - why the need?
  - anticipated demand/risk?

Question Module No.7.

Product Design Specification (PDS)

- Is a specification produced for every product development project and was a specification produced for the specific project?

What different types of brief / specification are produced
e.g. product / market brief, product design specification, separate marketing and functional specifications, etc?

- How was the PDS developed?

Who was involved in writing it?
e.g. Team, Marketing or design task

Do you follow a set procedure?
- Is it formally documented?

Do you use checklists/identify crucial factors and elements?

- Specification characteristics

Is it possible to have/see a copy of the PDS?

Is the specification of a standard format?

Does it comprise clear, succinct statements of the engineering requirements setting quantitative targets under functional headings?

Does it express wants and wishes?

Do the requirements define what is required rather than what it will be?

Is the specification continually updated and changes dated against the modification?

Question Module No.8.

Organisation, Planning and Control - Summary Sheet

Project Objectives, Performance Criteria and Constraints

Project Organisation
- Team Management
- Internal Functions / External Organisations Involved

Project Planning
- Planning Techniques
- Milestone/Task/Resource Definition
- High Risk Areas
- Sample Planning/Control Documentation
  - Planned Vs Actual - Why?
  - Front End Duration

Design Procedures & Standards
- Procedures
  - Areas Covered
  - Adherence
  - Baseline Models and Improvement of the Design Process
- Codes/Regulations/Standards
  - External/Internal

Project Review & Design Review
- Meetings
  - Form, Length & Frequency
- Design Reviews
  - When & who Involved
  - Procedure / Review Criteria
  - Intermediate Reviews
  - If not - Who/How Approved
- External Approval
- Project Reviews
  - Was Progress Monitored/Reported
  - Review Meetings
  - When/How/Who
  - Objectives & Criteria

Design Changes
- What Changes
- Source
- When
- Effect

New & Improved Technology Management
- New, Modified & Existing
- Re-usability Assessment
- Technology Readiness Assessment
- High Risk/Off-line R & D
- Implications of New or Improved Technology
  - Design, Procurement, Production, Etc.
  - When Identified/How Satisfied

Question Module No.8.

Organisation, Planning and Control

Project Objectives

- Are clear objectives and performance criteria set for the project?

What objectives and performance criteria were applied to the project?
(See guidance sheet - Project Objectives and Performance Criteria)

How were they determined?

- What constraints were applied to the project?
(See guidance sheet - Project Constraints)

When and how were they identified, and how were they tackled?

Project Organisation

- How was the project organised?

a) During the project initiation / tender stages

Function / department	Interfunctional cooperation
Project team	Committee
Etc.	

b) During the main project stages

Functional	Project Management
Matrix structure	Project team
Autonomous team	Multi-project structure

If a team-based project structure was adopted was it a single core team or one which extended into the functions?

Were the principles of teamworking and co-location applied?

- Who was responsible for the project (i.e. the project leader)?

Which functions and individuals were involved?

What was their level of seniority?

What was their commitment (permanent or temporary and full-time or part-time)?

Were there formal inputs by external organisations (i.e. customer and suppliers)?

What was the level of involvement of the internal functions, customers and suppliers during the different stages of the project?

Project Planning

- Was a project plan produced for the project?

Can you provide sample planning/control documentation for the project?

What techniques and tools were used to plan and control the project?
e.g. Gantt charts, task lists, CPM/PERT networks, project management software.

Did the project plan define:
- Critical milestones, decision points, progress reviews, design reviews?
- Task descriptions, objectives, schedule, resourcing, skills, & costs?

Were high risk areas identified and what were the contingencies?

- Was planned and actual performance monitored?
  - How long was the development scheduled to take?
  - How long did it actually take?
  - If different, what reasons can be attributed?

How long between identifying market need/idea to authorising and committing resources and project start i.e. 'fuzzy front end'?

What is the current performance against due date for development projects?

Design Procedures & Standards

- Is there a standard set of design procedures?

What do they cover?

How detailed are they?

How closely are they adhered to?

If speedy product development is important, have you recently reviewed your procedures?

- In attempting to understand the product development process have you developed a data flow model/activity analysis?

Have generic (baseline) models been developed?

What steps (if any) have been taken to reduce design lead-times e.g. parallel activities?

How do you think the design process might be improved?

- What codes/regulations/standards affected the design?

- What Internal company standards have you developed and why?

Project Review and Design Review

- Meetings - what were their form, length and frequency e.g. progress meetings, design reviews?

Design Reviews

- Were design reviews undertaken?

When were they undertaken (i.e. key milestones, intermediate milestones, problem)?

How were they organised -who is involved and who chaired the meeting?

Did they follow a set procedure?
- Procedure written down?
- Checklist used?
- Agenda?
- Minuted?

Were major design reviews held separately to other meetings (i.e. separate from project review meetings)?

- Are intermediate design reviews held?

How are they organised - Informal/formal, etc.?

If design reviews were not held how were decisions/approvals made?

- Did external design approval need to be sought e.g. Safety, quality, customer requirement.

How long did it take?

Project reviews

- How was progress monitored and reported?
- Were progress / project review meetings held?

How were they organised?

Who was involved?

Did they include go/no-go decisions?

How and when were resourcing (£) decisions made (e.g. phased funding)

Are objectives and evaluation criteria clearly defined?

What are they?

Design Changes

- What changes/modifications to the design were requested?

Where did they originate?
- Customer
- Design / Engineering
- Manufacture
- Assembly
- Purchasing (e.g. unable to obtain parts on time)

At what stage in the development process were these changes requested?

What was the consequence of these design changes (e.g. time delays and increased product costs)?

How were the changes assessed?
- against criteria in the product specification, based on experience, etc.?

- Have any problems been identified with the new product in the field?

What are the causes and how were they overcome?

New & Improved Technology Management

- What proportion of the product consists of new technology, modified technology, and existing technology?

How does it compare with the previous model?

- Did you assess the re-usability of existing/possible solutions to systems, assembles, modules and components?

- Did you assess readiness of potential new technology / modified technology for use in the product's systems, assembles, modules and components?
  e.g. Can the technology be manufactured with known processes?
  Are critical parameters that control the function identified?
  Safe operating latitude and sensitivity of the parameters known?
  Failure modes identified?
  Hardware exists demonstrating answers to above questions?
  Is the technology controllable throughout the products life cycle?
  (Reusability and technology readiness are important to project risk evaluation, producibility, reliability)

- Is new technology development kept off-line, through market/strategic led R & D?

- Did any new/modified technology have implications for design, procurement, production, etc.?

Product design:
- localised risk via separate problem/team
- backup contingencies
- outside sources e.g. customer, supplier, academic

Procurement:
- make/buy/subcontract
- design input e.g. collaborative input/partnership
- new suppliers
- new performance e.g. tolerances, defect levels
- single or multi-sourcing

Production:	- span of process i.e. make/buy - required new processes to company/industry - modifications to existing processes - new/additional machinery - new use of existing equipment - change in dedicated/general use - flexibility/automation - effect on information capture/feedback
Process quality:	- revised process tolerances and/or QA assessment procedures
Skills:	- retraining required - services bought-out

At what stage(s) were these implications identified?

How were the new requirements satisfied?

Question Module No.9.

Production Issues

- What are the types of manufacturing process?
  - Project, job, batch, line
  - MTO, CMTO, ETO, MTS

What is the complexity of the process i.e. the number and type of processes?

What is the process flexibility i.e. product/process mix handled

How are the manufacturing and assembly processes organised?
- functional, product module / cells, etc.

What proportion of the product is manufactured internally (i.e. internal span of process)?

- Is there a manufacturing strategy and is it formally documented?

How does manufacturing input into business strategy formulation and integrate with the other strategic areas?

What are manufacturing's key strategic goals/objectives and how do these relate to the CSF's of the business?
e.g. Lead-time reduction, quality improvement, cost reduction, flexibility, due date performance, etc.

How is manufacturing responding to these key objectives?
e.g. JIT, inventory reduction, new machinery, training, etc.

What measures are used to assess effectiveness?
e.g. Stock-turn ratio, m/c utilisation, P:D ratio, distance travelled, changeover time, schedule adherence, etc.

What requirements resulted (or should result) for the upstream product development activities of marketing, design and purchasing?
e.g. Logistics considerations (lead-time reduction, reduced inventories and flexibility) requiring standardised processes and standard components common to a variety of products, with variability at assembly, etc.

- Has the product/technology had implications for Manufacturing?

Production:
- span of process i.e. make/buy/sub-con
- required new processes to company/industry
- modifications to existing processes
- new/additional machinery or new use of existing equipment
- change in dedicated/general use
- flexibility/automation

Quality:
- revised tolerances and/or QA assessment procedures.

Skills:
- retraining, services bought-out, etc.

At what stage(s) were these implications identified?

How were these new requirements satisfied?

Question Module No.10.

Information Systems

- Is there an explicit IT strategy?

Is there an individual responsible for IT matters?

Are there criteria for evaluating the quality of information?

Have departmental analyses been carried out?
e.g. As part of TQM improvement effort

- Can you indicate the use of electronic/computer and traditional media within the product development process?

What CAE (design and development) systems are there (hardware/software)
- PCs and workstations?
- Networks (LAN / WAN etc.)?
- Software applications?

What is their purpose and at what stages are they used?

Is drafting on CAD?
- What % of drawings?
- 2D or 3D?
- Product data base?

Is design information shared by common data bases?

Are local data base / spreadsheet programs used?

- Does the design department have access to other company data (e.g. is production cost, quality data collated and reported)?

What planning and production systems are there and to what extent do they interface with the design data bases e.g. CADCAM?

- What are your information links to other firms e.g. EDI, Shared CAD data, E-Mail, FAX?

- What implications did the product have for information systems?

Were any changes required?

What changes/enhancements do you plan for the future?

Question Module No.11.

Quality

- Does the company operate a quality system?

Is it compliant with ISO 9000 / BS5750 or equivalent?

Does the company have a policy towards Total Quality Management (TQM), continuous improvement, quality circles?

Does this include the design/product development area?

- Has a departmental analysis been undertaken, and performance improvement targets established?

- At what stages in the product development process were QA/QC issues addressed, and what did this entail (e.g. reusability, technical readiness, process capability assessment, robust design, FMEA)?

Has the product had any impact on quality procedures (e.g. standards, testing procedures, training, tolerance requirements, defect/rework levels)?

Have the quality targets been met?

What QC procedures are applied in production (e.g. SPC)?

How were tolerances established?

Question Module No.12.

Performance measurement

Do you apply any form of performance measurement to the product development process for monitoring and assessing effectiveness (e.g. at project, department, and strategic levels)?

Do the performance improvement targets reflect the goals of the business strategy?

Question Module No.13.

Supplementary questions

Are there any aspects of the product development process which cause difficulties, or which you consider unsatisfactory?

What changes could / should be made?

Are there any aspects about design / product development you think are important but have not been covered in this discussion?

Are there any comments you would like to make about the question you have been asked?

Guidance Lists

Guidance List - Design Information Records and Documentation

Design Stage	Documentation
Market	Description of Customers Customer Requirements Weighting of Customer Requirements Competition Benchmark Vs Customer Requirements Engineering Requirements Competition Benchmark Vs Engineering Requirements Engineering Targets Product Design Specification
Project Planning	Tasks and Milestones Task Objectives Personnel (Resource & Skill) Requirements of Tasks Time requirements of Each Task Schedule of Tasks
Concept Generation	Functional Decomposition Diagrams Literature and Patent Search Results Morphological Charts Sketches of Overall Concepts*
Concept Evaluation	Documents to Support Technological Readiness Decision Matrices Data from Models
Detail	Layout Drawing* Detail and Assembly Drawings Bill of Materials / Parts Listings Component Specifications Cost Estimations Decision Matrices Data from Performance Evaluation Models Installation, Operation, Maintenance Instructions Retirement Instructions Patent Applications
Manufacture	Manufacture and Assembly Data Quality Control and Quality Assurance Data Engineering Change Notices

* The stage for which initial provision of layout/form information is assigned, is dependent upon whether embodiment is categorised as a conceptual or detail design issue.

Guidance List - Design Texts

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Krick,E.V. (1969) *Engineering and Engineering Design.* John Wiley & Sons, New York.

Pahl,G. and Beitz,W. (1988) *Engineering Design.* The Design Council, London.

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Smith,P.G. and Reinertsen,D.G. (1991) *Developing Products in Half The Time.* Van Nostrand Reinhold, New York.

Suh,N,P. (1990) *The Principles of Design.* Oxford University Press.

Ullman,D.G. (1992) *The Mechanical Design Process.* McGraw-Hill, London.

Walsh,V, Roy,R, Bruce,M, and Potter,S. (1992) *Winning by Design.* Blackwell Publishers, Oxford.

Guidance List - Design Methods and Techniques

Design Stage	Formal Method
Market	Literature searches
	Patents; Reports, proceedings, and reference books; Market data publications; Statistical data; Product data for competitive and analogous products
	Parametric analysis
	Matrix analysis
	Competition analysis
	Literature, sales reports, trade fairs & exhibitions
	SWOT analysis
	Reverse engineering
	Market research analysis
	Sales data; Economic; Political; Legal; Technological innovation; Demographics; Market trends
	Need analysis (Customer requirements)
	Market feedback mechanisms
	Customer complaints; Field (service) reports; Sales reports.
	Customer interviews & customer questionnaires
	Competition benckmarking
	Quality function deployment (QFD) matrices
Specification	QFD matrices
	Engineering requirements
	Competition benchmarking
	Engineering targets
	Performance specification method
	Specification checklists & questionnaires
Concept	Concept Generation
	Objectives tree & functional decomposition
	Principle of division of tasks
	Design catalogues
	Literature and patent search results
	Function-concept mapping (Morphological charts)
	Concept Evaluation
	Feasibility judgement (Gut feel)
	Technology readiness assessment
	Go/no-go screening (customer requirements)
	Evaluation matrix (relative or weighted objective)
	Graphical or physical mockups
	Design review
	QFD matrices
Detail	Product Generation
	Component design specification
	Engineering design standards
	Producibility engineering (Mat'ls, form, process)
	Product Evaluation
	Evaluation matrix (engineering requirements)
	Evaluating performance
	Analytical, physical & graphical model development
	Evaluating costs
	Design review
	Design for manufacture and assembly (DFMA)
	Taguchi/Robust design
	Failure mode effect analysis (FMEA)
	Value engineering
	Functional cost analysis
	QFD matrices
	Prototyping and testing
	Manufacturing process design
	QFD matrices
	Process capability studies

Design Methods and Techniques (Continued)

Creative Methods

Brainstorming
Synectics
Analogy
Attribute Listing
Checklists
Inversion
Combination

Domain Dependent Methods

Vibration Analysis
Mechanical Stress Analysis
Finite Element Methods
Fluid Dynamics Methods
Efficient Circuit Design
Electrical Stress Analysis
Flow Calculation
Thermal Calculation
Etc.

Guidance List - R & D Project Evaluation Criteria*

Corporate objectives, strategies, policies, and values
- Is it compatible with the company's current strategy and long range plan?
- Is its potential such that a change in the current strategy is warranted?
- Is it consistent with the company 'image'?
- Is it consistent with the corporate attitude to risk?
- Is it consistent with the corporate attitude to innovation?
- Does it meet the corporate needs for time-gearing?

Marketing criteria
- Does it meet a clearly defined market need?
- Estimated total market size.
- Estimated market share.
- Estimated product life.
- Probability of commercial success.
- Likely sales volume (based on above)
- Time scale and relationship to the market plan.
- Effect upon current products.
- Pricing and customer acceptance.
- Competitive position.
- Compatibility with existing distribution channels.
- Estimated launching costs.

Research and development criteria
- Is it consistent with the company's R & D strategy?
- Does its potential warrant a change to the R & D strategy?
- Probability of technical success.
- Development cost and time.
- Patent position.
- Availability of R & D resources.
- Possible future developments of the product and future applications of the new technology generated.
- Effect upon other projects.

Financial criteria
- Research and development cost: (a) capital (b) revenue.
- Manufacturing investment.
- Marketing investment
- Availability of finance related to time scale.
- Effect upon other projects requiring finance.
- Time to break-even and maximum negative cash flow.
- Potential annual benefit and time scale.
- Expected profit margin.
- Does it meet the company's investment criteria?

Production criteria
- New processes involved
- Availability of manufacturing personnel - numbers and skills.
- Compatibility with existing capability.
- Cost and availability of raw material.
- Cost of manufacture.
- Requirements for additional facilities.
- Manufacturing safety.
- Value added in production.

Environmental and ecological criteria
- Possible hazards - product and production process.
- Sensitivity to public opinion.
- Current and projected legislation.
- Effect upon employment.

*Ref: Coombes et al, Economics and Technological Change, 1987

Guidance List - Project Objectives and Performance Criteria

- Reduce Lead-Time
- Meet Launch / Delivery Date
- Minimise Total Changes
- Minimise Costs
    - Development Cost
    - Production Cost
    - After Sales Cost
    - Maintenance Cost
    - Life Cycle Cost
- Increase Profitability
- Reduce Parts Count
- Reduce Part Families
- Improve Conformance to Performance Specification
- Improve Producibility
- Improve Reliability
- Improve Maintainability
- Minimise Environmental Cost
    - Safe Process/Operation
    - Safe Retirement
- Improve Quality
- Increase Technology, Added Value and Knowledge Input
- Minimise/Maximise Bought Out

Guidance List - Project Constraints

- Requirement for Modular Design
- Design for's
    - Manufacture
    - Reliability
    - Testability
    - Maintainability
- Use Only Existing Materials
- Use Only Existing Processes
- Knowledge Base of Design Teams
- Standards/Legislation
    - BS 5750 / BS 7000
    - HASWA
    - BSI Design Codes
    - Etc
- Existing Decision Making Processes
- Current Organisational Form
    - Poor Communication
    - Poor Cooperation
- MD's Right of Veto
- Limits of Existing Systems
    - CADCAM
    - DB's
- Budgetary Controls
- Time Constraints

Appendix C

Interview Survey Questionnaire

Date of interview:

Name of Establishment:

Address:

Telephone No:

Fax No:

Respondent's Name:

Respondent's Position:

Part 1: Details of the Establishment, Markets and Products

Q1. (i) Is this establishment (a) an independent company ☐

(b) part of a Group ☐

If (a) then go to Q2.

(ii) Which, if any, of the following activities are carried out, at least in part, on a Group basis? [SHOW CARD]

R & D ☐

Product development strategy ☐

Marketing ☐

Manufacturing ☐

Other (please specify) ☐

Q2. Can you either provide a copy or outline a description of the organisational structure of this establishment indicating the main departments and senior management?

Q3. What is the current full-time-equivalent employment of this establishment?

Q4. How many staff are employed in the Engineering / Design Function?

Q5. (i) Do you have a product development strategy?

Yes ☐

No ☐

If No then go to Q6.

(ii) Is it a written strategy?

Yes ☐

No ☐

If No then go to Q6.

(iii) Is it (a) separate from a Business plan ☐

(b) within a Business Plan ☐

Q6. What are the principal products of this factory?
(Ask for the product literature and/or specify in advance)

Q7. How a firm operates in particular markets may be categorised as ETO, CMTO, MTO, ATO, and MTS (briefly explain these). What types of market relate to your principal products?
(Tick as many as appropriate)

ETO ☐

CMTO ☐

MTO ☐

ATO ☐

MTS ☐

Q8. If there is only one product group, then go to Q8. (iii).

(i) Which product group <u>is</u> the strategically most important?

(ii) Has there recently been any successful technological development in this product group?

[Does this establish a suitable product area for study? If not, then reiterate Q8.]

(ii) How many distinguishable products, if any, are there in this group?

(iii) How frequently do technological changes occur in this group which are of:

(a) a substantial nature ____________

and (b) an incremental nature ____________

Q9. Approximately how many components are there in the basic product?

- <10 ☐
- 10s ☐
- 100s ☐
- 1000s ☐
- 10,000s ☐
- 100,000s ☐

If there is only one product group, then go to Q11.

Q10. What types of market relate to the product group?
(Tick as many as appropriate)

- ETO ☐
- CMTO ☐
- MTO ☐
- ATO ☐
- MTS ☐

Q11. (i) What are the major competitive success factors for this product's markets?
(Tick Column A as appropriate) [SHOW CARD]

(ii) Please indicate the rank ordering of these?
(Use Column B - 1, 2, 3)

	Column A	Column B
Price	☐	☐
Delivery conformance	☐	☐
Delivery lead-time	☐	☐
Time-to-market (Prod. Devel't)	☐	☐
Quality / reliability	☐	☐
Performance	☐	☐
Technical	☐	☐
Life-cycle costs	☐	☐
Environmental	☐	☐
Guarantees / warranty	☐	☐
Other (please specify)	☐	☐

Part 2: Project Level

Q12. (i) What was the most recent product development or change project undertaken for this product?
(Brief outline - what was involved, features of change, etc.)

(ii) Was this (a) for a general market need (prod. dev) ☐

(b) for a specific customer (contract) ☐

If (b), then go to Q23.

Product development project

Q13. (i) Was it concerned with (a) an existing market? ☐

(b) a new niche / segment? ☐

(c) a new general market? ☐

(ii) Which of the following best describes the nature of the product change?

(a) minor improvement ☐

(b) major enhancement ☐

(c) new core product ☐

If (b), would you describe this as:

(a) a major enhancement to an existing product ☐

(b) an enhancement to develop a new platform / next generation product. ☐

Q14. How did the idea for this development arise?
(Prompt and Tick as appropriate)

- Individual's proposal ☐
- Departmental proposal ☐
- Informal interdepartmental grouping ☐
- Executive group or committee ☐
- External party (please specify) ☐
- Other (please specify) ☐

Q15. (i) Was the proposal / idea initially <u>screened</u> prior to, and separate from, the project's approval decision?

- Yes ☐
- No ☐

If No, then go to Q16.

(ii) Was the purpose of this screening review to
(Tick as appropriate)

(a) determine further activities / information before approval? ☐

(b) make a go/ no-go decision ? ☐

(iii) Who undertook this screening review?

- Managing Director or Chief Executive ☐
- Director ☐
- Executive group ☐
- Interdepartmental committee ☐
- Product / marketing group ☐
- Product team ☐
- Other (please specify) ☐

(iv) Are these screening reviews organised on an ad-hoc or regular basis?

Ad-hoc ☐

Regular ☐

(v) How frequently do they occur?

Monthly ☐

Quarterly ☐

Other (specify) ☐

Q16. (i) Who reviewed and approved the project?
(Tick as appropriate)

Group (Prompt) ☐

Managing Director or Chief Executive ☐

Senior Executive (specify) ☐

Executive group / committee ☐

Senior manager (specify) ☐

Other (please specify) ☐

(ii) Did the review and approval take place:

at a specific meeting? ☐

at a general meeting (e.g. Board)? ☐

by an individual's decision? ☐

other? (please specify) ☐

Q17. (i) Was there a written design and/or project brief / specification?

Yes ☐

No ☐

If No, then go to Q18.

(ii) Who was involved in the preparation of the specification(s)?

	Marketing / Sales	☐
	Engineering	☐
	Production	☐
	Quality	☐
	Purchasing	☐
	Other (please specify)	☐
[prompt]	Customer	☐
[prompt]	Supplier	☐

(iii) Which of the following elements were covered by the written specifications?
Please indicate where any are not applicable?
[USE SHOW CARD]

	Spec'n	N/A
(A) Use of existing concepts, technologies, standard designs	☐	☐
(B) Manufacturing process requirements & constraints	☐	☐
(C) Overview of system & subsystem requirements	☐	☐
(D) Testing requirements	☐	☐
(E) Legislation, standards & codes	☐	☐
(F) Development time and costs	☐	☐
(G) Target product costs (materials, manufacturing, etc.)	☐	☐
(H) Production volume / quantity	☐	☐

Q18. (i) The show card illustrates different forms of project organisation. Which of these best approximates the organisation of the project?
[SHOW CARD]

(A) Functional ☐

(B) Project ☐

(C) Matrix ☐

(D) Project Team ☐

(E) Autonomous Team ☐

(F) Multi-project ☐

(ii) If (A) or (B) or (C), were individuals formally constituted as a team:
(Tick as appropriate)

(a) Collectively? ☐

and/or (b) Within individual functions? ☐

If (C if applicable) or (D) or (E) or (F?), which of the illustrations on the show card best illustrates the team structure: [SHOW CARD]

(a) Core Team? ☐

(b) Extended Team? ☐

(c) Other? (Please specify) ☐

Q19. (i) How many personnel were formally assigned to the project?

(ii) How many were (a) Permanent ________ or Temporary ________

(b) Full-time ________ or Part-time ________

(iii) Which functions did they represent?
(Tick as appropriate)

- Marketing / Sales ☐
- Engineering ☐
- Production ☐
- Quality ☐
- Purchasing ☐
- Service ☐
- Finance ☐
- Other (Specify) ☐

[prompt] Supplier ☐
[prompt] Customer ☐

(iv) Who did the 'team' routinely report to - indicated by ● on the organisational show card? (i.e. job title / seniority)

(v) Excluding ● identified in (iv) above, what levels of seniority were represented on the 'team'?
(Tick as appropriate)

- Director ☐
- Manager ☐
- Senior functional representative ☐
- Junior functional representative ☐
- Other? (please specify) ☐

Q20. (i) Do you have written procedures for this type of development project?

- Yes ☐
- No ☐

If No, then go to Q21.

(ii) Do they define a standard structure for the stages, activities and key events?

Yes ☐

No ☐

Q21. Our research has revealed that most projects involve the following activities [BASIC PRODUCT DEVELOPMENT PROCESS MODEL].

For the project, please outline the following:
(USE PROCESS TEMPLATE)

(a) main phases or process stages

(b) main activities and events

(c) primary inputs and outputs

Q22. Can you indicate best estimates of the following project durations:
[Make sure all of these are obtained!]

(a) Product idea to First production for sale? ___________

(b) Product idea to Project launch? ___________

(c) Project launch to Completion of detail design? ___________

Go to Q33.

Contract project

Q23. (i) Was the project concerned with:

(a) an existing market? ☐

(b) a new niche / segment? ☐

(c) a new general market? ☐

(ii) Which of the following best describes the nature of the product change?

(a) minor improvement ☐

(b) major enhancement ☐

(c) new core product ☐

If (b), would you describe this as:

(a) a major enhancement to an existing product ☐

(b) an enhancement to develop a new platform / next generation product. ☐

Q24. Who took responsibility for the initial enquiry review?
(Tick as appropriate and specify individuals e.g. Technical Manager)

Group ☐

Managing Director or Chief Executive ☐

Director ☐

Executive Group ☐

Senior Manager ☐

Other (please specify) ☐

Q25. Which individuals and/or departments were invoved in the development of the tender / bid?

(a) Specialist / functional department ☐
(specify)

(b) Interaction between departments ☐
(specify)

(c) Individual (specify position / seniority) ☐

(d) Other (please specify) ☐

Q26. Who takes responsibility for the review and approval of the tender?
(Tick as appropriate and specify individuals)

Group (Prompt) ☐

Managing Director or Chief Executive ☐

Director ☐

Executive Group ☐

Senior Manager ☐

Other (please specify) ☐

Q27. (i) Was a <u>written</u> design and/or project brief / specification provided at the contract stage?

Yes ☐

No ☐

If No, then go to Q28.

(ii) Who was involved in the preparation of the specification(s)?

	Marketing / Sales	☐
	Engineering	☐
	Production	☐
	Quality	☐
	Purchasing	☐
	Other (please specify)	☐
[prompt]	Customer	☐
[prompt]	Supplier	☐

(iii) Which of the following elements were covered by the written specifications? Please indicate where any are not applicable?
[USE SHOW CARD]

	Spec'n	N/A's
(A) Use of existing concepts, technologies, standard designs	☐	☐
(B) Manufacturing process requirements & constraints	☐	☐
(C) Overview of system & subsystem requirements	☐	☐
(D) Testing requirements	☐	☐
(E) Legislation, standards & codes	☐	☐
(F) Project time and costs	☐	☐
(G) Target product costs (materials, manufacturing, etc.)	☐	☐
(H) Production volume / quantity	☐	☐

Q28. (i) The show card illustrates different forms of project organisation. Which of these best approximates the organisation of the project?
[SHOW CARD]

(A) Functional ☐

(B) Project ☐

(C) Matrix ☐

(D) Project Team ☐

(E) Autonomous Team ☐

(F) Muti-project ☐

(ii) If (A) or (B) or (C), were individuals formally constituted as a team:
(Tick as appropriate)

(a) Collectively? ☐

and/or (b) Within individual functions? ☐

If (C if applicable) or (D) or (E) or (F?), which of the illustrations on the show card best illustrates the team structure: [SHOW CARD]

(a) Core Team? ☐

(b) Extended Team? ☐

(c) Other? (please specify) ☐

Q29. (i) How many personnel were assigned to the project from the technical perspective (i.e. excluding routine functional activities - manufacturing, accountancy, etc.)?

(ii) How many were (a) Permanent ________ or Temporary ________

(b) Full-time ________ or Part-time ________

(iii) Which functions did they represent?
(Tick as appropriate)

Marketing / Sales ☐

Engineering ☐

Production ☐

Quality ☐

Purchasing ☐

Service ☐

Finance ☐

Other (Specify) ☐

[prompt] Supplier ☐
[prompt] Customer ☐

(iv) Who had routine responsibility for managing the contract - indicated by ● on the organisational show card? [SHOW CARD]
(i.e. job title / seniority)

(v) Excluding ● identified in (iv) above, what levels of seniority were represented on the 'team'?
(Tick as appropriate)

Director ☐

Manager ☐

Senior functional representative ☐

Junior functional representative ☐

Q30. (i) Do you have written procedures for this type of project?

Yes ☐

No ☐

If No, then go to Q31.

(ii) Do they define a standard structure for the stages, activites and key events?

Yes ☐

No ☐

Q31. Our research has revealed that most projects for a specific customer involve the following activities [BASIC CONTRACT PROCESS MODEL].

For the project, please outline the following:
(USE PROCESS TEMPLATE)

(a) main phases or process stages

(b) main activities and events

(c) primary inputs and outputs

Q32. Can you indicate best estimates of the following project durations:
[Make sure all of these are obtained!]

(a) Customer enquiry to Delivery / installation? __________

(b) Customer enquiry to Tender submission? __________

(c) Tender submission to Contract? __________

(d) Contract to Completion of detail design? __________

-oOo-

Q33. (i) Was the product prototyped?

Yes ☐

No ☐

(ii) Was there an internal testing programme for the prototype or product, and if so, what was its duration?

Prototype ☐ Duration: ________________

Product ☐ Duration: ________________

No ☐

(iii) Were field trials or site testing required, and if so, what was its duration?

Yes ☐ Duration: ________________

No ☐

Q34. (i) [CONCURRENCY MATRIX]

(ii) Having discussed the concurrency aspects of the project I would now like to address the degree of integration. Would you describe the projects as been:

(a) focused on individual functions and/or specialist disciplines ☐
[e.g. technical advancement project]

(b) <u>integrating</u> several functions and/or specialist disciplines ☐
[e.g. integration project]

Q35. Excluding suppliers, were any specialist skills sourced externally for the project?

Yes ☐

No ☐

If Yes, please specify i.e. HEI, consultant, etc.
(Note their locality)

Q36. (i) Were there any key supply items for the product?

Yes ☐

No ☐

If No, then go to Q37.

(ii) Were/did any of these: (Tick as appropriate)

(a) on long-lead times ? ☐

(b) involve significant design content ? ☐

(If ticked) is this by the supplier ? ☐

(d) significantly impact on product performance? ☐

(e) significantly impact on cost? ☐

(f) sourced for particular production skills or capability ? ☐

Q37. Did this project necessitate the use of new production equipment or processes?

Yes ☐

No ☐

If Yes, how was this achieved:
(Tick as appropriate)

(a) in-house process design change ☐

(b) purchase of new equipment ☐

(b) use of supplier / subcon ☐

(c) use of Group resource ☐

Q38. Which, if any, of the following characterise the nature of the production considerations? (Tick as appropriate)

(a) Design of the product for effective production ☐

(b) Design of the production process ☐

Q39. (i) Did you make significant use of existing designs / concepts in order to identify or understand the product requirements?

Yes ☐

No ☐

(ii) Which of the following statements best describes the design approach taken: [SHOW CARD]

(a) at the overall product level? (A) ☐ (B) ☐

(b) at the subsystem and component levels? (A) ☐ (B) ☐

Q40. (i) Which, if any, of the design methods listed on the show card were used during the project? [SHOW CARD]

Functional decomposition / tree method ☐

Morphological / concept generation matrices ☐

Brainstorming & lateral thinking techniques ☐

Design evaluation matrices ☐

Design rules, codes and standards ☐

Patent Searching ☐

(ii) Which, if any, of the techniques listed on the show card were used during the project? [SHOW CARD].

Quality Function Deployment (QFD)	☐
FMEA / Root Cause Analysis	☐
Value Engineering / Functional Cost Analysis	☐
Robust Design / Taguchi	☐

(iii) Which, if any, of the analysis and modelling tools listed on the show card were used during the project? [SHOW CARD]
(Tick column A as appropriate)

(iv) For those tools indicated in (ii) above, which, if any, were used prior to 'proof of concept'?
(Tick column B as appropriate)

	Column A	Column B
Empirical methods	☐	☐
Rig testing	☐	☐
Physical models	☐	☐
2/3D CAE modelling/analysis (FEA, fluids, etc)	☐	☐
Rapid prototyping	☐	☐

Q41. (i) Was a project schedule developed for / during the project?

Yes	☐
No	☐

If no then go to Q42.

(ii) To what level of detail did this extend:
(Tick column A as appropriate)

(iii) Which of these, (ii) above, were developed prior to the project launch?
(Tick column B as appropriate)

	Column A	Column B
(a) Overall plan ?	☐	☐
(b) Work package plans ?	☐	☐
(c) Detailed activity plans?	☐	☐

(iv) Which of the planning tools listed were used? [SHOW CARD]
(Tick as appropriate)

Gantt (Bar) chart	☐
Task lists	☐
CPA / network diagrams	☐
Project management software	☐
Other (please specify)	☐

(v) Who was/were responsible for project planning and budget development?
(i.e. position / seniority)

Q42. [Briefly explain and distinguish between major project reviews, routine progress reviews, design reviews, and post project audits]

(i) Were project reviews held?

Yes ☐

No ☐

If No, then go to Q44.

(ii) Can you briefly indicate the different types of project review undertaken?

<u>Review type 1</u>:

(a) Who convened the meetings?

(b) Who was involved in the meetings?

(c) On what basis were these reviews organised?

Ad-hoc ☐

Pre-defined (or Regular) ☐

Also, were they:

Regular: Monthly ☐ Weekly ☐ Daily ☐ Other (specify) ☐

Key Milestones (specify) ☐

Review type 2:

(a) Who convened the meetings?

(b) Who was involved in the meetings?

(c) On what basis were these reviews organised?

Ad-hoc ☐

Pre-defined (or Regular) ☐

Also, were they:

Regular: Monthly ☐ Weekly ☐ Daily☐ Other (specify)☐

Key Milestones (specify) ☐

Review type 3:

(a) Who convened the meetings?

(b) Who was involved in the meetings?

(c) On what basis were these reviews organised?

Ad-hoc ☐

Pre-defined (or Regular) ☐

Also, were they:

Regular: Monthly ☐ Weekly ☐ Daily☐ Other (specify)☐

Key Milestones (specify) ☐

[Have both major and routine project reviews being considered?]

Q43. Were formally defined review criteria used for the project reviews?

Yes ☐

No ☐

If Yes, were they defined for specific phases or milestones?

Yes ☐

No ☐

Q44. (i) Were major design reviews undertaken during the development?

Yes ☐

No ☐

If No, then go to Q45.

(ii) Who was involved in these meetings?
(Prompt for individuals outside design)

(iii) On what basis were they organised?

Planned ☐

Ad-hoc ☐

When did they occur?

Key design milestones ☐

Major progress review points ☐

Other (specify) ☐

Were they formal or informal?

Formal ☐

Informal ☐

(iv) Are formal review criteria established?

Yes ☐

No ☐

Q45. (i) Were design reviews undertaken for intermediate design elements i.e. subsystems, modules, etc.?

Yes ☐

No ☐

If No, then go to Q46.

(ii) Were they different from the major reviews in terms of who was involved, when they occured, their organisation, formality, and review criteria?

Yes ☐

No ☐

If No, then go to Q46.

(iii) What were the principal differences?

(a) Those involved in these meetings?
(Prompt for individuals outside design)

(b) Basis by which were they organised?

Planned ☐

Ad-hoc ☐

(c) When they occured?

Key design milestones ☐

Major progress review points ☐

Other (specify) ☐

(d) Whether formal or informal?

Formal ☐

Informal ☐

(e) Whether formal review criteria established?

Yes ☐

No ☐

Q46. Was a post-project audit undertaken?

Yes ☐

No ☐

If Yes, did this relate to issues concerning:
(Tick as appropriate)

(a) the product? ☐

(b) the project and its management? ☐

Q47. In this project do you consider that you were exposed to potential risks through a lack of formal assessments?

Yes ☐

No ☐

Part 3: Supplementary Questions

Strategy

Q48. Please indicate the relative importance (1, 2 ,3) of the following strategic areas for the main product group?

Market focus / customer intimacy

Operational Excellence

Product Leadership

Q49. If there is a formally written product development strategy what aspects does it cover?

(Tick as appropriate)

- Types of product to be developed - PI, NPD ☐
- Markets to be targeted ☐
- Features / differentiating factors / customer benefits ☐
- Types of technology to be used & how introduced ☐
- Research areas - key technologies ☐
- Means for prioritisation between product developments ☐
- Resources required - people, facilities, etc . ☐

Staffing & skills

Q50. Which of the following attributes predominate in your design team?

(Tick as appropriate)

- Highly specialised skills ☐
- General skills ☐
- Multi-skilled ☐
- High level of experience ☐

Standards

Q51. Do you make significant use of standard modules, components, etc.?

Q52. Are you subject to statutory design rules, standards and codes?

Yes ☐

No ☐

Performance measures

Q53. What performance measure, if any, do you use to evaluate your product development or contract processes (a) generally, and (b) for specific projects?

And finally...

Q54. (i) Are there any aspects of engineering design and product development which cause difficulties, or which you consider unsatisfactory?

(ii) Are there any aspects of engineering design and product development which you think to be important and which have not been covered in this interview?

(iii) Are there any comments or questions you might have?

Reminder

	Obtained	To-follow
Company and/or product literature	☐	☐
Organisational Chart	☐	☐
Other e.g. procedures (if applicable)	☐	☐

SHOW CARD for Q1(ii)

CENTRALISED ACTIVITIES

R & D

Product strategy

Marketing

Manufacturing

Other (please specify)

SHOW CARD for Q11(i)

COMPETITIVE FACTORS

Price

Delivery conformance

Delivery lead-time

Time-to-market (Prod. Devel't)

Quality / reliability

Performance

Technical

Life-cycle costs

Environmental

Guarantees / warranty

Other (please specify)

SHOW CARD for Q17(iii) or Q27(iii)

SPECIFICATION ELEMENTS

A. Use of existing concepts, technologies, standard designs

B. Manufacturing process requirements & constraints

C. Overview of system & subsystem requirements

D. Testing requirements

E. Legislation, standards & codes

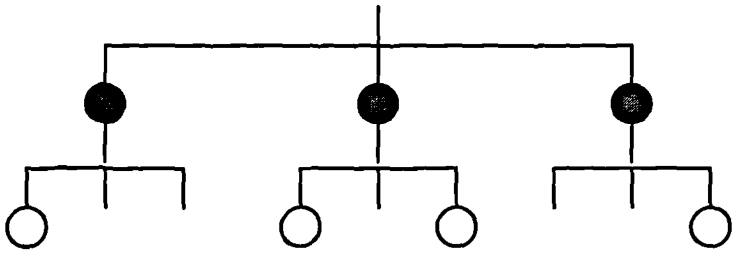
F. Development/project time and costs

G. Target product costs (materials, manufacturing, etc.)

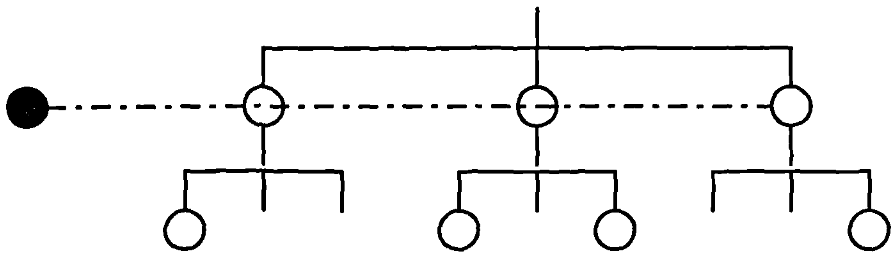
H. Production volume / quantity

SHOW CARD for Q18(i) or Q28(i)

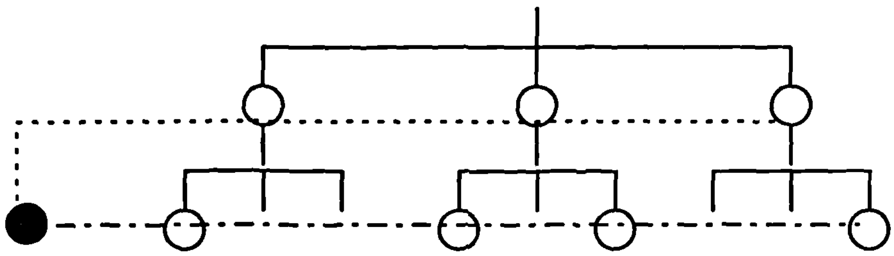
PROJECT ORGANISATION



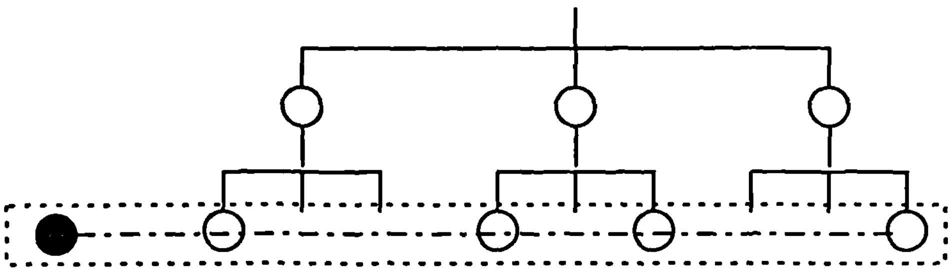
(A)



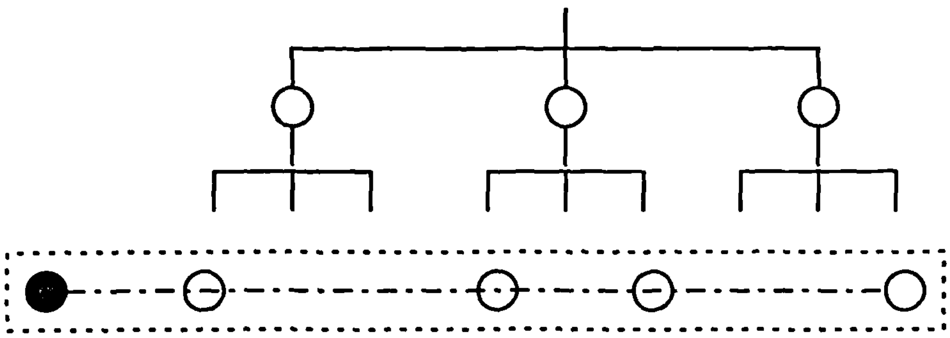
(B)



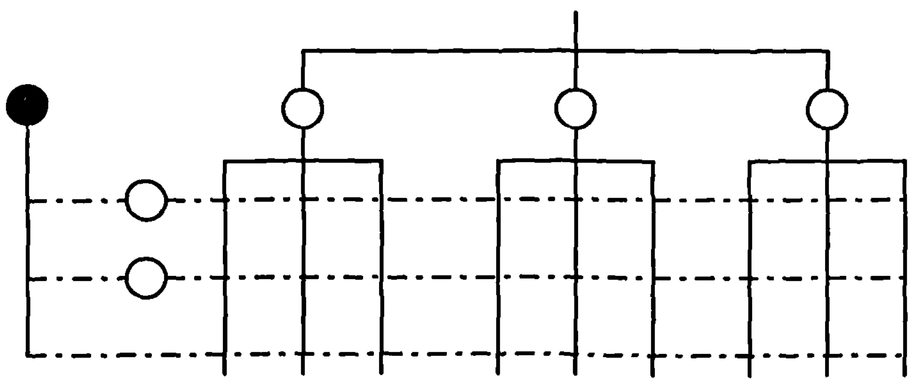
(C)



(D)



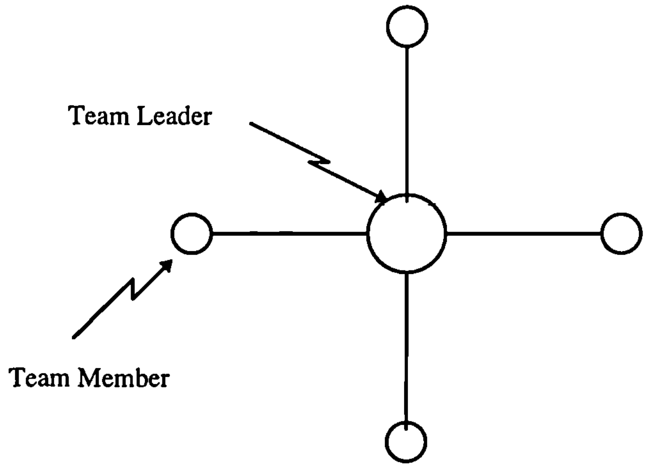
(E)



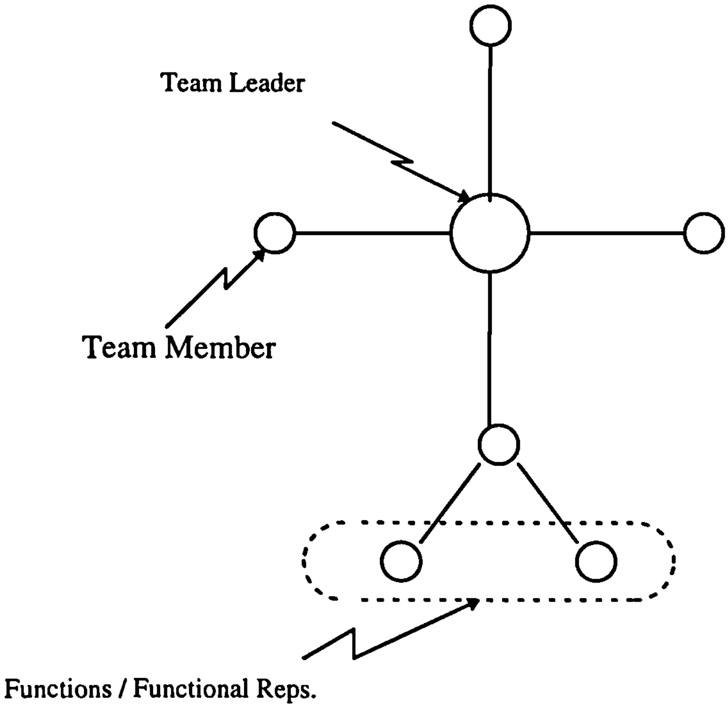
(F)

SHOW CARD for Q18(ii) or Q28(ii)

PROJECT TEAM STRUCTURE



(A) Core Team



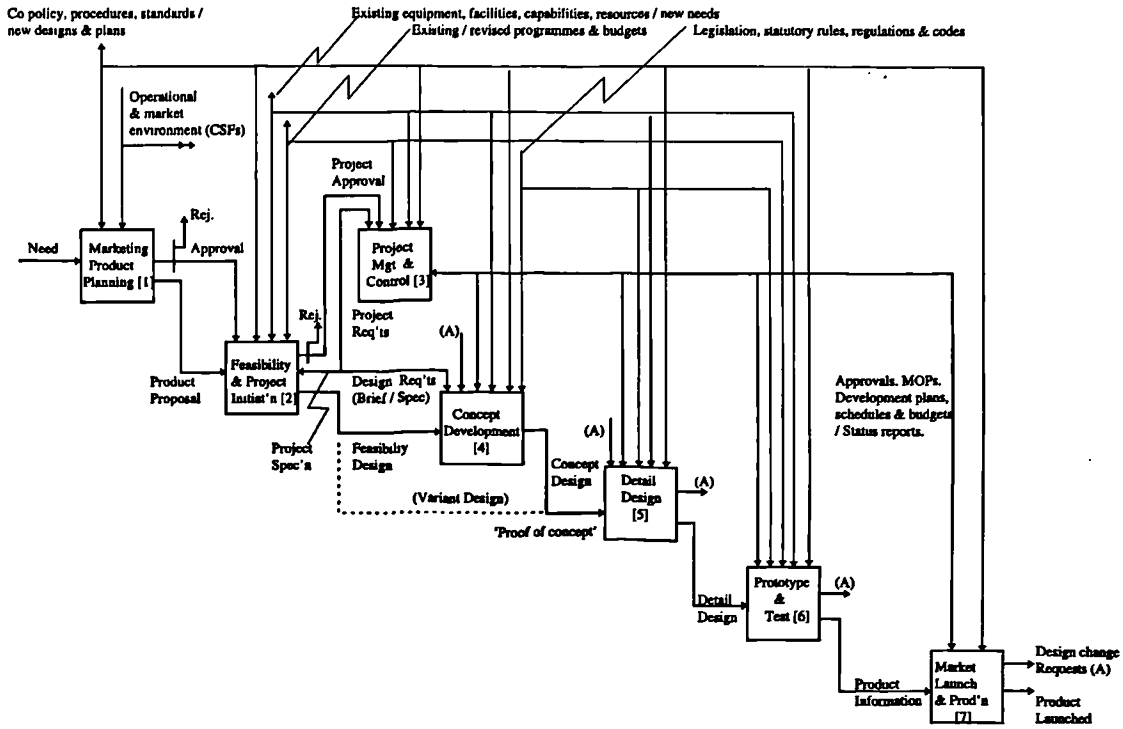
(B) Extended Team

(C) Other

(Please specify)

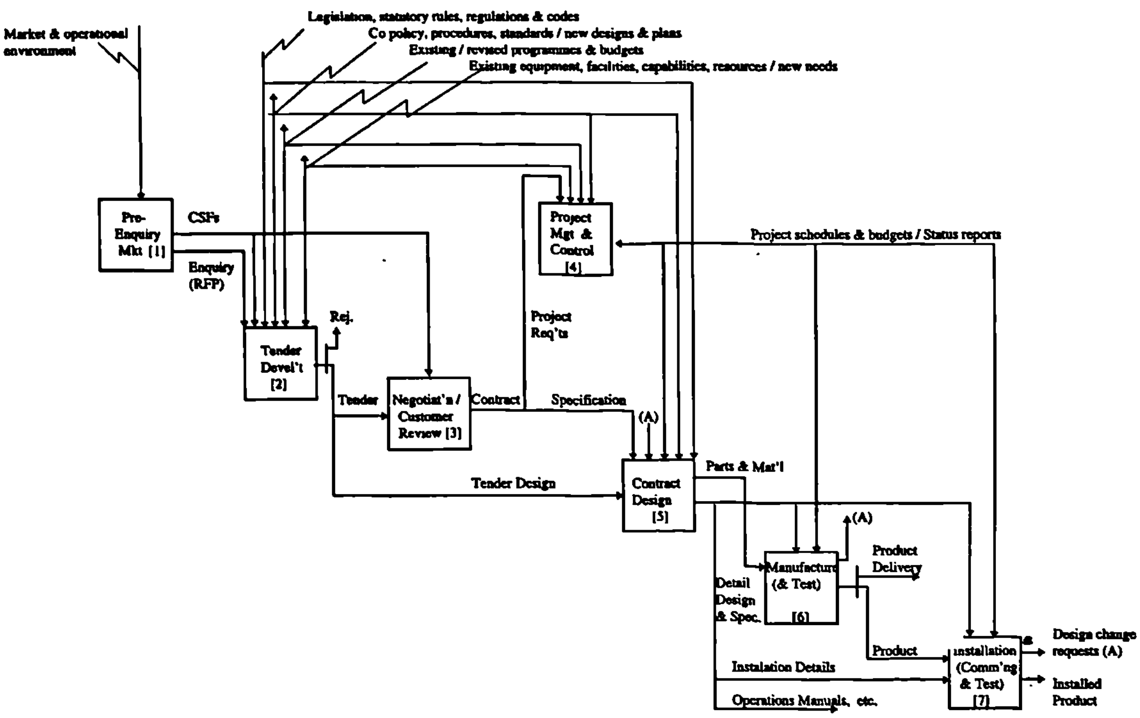
SHOW CARD for Q21.

PRODUCT DEVELOPMENT PROCESS MODEL



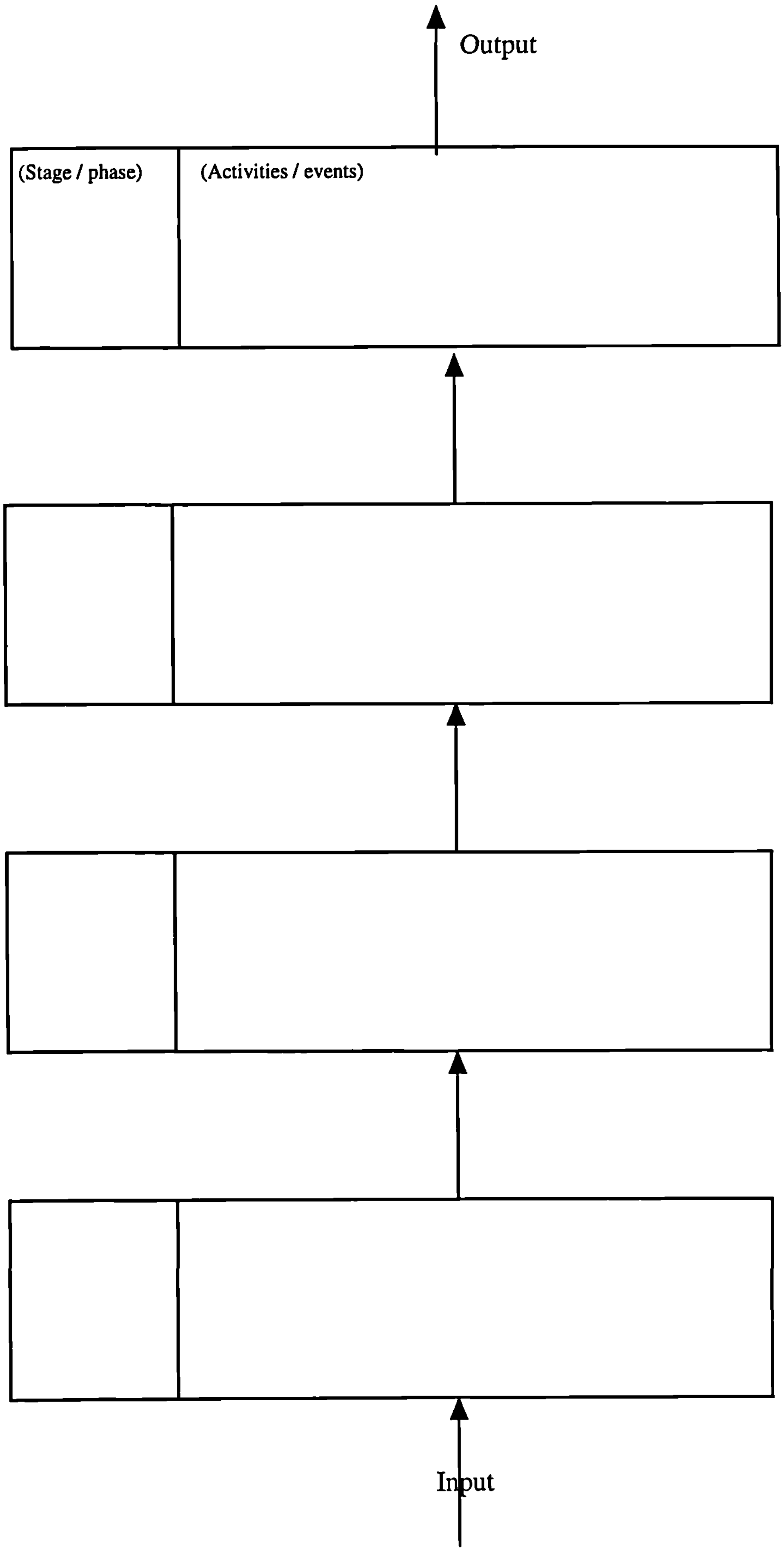
SHOW CARD for Q31.

CONTRACT PROCESS MODEL



TEMPLATE for Q21 OR Q31.

PROCESS TEMPLATE



TEMPLATE for Q34.

Concurrency Evaluation Matrix

(Contract)

Function[1]	Project Stage					
	Pre-enquiry (Marketing)	Tender Development	Negotiation	Contract Design	Manufacture (& Test)	Install'n (Com'n & Test)
Mkt/Sales						
R&D/Eng						
Production						
Procurement						
Key Suppliers						
Customers						

Concurrency Evaluation Matrix

(Product Development)

Function[1]	Project Stage					
	Mkt / Product Proposal	Feasibility / Proj. Initiation	Concept Development	Detail Design	P/rototype & Test	Mkt Launch & Manufacture
Mkt/Sales						
R&D/Eng						
Production						
Procurement						
Key Suppliers						
Customers						

Contribution rating: [ ] - none [*] - some [**] - significant

[1] Our primary interest is with disciplines, so prompt and note reasoning where a functional involvement is not indicated when it might be anticipated.

SHOW CARD for Q39(ii)

DESIGN STRATEGY

(A) An initial solution was generated, developed and evaluated. If this proved inadequate in some way it was either modified or another solution was sought.

(B) Several solution ideas were generated, and through progressive development analysis and evaluation a preferred solution was selected.

SHOW CARD for Q40(i)

DESIGN METHODS

Functional decomposition / tree method

Morphological / concept generation matrices

Brainstorming & lateral thinking techniques

Design evaluation matrices

Design rules, codes and standards

Patent Searching

SHOW CARD for Q40(ii)

MUTUAL TECHNIQUES

Quality Function Deployment (QFD)

FMEA / Root Cause Analysis

Value Engineering / Functional Cost Analysis

Robust Design / Taguchi

SHOW CARD for Q40(iii) and Q40(iv)

ANALYSIS AND MODELLING TOOLS

Empirical methods

Rig testing

Physical models

3D CAE modelling/analysis (FEA, fluids, etc)

Rapid prototyping

SHOW CARD for Q41(iv)

PLANNING TECHNIQUES & TOOLS

Gantt (Bar) chart

Task lists

CPA / network diagrams

Project management software

Other (please specify)

Appendix D

Performance Measures

The performance measures listed in this appendix are derived from a review of the product development literature. A limited number of addition performance measures have been added by the author. These have been collated according to their relevance to strategic business considerations, measuring overall process effectiveness, and controlling specific projects.

Strategic Level CSFs

Market Driven

* Time
    - customer lead-time
    - delivery conformance (on-time delivery)
* Cost
    - price (1st cost)
    - total life-cycle / service costs
* Quality
    - product capability and consistency
    - performance
    - aesthetics
    - features
    - reliability (MTBF)
    - conformance
    - durability
    - serviceability / after sales service
* Technology
    - performance
    - high added value
    - multi-tech products
    - intensification
* Customer Satisfaction

Business Driven

* Market Share
    - units / £ of total
    - relative
    - growth
* Profitability
    - margin
    - ROA, RO Equity
* Revenue
    - sales (units/£)
    - growth
* Stakeholder Benefits

Strategic Level
(Senior management measures of effectiveness)

Sales / revenue / profit:	% sales / profit from products introduced in last x years
	% sales / profit from products introduced with significant enhancements (or new products) in last x years (i.e. technical innovation requirement/CSF)
	% sales / profit by product / group
Market share:	units / relative / growth - by product - by global / local markets
Product strategy & planning:	planning horizon (years)
	projected future market value of current projects
	number & type of projects in relation to future strategy and needs i.e. in key categories
	% of total expenditure on R&D (R&D overall and by type)
	R&D investment in given period as % of sales / profit / to industry norm.
Rate of innovation:	number of new products introduced last year / in last x years
	number of patents obtained in last x years
Quality:	customer satisfaction rating by product / markets Note 5 point scale market success rating - Griffin (1993)

Overall Process Level
(Management control measures of effectiveness)*

Product innovation / technology acquisition:

number of new product ideas evaluated last year

number of patents over last x years

number of licences in/out over last x years

% of R&D projects leading to new or enhanced products (or processes), licences
as % R&D spend, or % number of projects

% of failed projects (killed off or not achieving target sales, profit, market share)
as % R&D spend, or % number of projects

% of projects killed off at late stage (post concept review) or at substantial cost (% project's budget spent)

Time:

time-to-market (TTM) / order cycle-time

concept-to-launch (CTL) / contract-to-delivery

development time (DT)

time per phase

conformance: average overrun of launch / delivery dates
% projects overrunning planned launch / delivery dates
% project mile stones achieved on-time

% improvement in project cycle-times

average time between product enhancements and redesigns

Cost:

% of projects exceeding (or achieving) target product costs (incl. manufacturing costs)

% of projects exceeding (or achieving) target servicing costs

% of projects exceeding (or achieving) target development costs / budgets

Quality:

% of projects achieving target for product performance, reliability, serviceability, etc.

warranty / guarantee claims as % of product sales

customer complaints (number and type)

Tools:

% designers / engineers with access to CAD

% teams trained in specific techniques i.e. FMEA, DFMA, Design to Cost, etc.

% teams using specific techniques

Misc:

% of tenders leading to contracts

* Note: possibilities for comparisons vs plan, absolute, trend, competition

Project / Team Level Control Measures

Time:	project schedule / key milestone adherence
	launch / delivery date adherence
	% man-hours vs % progress
Cost:	target product cost adherence (include. manufacturing, quality, & service costs)
	target project budget adherence
Quality:	achievement of targets for product i.e. performance, reliability, serviceability, etc.
	compliance with testing parameters e.g. first time through test
	achievement of required process capability / reworking costs e.g. defects per million
	cost of quality
	customer complaints per unit sold
	number of engineering change orders / changes per drawing
	improvement in performance of product/process - incremental investment : ratio
	cost - benefit : ratio
Market:	achievement of required market share, sales revenue absolute or growth.