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New Product Performance And The Deployment Of Manufacturing Engineering Resources

Paul Donal Coughlan

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NEW PRODUCT PERFORMANCE AND THE DEPLOYMENT OF MANUFACTURING ENGINEERING RESOURCES

by

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Submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy

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ABSTRACT

New product manufacturability is both a problem and an opportunity for manufacturing firms in an environment where, increasingly, competition is based on rapid production ramps and high manufacturing yields at competitive costs. In this environment, design and engineering techniques are no substitute for a deeper understanding of the management task involved in developing a manufacturable product.

Many functional groups, including manufacturing engineering (ME), interact during the new product development process. This study focused on the ME group, for whom a major objective is the development of manufacturable new products. A framework was constructed around the theme that manufacturability-related performance of new products was associated with the way in which ME staff were deployed during the new product development process. The context within which this development activity took place was defined by the manufacturing strategy of the firm. Twelve new product development projects were investigated in four divisions of one company.

The use and source of components and subassemblies, time pressures, and the approach to coordination of design and ME defined different development contexts. In certain contexts, manufacturability, the incidence of engineering change, and the length of the development interval reflected the deployment of ME resources during the development process. When to become involved in a project, when to withdraw, when and how much emphasis to place on manufacturability, and what staff to assign constituted a deployment strategy for the development of manufacturable new products.

This study contributes to research on new product success and failure, design-manufacturing integration in the new product development process, and manufacturing engineering management. The findings carry many implications for senior manufacturing managers and manufacturing engineering managers. Key among these is the development, maintenance and use of the intellectual assets in manufacturing engineering.

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CHAPTER ONE: INTRODUCTION

A firm can build a competitive advantage through superior manufacturing, but sustaining it over time requires comparable skills in creating a continual stream of new products and processes (Hayes, Wheelwright & Clark, 1988). This is a difficult competitive challenge. The rules of the game in new product development have changed: not only does it require high quality, low cost and differentiation to succeed, it also takes speed and flexibility in developing products (Takeuchi & Nonaka, 1986; Miller & Roth, 1987). In this environment, manufacturing managers face a diminishing 'window of opportunity' for each new product, and must achieve high manufacturing yield rates earlier, in sufficient volume, and at competitive cost levels, to enable rapid market penetration. Words and phrases like manufacturability, producibility, design for automation, design for assembly, cost avoidance instead of cost reduction, and design right-first-time crystallize the objective. Quantitative evaluation methodologies, such as the Boothroyd - Dewhurst Design for Assembly Method or the Hitachi/GE Assemblability Evaluation Method, focus on ease of assembly. However, of themselves, these methodologies are of little use in the hands of a mis-managed development team. This study investigates the development of manufacturable new products from a management perspective.

The Issue of Manufacturability

Many irreversible decisions concerning product manufacture and assembly are taken during the development process. Once production commences, the character and functioning of a new product is largely set - and with them several crucial elements affecting product quality (Garvin, 1988). At General Motors, 70% of the cost of manufacturing truck transmissions is determined in the design stage, while Rolls-Royce found that design determined 80% of the production costs of 2000 components (Whitney, 1988). British Aerospace concluded that 85% of a product's manufacturing cost is determined in the early stages of design (Walleigh, 1989). General Electric estimates that up to 90% of the manufacturing costs are determined by the design of a product (Daetz, 1987). Thus, no matter how clever manufacturing engineers, production managers or production control specialists are, they may not be able to affect more than 30% of the manufacturing costs of a given design after the commencement of volume production.

There are opportunities to reduce manufacturing costs during the development process. Northern Telecom reduced the number of components in a telephone by 60 percent and the manufacturing cost by 50 percent using value engineering (Richardson, 1988). However, while the apparent benefits from manufacturing involvement in the development process are high, the development of new products is characterized by tradeoffs which sacrifice manufacturability for other objectives. Increased new product development activity, and higher levels of technological and market uncertainty, often combine to place manufacturing under pressure to accept incomplete or unmanufacturable designs.

> 'The designers design it and then 'heave it over the transom' to manufacturing. Manufacturing tries to build it. It's unbuildable, and that brings forth the first round of engineering changes. It still isn't makable, which requires a second round of engineering changes' (Schonberger, 1986: 144).

The consequences are costly, but often predictable. Implementation of an engineering change involves modification of the current specification of the product or of the manufacturing process employed, and occurs for performance improvement, cost-reduction, or corrective reasons. Such change may originate with the product design, manufacturing, test, purchasing, quality, or marketing functions. However, due to interrelationships among product features, a change to a single feature may precipitate collateral changes to other aspects of the product design (Hauser & Clausing, 1988). Such change is most disruptive after the commencement of routine volume production.

> 'A poorly designed product...creates complexity that leads to confusion, and triggers demand for engineering changes. Poorly handled ECOs (engineering change orders) create wasted material as well as increased reject rates...One of the most important tasks of management, therefore, is to prevent confusion or mitigate the potentially damaging effects of confusion-causing activities' (Hayes et al., 1988: 182-183).

The management of engineering resources during the new product development process is key to a strategic response to this competitive environment. Empirical studies over the past thirty years offer consistent support for the importance of engineering resource management to new product performance (Carter & Williams, 1957; Myers & Marquis, 1969; Rothwell et al., 1974; Maidique & Zirger, 1984). The management task includes coordination of the design, manufacturing and marketing functions. This task requires management abilities in the selection, development, retention and effective utilization of technical personnel, and in the allocation of managerial and engineering resources, both at the start, and at the peak of the innovation process. However, several questions remain, which are of importance if firms are to have the opportunity to compete based on manufacturable products:

> What specialist engineering resources are deployed in the development of manufacturable new products?
>
> When, during the new product development process, are these engineering resources deployed?
>
> Is the successful achievement of manufacturable new products associated with the way these engineering resources are deployed?
>
> Is an association between the achievement of manufacturable new products and the way these engineering resources are deployed, contingent upon the development context?

Underlying these questions is the ongoing challenge to firms, to be innovative as well as efficient. Abernathy (1978) spoke of the 'productivity dilemma', where the conditions needed for rapid innovative change differed from those that supported high levels of production efficiency:

> 'Decisions that determine equipment development, product line standardization, labor-force characteristics, and vertical integration simultaneously influence capabilities for innovation and productivity improvement' (p.164).

In terms of the 'productivity dilemma', a 'new' product which is manufacturable is a contradiction in terms. A product represents a series of technological choices. Each choice is made in relation to a design concept, or technological approach, to the product's basic functional requirements and market demands (Abernathy, Clark & Kantrow, 1983). Where product concepts are new and ill-defined, where experience in use is limited, and the context of use complex, product design becomes a search for information and new understanding (Clark, 1985).

In their descriptive model of product and process evolution, Abernathy and Utterback (1982) indicate that only as core concepts appear and stabilize the product design, can processes be focused and costs reduced. Manufacturability of products is consistent with achieving this level of stability. Yet, as firms change their manufacturing strategies, with shifts towards continual improvement in product and process development cycle times and performance as keys to successful competition (Hayes & Abernathy, 1980; Hayes & Wheelwright, 1984; Skinner, 1984; Schonberger, 1986; Suzaki, 1987; Hayes et al., 1988), the management challenge is to achieve manufacturability earlier in the evolution and mutual fit of the product and process concepts.

The Research Challenge

Taken from the perspective of the manufacturing manager, this field of enquiry is rich but relatively neglected (Deschamps, 1989). This neglect is measured not just in terms of the number of studies, it is even more serious: the studies that have been carried out serve to illustrate how lacking our understanding is of this area. Research on new product success and failure has been carried out for many years. The studies have demonstrated clearly that there is no single factor that explains success or failure. Yet they have failed to address the management issues which must be faced if newly developed products are to be manufacturable, and still meet the market window.

To help consider manufacturability of the product early in the product design process, many product-focused principles, rules, and guidelines have been stated in systematic and codified ways. However, the implicit assumption is that manufacturing managers will know who they should assign to the project, and once 'involved', what to do, and when they should do it. The reality is that many managers indeed know what resources to deploy and when. But they operate by 'rules of thumb', and without reflection on their experience. As researchers, we have not helped them to structure their experience. We have not identified the key manufacturing players on the development team, the activities they perform, how they are organized, when they should be deployed, and if they really make a difference in the product performance.

In sum, management research in the area of the development of manufacturable new products is still emerging. We must identify the key dimensions of product performance, the key levers which are managerially controllable during the development process, and the context within which these levers must be controlled, all from a manufacturing perspective. We must then structure these elements in relation to each other. Only through exploratory research can this field advance, which, by definition, means small sample studies based on in-depth interviews with the present experts, the manufacturing and engineering managers involved in new product development. This study is a step towards reaching the necessary level of understanding through structuring the experiences of a group of these experts.

OUTLINE OF THE STUDY

A study to address the four questions, posed earlier in relation to manufacturability and the management of engineering resources during the new product development process, spans a number of distinct research areas. These areas deal with new product success and failure, design-manufacturing integration in the new product development process, and the management of manufacturing engineering. In Chapter Two, I examine the work of other writers in these areas, in order to differentiate their work from the present study.

In Chapter Three, I develop a conceptual framework with the central theme that the manufacturability-related performance of new products is associated with the deployment of manufacturing engineering resources during the new product development process. The context within which this new product development activity takes place is defined by the manufacturing strategy of the firm. I ground this framework in the works of earlier writers. In Chapter Four, I develop the operational measures for each of the constructs in the conceptual framework relating new product performance to the deployment of the manufacturing engineering function during the new product development process. I then outline the exploratory field study to investigate the relationships in the conceptual framework, in which I collected data on twelve new product development projects in four divisions of one company.

Chapter Five is the first of four chapters in which I report the results of the field study. In many respects, this chapter prepares the ground for the subsequent chapters, providing a description of each of the company divisions, their associated products and manufacturing engineering organizations. However, this chapter also provides a detailed description of the activities carried out by manufacturing engineering, and explores differences in manufacturing engineering deployment and in new product performance in a variety of strategic contexts defined by manufacturing strategy. In Chapters Six, Seven and Eight, I explore the relationships observed between each of the three dimensions of new product performance, development interval, manufacturability and engineering change, and the deployment of ME during the new product development process.

Finally, in Chapter Nine, I summarize the findings of the study, in relation to the research questions posed. I also discuss the implications of these findings for managers involved in the development of new products, and identify several emergent opportunities for future research.

CHAPTER TWO: THE STATE OF OUR UNDERSTANDING

INTRODUCTION

This study investigates the development of manufacturable new products from a management perspective. To guide the study, I posed four specific questions in the preceding chapter which focused on the relationship between manufacturability-related performance of new products and the deployment of engineering resources during the development process. These questions are timely in the present context of new product development, where manufacturability is a key competitive variable. However, questions about both new product development and engineering management have been investigated before, and are reported in the empirical findings and writings of many others. The objective of this chapter is to discuss these earlier investigations in relation to the questions posed.

The case of Plus Development Corporation captures the issues in this study, and serves to guide in the structuring of this chapter (Langowitz & Wheelwright, 1986; Westcott & Wheelwright, 1988; Hayes et al., 1988; Langowitz, 1989; Wheelwright & Sasser, 1989). Plus entered a long-term manufacturing agreement with JEMCO, a Japanese manufacturer, under which both firms worked closely to design a new hard disk drive, and to set up the manufacturing system to produce a high-quality product at an economical price. Previously, as product designers and manufacturers, Plus had designed for functionality, and looked for manufacturing problems when in production. In this case, the JEMCO manufacturing engineering group asked the Plus design engineers to make product design and specification changes before they would accept the design for manufacture, in order to eliminate manufacturing problems before commencing production.

Initial production yield was 90 percent, a phenomenal improvement in relation to typical initial yields of 30 to 40 percent for this type of product in the US. Product returns from customers were less than one percent, and sales reached an unprecedented $6 million for the first three months of shipments. The product respected the limits in the process, yet made maximum use of its capabilities. The process, in turn, was matched to the product and provided the capabilities it needed. Plus thought that it had a unique product with at least a nine-month lead on competitors. However, by the fifth day of the industry show where the product was introduced, a competitor was showing a prototype of a competing version. Within three months, the competitor was shipping its new product.

The JEMCO approach to new product development was successful, in terms of manufacturability-related performance. The project required both product designers and manufacturing engineers to interact with and accommodate each other during the new product development process. This interaction demanded a clear understanding of manufacturing engineering

(ME) tasks and responsibilities, not just by those interacting with the ME group, but also by ME itself.

In this chapter, I will examine a selection of writings in three distinct research areas. First, I will describe the manufacturing engineering function, and its role in new product development. Then, I will compare differing approaches to the integration of design and manufacturing during the new product development process. Finally, I will examine the empirically-supported determinants of new product success and failure.

MANAGEMENT OF MANUFACTURING ENGINEERING

Organizational 'fit' of Manufacturing Engineering.

Manufacturing Engineering is a relatively young functional area in manufacturing management. In elemental form it has always been present, yet, by the early sixties, industry had not standardized on a specific title for the area. It was called production engineering, tool and operations planning, manufacturing process engineering, methods engineering and production process engineering.

In larger firms, ME activities are divided up among a team; in smaller plants, one person does it all. To some the manufacturing engineer is the production engineer, to others the process engineer, or the industrial engineer, the process planner, or the facility engineer. ME activities may be carried out by a variety of functions, including manufacturing engineering, process engineering, and tool engineering. ME may be separate from, include, or be included as part of, the industrial engineering function (Gloede, 1970; Lebenbaum, 1971; Amrine, Ritchey & Hulley, 1975; Blanchard, 1976). Related functions, such as methods and plant engineering, may or not be included under the ME function. Finally, ME staff usually represent many engineering disciplines, but industrial engineers predominate.

In sum, there is only broad agreement among writers on the scope of ME activities, or even what the ME function is.

Focus of ME activities.

ME objectives, tasks, and success factors are tied directly to manufacturing strategies and competitive priorities (Wood & Coughlan, 1988 b). However, this conclusion from an empirical study, while indicating a strategic dimension to the management of the ME function, did not consider the detail of these tasks, or the relationships among them. An early description of the activities required to fulfill the responsibilities of ME was of a 'typical manufacturing engineering department', in a machine shop environment (Wage, 1963). A range of activities were identified which included production planning; process engineering; tool design; tool room management; equipment engineering; plant layout; material handling; production analysis; manufacturing standards; work standards/methods; reproduction & records.

By the early seventies, the focus of ME, and of its accompanying activities, broadened beyond tool design and manufacture, to design and building of equipment and test sets; beyond manufacturability assessment of prototypes to prototype building and assessment; beyond document publication and distribution to instruction of operators in procedures; beyond periodic study of operations to analysis of the impact of change (Gloede, 1970). Lebenbaum (1971) added value engineering, development of advanced manufacturing techniques and methods, facilities maintenance and disposal to the range of ME activities. The perspective of Doyle (1971), although rooted in tool engineering, added a strategic dimension to the focus of ME through planning of manufacturing requirements and facilities.

Amrine et al. (1975) saw ME playing a 'considerable' role in setting up and operating manufacturing processes, making one of its greatest contributions by constantly devising ways and means to reduce costs. Schonberger (1987) re-emphasized the importance of this activity. Matisoff (1986) considered ME in an electronics manufacturing context and added to the growing classification of the ME activities. These additional ME activities included feasibility studies by ME of the integration of new or different products into existing facilities; and, R&D of new manufacturing methods, techniques, tools, and equipment to improve product quality and reduce manufacturing costs.

In sum, ME has responsibility for translating product design specifications into simple work instructions and standards, so that production staff know what they have to do to build the product. But before these work instructions can be prepared ME must determine how the product is to be built, what and who will be needed to build it, and what the build schedule will be. After these instructions have been prepared, ways and means must be constantly devised to reduce costs, improve quality, process flexibility or whatever competitive priorities defined as important to operating success.

In order to identify operational dimensions of the ME function, I classified the activities identified by the various writers in terms of their focus (product or process), and emphasis (development, support or improvement - the last two during routine manufacture). This classification is outlined in Table 2.1, and represents an improvement over the simple lists of activities on which it is based.

Table 2.1

Manufacturing Engineering Activities by Focus and Emphasis as reflected in the literature

ME FOCUS

ME EMPHASIS	Process	Product
Development	prodn. planning tool design work stds./methods equipt. spec., dev., installn. & startup plant layout manfng. standards operator training documentation advanced techniques facilities planning test set development	manufacturability assessment value engineering prototype building
Support	prodn. planning work stds./methods equipment disposal reproduction/records plant layout manfng. standards tool room management facilities maintenance safety	
Improvement	plant layout tool design work stds./methods equipment improvement manfng. standards	

When the activities identified by the earlier and later writers are examined in relation to the classification, there is a clear indication of an evolution over the years beyond process development, support and improvement to include support of product development. However,there is no indication of emphasis by ME on product support or improvement once routine operations commence. Further, the categorization raises the issue of tho dynamics of the function, including the relative phasing of emphases and interrelationships among activities. Finally, carrying out these responsibilities is complicated by an increasing reliance on external suppliers of product components and subassemblies. The implications of these changes for ME have been expressed as follows:

> 'The premier manufacturers in the world - IBM, GE, Toyota - send their own manufacturing engineers out to their suppliers to help them improve their processes, improve designs, and improve quality, reduce costs and improve schedule compliance. If a firm has too few manufacturing engineers in its own plants to do that for itself, how is it going to do that for 20 or 200 of its suppliers?' (Gunn, 1987: 106-107).

Manufacturing Engineering: Summary & Conclusions.

Much of manufacturing success arises from the management of change, and, in particular, change in the context of increasingly capital intensive processes. Management of such change requires higher levels of technical and management skills in the adaptation, supplementing, and superceding of existing manufacturing processes and products. Many of these skills are to be found and managed in the ME function. However, this management task is made more difficult by the lack of uniformity in perception of what ME does, and in where it 'fits' in the organization. Further, management of the ME function is made more difficult by the almost complete absence of recognition of a strategic role for ME which relates activities, skills, and organizational 'fit' to an implicit or explicit manufacturing strategy, or choice of competitive priorities.

There is a clear indication of evolution in the scope of ME activities. However, there is a lack of guidance on the means by which the ME function carries out its responsibilities in interfacing with specified other functions over an extended period of time. While the management of such interactions may be achieved in a variety of ways, questions remain as to the impact of these different approaches on the deployment of the ME function, and how the performance of a newly-developed product varies with differing emphases by ME. I will address these issues of integration and performance in the following two sections.

DESIGN-MANUFACTURING INTEGRATION IN NEW PRODUCT DEVELOPMENT

Each new product development project has a life cycle, with identifiable start and end points, that includes all development phases from point of inception to final project completion (Archibald, 1976).

The interfaces between phases are rarely clearly separated, except in cases where proposal acceptance or formal authorization to proceed separates two phases.

The range of approaches to the integration of design and manufacturing in the new product development process may be divided into two basic types: a conventional approach, and a set of new approaches. The conventional approach is characterized by distinct phases: design first, engineer, and manufacture later. The new/alternative set of approaches to the new product development process is characterized by the design of the product and the manufacturing process at the same time, and overlapping development phases.

The Conventional/Traditional Approach to New Product Development

In the traditional approach to new product development, a project moves through different phases - for example, concept, feasibility, definition, design, and production - in a logical, step-by-step fashion (Imai, Nonaka & Takeuchi, 1985). Concept decisions, product design, and testing are performed prior to manufacturing system design, process planning and production (Stoll, 1986). In each succeeding phase of a project new and different intermediate results are created, with the outputs of one phase forming major inputs to the next. The project proceeds to the next phase only after all the requirements of the preceding phase are satisfied. Each function is expected to play a specific and limited role: engineering designs the product, manufacturing makes it, and marketing sells it (Hayes et al. , 1988). The serial nature of this traditional approach prevents integration of product and process designs, even when manufacturability is recognized as being important:

> 'The result is suboptimal manufacturing system design. Compounding the sub-optimality is the needless time, effort, and money spent solving manufacturing problems which could have been avoided in the first place through proper product design. Even after the problems are ironed out and the engineering changes made, usually at considerable expense, the advanced manufacturing technologies still fall short of providing hoped for gains because they are simply not matched to the product being manufactured' (Stoll, 1986: p.1357).

In sum, this traditional approach leads to problems such as slow product launch, high manufacturing cost, poor initial yield, and disruptive engineering change (Imai et al., 1985; Putnam, 1985; Stoll, 1986; Ettlie & Reifeis, 1987; Hayes et al., 1988; Stauffer, 1988).

The New/Alternative Approaches to New Product Development

> 'From the experience of companies that have been able to improve their manufacturing performance significantly through better design, two approaches stand out: reducing parts complexity and integrating process design with product design' (Hayes et al., 1988: 173).

Firms that excel in product development tend to exhibit a distinctive pattern in their approaches to managing their product development projects. This pattern represents an alternative approach to product development, under which development is characterized by extensive overlap of phases, with continual two-way interchange of information at low levels (Lorsch & Lawrence, 1965; Imai et al., 1985; Putnam, 1985; Hayes et al., 1988). Overlapping may occur either at the interface of adjacent phases, or it may extend across several phases.

Within phases, there is the simultaneous collaboration of specialized functions, including design engineering, manufacturing engineering, quality engineering, test engineering, and marketing. Rather than operate as isolated entities, these functions work together to coordinate activities, integrate technical and commercial information and use each others' technologies. Integrative innovation involves users of technology as 'codevelopers', rather than receivers of the technology (Leonard-Barton, 1987).

Design for manufacture (DFM) evolved out of experience with the conventional approach as a philosophy forming the basis of a common language between design and manufacturing for the achievement of manufacturability. To help consider manufacturability of the product early in the product design process, many product-focused principles, rules, and guidelines have been stated in systematic and codified ways. Further, quantitative evaluation methodologies, such as the 'design for assembly' method (Boothroyd & Dewhurst, 1983 a,b), have been developed which allow the designer to rate the manufacturability of his design quantitatively.

Implementation of the DFM philosophy is strongly tied to the way in which a product is conceived, designed, produced, and eventually brought to the market place to be sold and serviced (Stoll, 1986):

> 'The challenge lies in making the DFM philosophy work under the constraint of existing company policy' (Stoll, 1986: p. 1356).

Implementation of the DFM philosophy is one of a number of related administrative innovations directed at the integration of design and manufacturing (Ettlie & Reifeis, 1987). Other such innovations implemented in parallel with DFM include design-manufacturing teams; disciplined management procedures that take team members through design decisions; common CAD systems for design and tooling; and engineering generalists such as new, highly expert manufacturing and advanced manufacturing engineers to address modernization issues in new materials, processing, and product design for manufacturing (Ettlie & Reifeis, 1987; Whitney, 1988; Dean & Susman, 1989).

The second dimension to the alternative approach to new product introduction, 'simultaneous engineering', is a process in which key design engineering and manufacturing personnel provide input during the early product design phase in order to reduce the downstream difficulties and build in quality, cost reduction and reliability at the outset. Product and process design run in parallel and occur in the same time frame, allowing process constraints to be considered as part of the product design. The scope of the simultaneous engineering involves the following activities:

> Improvement of new product designs to make them less costly to manufacture;

Address of flexibility issues;

Planning and implementation of advanced process technology;

Integration of new technologies into existing processes (Stauffer, 1988).

The new/alternative approach contrasts with the conventional approach, becoming most apparent when considering early manufacturing involvement in design for manufacturability. The new/alternative approach involves manufacturing in the project earlier than in the conventional approach, the speed of development is faster, and there is increased flexibility and sharing of information. On the other hand, the overlapping approach increases the complexity of managing the development process because of the ambiguity, tension, and conflict within the development group, and less than complete design information available to manufacturing.

While the new/alternative approach may lengthen the product development and planning stages, it should result in the earlier delivery of a higher quality product to the customer than the conventional approach. Further, if functions communicate effectively from the start, disputes, such as over tolerances, can be resolved before the development process has gone too far. Any problems that quality and test engineering cannot handle can be incorporated in the original design, not in subsequent engineering changes (Putnam, 1985). However, Hayes et al. (1988) are less clear about such positive implications of the alternative approach for engineering change.

Design- Manufacturing Integration: Summary and Conclusions

In summary, there is consensus among writers on design-manufacturing integration that an alternative to the classical/conventional model/paradigm is desirable on the basis of perceived improvements in the delivery of manufacturable new products to the market. Second, there is consensus on the need for integration of manufacturing and engineering early in the process. In particular, a specific need for early involvement of the manufacturing engineering function is clearly identified. Finally, formal techniques and guidelines have been developed, which address technical problems in the development process.

However, despite the descriptions of differing approaches, little systematic empirical research has been done in the area of design-manufacturing integration. As such, despite the above consensus, there is little guidance on the management task, including the staffing and deployment of such technical functions as manufacturing engineering, in the new product development process. Ettlie & Reifeis (1987) qualified their identified administrative mechanisms as representative of 'preliminary, emergent, empirical trends' just beginning to be compared to established management theories. Further, there is some disagreement on the implications of each approach for the incidence of engineering change after the commencement of routine volume production.

NEW PRODUCT SUCCESS AND FAILURE

In the previous sections, I identified that manufacturing engineering had responsibility for translating product design specifications into simple work instructions and standards, so that production staff would know what they had to do to build the product. However, I found no indication of the how the performance of a newly-developed product varied with differing emphases by ME. I compared conventional and alternative approaches to design-manufacturing integration in the new product development process, but found little empirical research linking these approaches to the success or failure of new products.

In contrast, empirical research on the performance of new product development projects has generally focused on:

key factors leading to success;
comparison between success and failure.

Table 2.2 lists a selection of the major empirical research on these issues over the past twenty years.

I summarize the various definitions of product performance and findings of these studies in Appendices I and II. In spite of differences between studies in terms of data base, variable descriptions, models and analytic procedures, many of the findings of these studies are similar and consistent (Lilien & Yoon, 1989). The fundamental conclusion remains: there is no single factor that explains success or failure.

Table 2.2

Selected Empirical Research on
the Performance of New Product Development Projects

Research Focus	Empirical Research
Determinants of Success	Myers & Marquis (1969)
	Globe et al. (1973)
	Rubenstein et al. (1976)
	DeCotiis & Dyer (1977; 1979)
	Yoon & Lilien (1985)
	Ettlie & Rubenstein (1987)
	Cooper & Kleinschmidt (1987 a)
	Langowitz (1988)
	Hise et al. (1989)
Comparison between Success and Failure	Rothwell et al. (1974)
	Gerstenfeld (1976)
	Cooper (1979)
	Hopkins (1980; 1981)
	Maidique & Zirger (1984)
	Baker et al. (1986)
	Cooper & Kleinschmidt (1987 b)

Note: this research selection was based in part on Rothwell (1977) and on Lilien & Yoon (1989).

The basic set of relationships emerging from this empirical research relate controllable and situational variables to product performance. In general, the factors that separate new product successes from failure include those controllable by project or top management, and those situational or environmental factors which describe the competitive setting of the project. Variables, controllable by management, include:

> internal communications (Myers & Marquis, 1969; Rubenstein et al., 1976; Rothwell et al., 1974);

clarity of performance requirements (Rubenstein et al., 1976; Cooper & Kleinschmidt, 1987 a; Baker et al., 1984);

development process coordination (DeCotiis & Dyer, 1977; Gerstenfeld, 1976; Hopkins, 1980; Maidique & Zirger, 1984; Langowitz, 1988);

performance of specific technical activities (Hise et al., 1989; Langowitz, 1988; Cooper & Kleinschmidt, 1987 b).

Situational or environmental variables relate to both the market and technological settings of the project, and include:

product characteristics (Globe et al., 1973; Ettlie & Rubenstein, 1987; Cooper, 1979; Cooper & Kleinschmidt, 1987 b);

closeness to firm's areas of expertise (Cooper & Kleinschmidt, 1987 a; Maidique & Zirger, 1984; Langowitz, 1988).

The success of a new product depends to a large extent on the process by which it is developed and launched. What activities are undertaken or omitted, how much emphasis each receives and how well each is executed are critical to the fate of the product (Cooper, 1983; Cooper & Kleinschmidt, 1986; Langowitz, 1988; Hise et al., 1989). A number of classification schemes for the new product development process have been proposed (Cooper, 1983; Saren, 1984). These two schemes complement each other, with that proposed by Saren having the wider scope. Saren (1984) reviewed models of the innovation process which had been proposed, and classified them as follows:

Department - stage models;
Activity - stage models;
Decision - stage models;
Conversion process models;
Reponse models.

The innovation process lends itself particularly well to being broken down into a series of decisions, and, in particular, decisions between stages. The end of an activity phase represents a clear point of decision: explicit criteria can be set for detemining whether a product is suitable for being carried forward to the next phase. The division of activities into phases is accordingly a function of the criteria used, likewise the number of phases is determined by the number of recognizable decision points (Cox & Styles, 1979).

Department-stage models are an accurate representation of the process in so far as the departments cited - R&D, Design, Production, Marketing - are usually involved in the process in some way. Activity - stage models identify different types of activities, and the variations in the proportion of time and effort allocated to each activity stage. According to these models, the new product development process consists of sequential or overlapping stages, in each of which some specific activities are performed. Key technical activities include initial concept screening for technical feasibility, product development, prototype construction and testing, pilot production and full production (Calantone & di Benedetto, 1988). More sophisticated models represent an activity breakdown linked with a department-stage approach (Granstand & Fernlund, 1978; Twiss, 1980).

Each of these models provides some guidance on when a technical or production orientation may be appropriate and timely. Some may even suggest the level of proficiency required in these activites for success (Cooper & Kleinschmidt, 1986). Yet, few identify the function by name, identify the activities to be carried out by that function, or the criteria for evaluation of the performance of the function.

Some studies have defined success in purely financial terms, and others have distinguished among various dimensions of success, including technical and commercial success. The basis for this distinction was the expectation that different factors led to different types of success (Rubenstein et al, 1976; Cooper & Kleinschmidt, 1987). As such, a project can be simultaneously successful and unsuccessful (DeCotiis & Dyer, 1977). Yet, many studies fail to match managerially controllable technical variables with technical rather than commercial performance.

For example, Hise et al. (1989) identified seven product design activities and investigated the extent to which these specific steps in designing new industrial products were related to the levels of commercial success achieved by those products. While this study concluded usefully that performing specific product design steps resulted in higher commercial success rates than not doing them, a technical rather than commercial performance dimension would have been more appropriate. Further, the study did not address the situations under which activities could be by-passed, nor did it identify the functional specialists engaged in these activities.

On the other hand, DeCotiis and Dyer (1977; 1979) identified manufacturability and business performance as one of five dimensions of new product performance. They examined the determinants of each dimension, and found that manufacturability and business performance were determined by the way in which project technology and operations were transferred from R&D to the factory. Also critical to manufacturability and business performance were the planning and scheduling of the new product project. Yet, DeCotiis and Dyer did not relate this technical performance dimension to the activities of any particular function.

The study by Langowitz (1988) stands apart from the other empirical work surveyed. Although her focus on the individual new product development project was not new, the explicit consideration of the management of the emphases and phasing of emphases on manufacturability by the manufacturing function during the new product development process was new. Further, she related these emphases to the problems and smoothness of initial commercial manufacture, rather than some other indicator of performance, conceptually or managerially unrelated to manufacturing efforts.

Langowitz found that the smoothness of initial commercial manufacture increased as the priority given to manufacturability increased. She concluded that management of the development process made a difference in the outcome of the initial commercial manufacturing experience of a product. Further, on technically ambitious projects, she concluded that a high emphasis should be placed on including and working with manufacturing in the development process. A sub-divided design team, clear project definition, and joint ownership facilitated involvement by manufacturing in development. Feedback to design, by manufacturing, of product requirement implications for the factory seemed likely to help build manfacturability and quality into the product.

While Langowitz drew out some implications for managers, and manufacturing managers in particular, many different specialties are represented in manufacturing, including production, manufacturing engineering, planning and control, materials management and maintenance, to name but a few. A new product development project may impact on each of these specialties, but in differing ways with implications for the emphases and phasing of emphases placed by these specialties during the new product development process. Langowitz did not consider these specialist functions individually. In sum, while Langowitz's study is certainly a microscopic view of new product development, when compared to most other studies, it is still relatively macroscopic relative to the operational aspects of new product development from the perspective of the specialties within manufacturing.

New Product Success & Failure: Summary

Empirical research on the performance of new product development projects has identified factors that separate new product successes from failure which are controllable by management, and which are situational or environmental. However, the studies have approached the investigation of new product success and failure largely from an external perspective. They have identified factors associated with success and failure, with little consideration for these factors in differing functional contexts.

First, empirical research on new product success and failure, while integrating the roles of the various functions, does not differentiate among the management tasks in these functions. Product development, as an activity, involves the selection, development, retention and effective utilization of technical personnel (Myers & Marquis, 1969). These personnel typically originate in different functional groupings in the firm. By their very nature, the functions differ in the resources, experience and skills required in each for successful new product development.

Second, empirical research on new product success and failure contains various criteria to judge the success or failure of a new product development project, including return on investment of various types, competitive position maintenance in current markets, new markets successfully entered, number of new products launched. These criteria are external to the functions involved in the development process, and do not disaggregate the performance of these individual functions. However, the impact of the performance of individual functions on project success is function-specific, demanding measures of success which are function-specific also. Further, perceptions of project success vary widely among functional units. Such perceptions may also vary among management levels and different levels of experience in the organization (Maidique & Zirger, 1984).

Third, for many functional managers, new product development tasks are more likely to be carried out in relation to a sequence of related products, or a product family, rather than in the context of an individual product, unrelated to any past or future product. However, while Langowitz focused her questions at the individual new product project level, she selected the projects for study on the basis of technical or cost ambitiousness, and from a number of product categories. As such, her study offers no guidance on the relationship between emphasis and phasing of emphasis on manufacturability and product manufacturability, in the context of succeeding members of the same product category.

Finally, product development, as an activity, takes place within a strategic context, such as whether the firm is adopting a first-to-market, second-to-market, late-to-market or a market segmentation strategy (Ansoff & Stewart, 1967; Maidique & Patch, 1982). Technical resources, drawn from a number of functional areas, interact with each other to varying degrees at different phases of a new product development project. In these interactions, the primacy of responsibility for achievement of various milestones or project targets may pass among the various functions. The particular strategic role played by individual functions may be influenced by the strategic context of the development project, and have implications for the deployment of the technical resources within the function.

In sum, while the impact on project success of functional performance, including that of manufacturing engineering (ME), may be function-specific, empirical research on new product success and failure does not address the task of managing the development activities undertaken by the ME function, the deployment of ME staff in the execution of these activities, or the relationship between deployment and product performance.

SUMMARY

Empirical studies have demonstrated that there is no single factor that explains success or failure: each study has presented its list of key factors which are controllable by management, or which are situational or environmental. However, the studies have approached the investigation of new product success and failure largely from an external perspective, with little consideration for these factors in differing functional contexts.

Manufacturing engineering is a specialized engineering resource which has an explicit role in the development of new products and processes, and in the support and improvement of existing processes. In particular, ME has responsibility for achieving manufacturability in new products during the development process. There is consensus among writers on the need for integration of manufacturing and engineering early in the new product development process. However, there is little guidance on the management task, including the staffing and deployment of ME in the new product development process. In the next chapter, I develop a conceptual framework with the central theme that the manufacturability-related performance of new products is associated with the deployment of manufacturing engineering resources during the new product development process. The context within which this new product development activity takes place is defined by the manufacturing strategy of the firm.

CHAPTER THREE: RELATING PRODUCT PERFORMANCE TO MANUFACTURING ENGINEERING DEPLOYMENT

Previous studies have pointed to a number of key factors that influence the performance of new product development projects. There is consensus on the need for integration of manufacturing and engineering early in the process. However, there is little guidance on the management task included in the deployment of the manufacturing engineering function in the new product development process. In sum, the burden of the argument of the previous chapter was that existing knowledge is inadequate as a vehicle for reporting or understanding the performance of new product development projects in terms associated with the deployment of manufacturing engineering resources during the product development process. This chapter is devoted to the construction of a conceptual framework for describing this deployment-performance relationship, and deriving a set of hypotheses for testing.

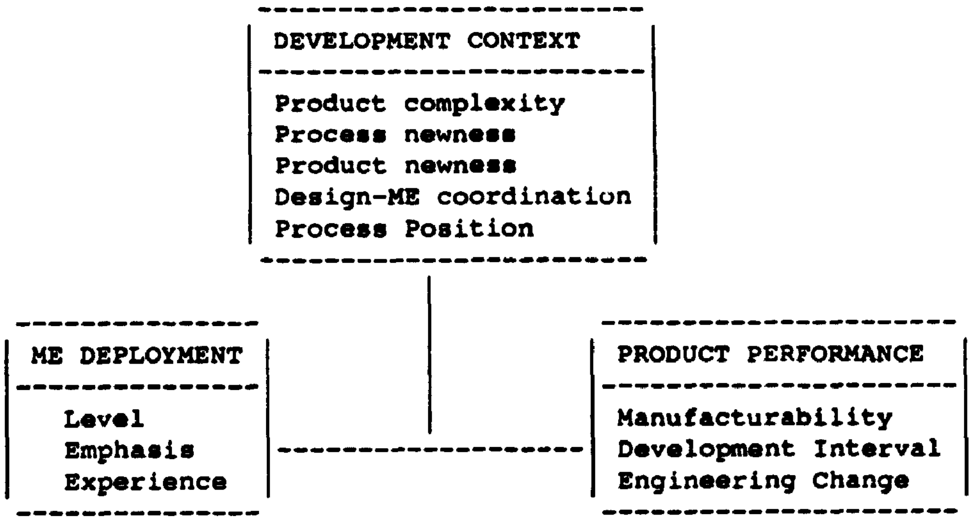
A CONCEPTUAL FRAMEWORK

The conceptual framework for this study identifies relationships among the elements of ME deployment and the components of product performance. This framework is illustrated in Figure 3.1. The underlying hypotheses of the framework are as follows:

> the performance of a new product is related to the deployment of ME resources during the development process of the product;
>
> the relationship between product performance and ME deployment is moderated by the context in which the product development takes place.

Figure 3.1

Relating Product Performance to Manufacturing Engineering Deployment



Three major blocks of variables are identified in the framework:

Product performance;
Deployment of ME;
Development Context

The basic relationships among these variables have their origins in the literature; what is different in this framework is the functional level at which they are being related: the ME function. Product performance reflects the activity of the ME function, and is assessed when volume production for sales commences. The deployment of ME is a variable over which the ME manager has control during the new product development process. The development context, is defined by the manufacturing strategy of the firm, and is more or less fixed for an individual new product development project. My expectation is that the greater and earlier the deployment of more experienced ME resources during the development process, the better will be the product performance, in terms of greater manufacturability, lower incidence of manufacturability related-engineering change, and shorter development interval.

There is no inference of cause and effect in the conceptual framework as outlined. The relations proposed are associational rather than causal, although certain constructs precede others in time. In the next three sections, I will discuss each of the three major blocks of variables identified in the framework.

PRODUCT PERFORMANCE

In this study, product performance has three dimensions:

manufacturability;
development interval;
engineering change.

These dimensions of performance are separated in time terms. Product manufacturability and the length of development cycle both may be assessed on completion of the project. The incidence of engineering change does not occur until after completion of product launch.

Conceptually, the elements of product performance are related to each other. For example, a product with a low degree of manufacturability at the start of routine volume production would likely have manufacturability-related problems. Rectification of these problems would require development and implementation of manufacturability-related engineering changes. On the other hand, achievement of a high degree of manufacturability prior to the start of volume production would require engineering to spend additional time which, in turn, may extend the development interval, which is consistent with suggestions of Putnam (1985) and Hayes et al. (1988).

Manufacturability

Design is the first stage of manufacturing. The design of a product, its components and the technology used to fasten it together are the basic factors which govern the ease or difficulty with which the product may be manufactured and assembled. Ease of assembly is sometimes described in terms of assemblability, manufacturability, or producibility. For the purposes of this study, I take these terms to be synonymous, and for clarity I will use the term manufacturability.

A structured look at manufacturability reveals three common concerns:

ease of fabrication and handling of individual piece parts;

ease of inspection and test of parts and assemblies;

ease of assembly and associated kitting and handling (Dewhurst & Boothroyd, 1984; Hales, 1987).

To address each of these concerns requires a reduction in the number of parts, the development of foolproof assemblies and a simplified assembly process, use of common components across product families, avoidance of tolerances that exceed process capabilities, and use of modular product options (Starr, 1965; Whitney, 1988; Walleigh, 1989). Conceptually, for a firm to address each of these concerns requires the deployment of ME resources during the product development process.

Development Interval

The development interval includes the total elapsed time from the beginning of the development project to commercial introduction. During this time, each of the functions involved in the development process commences, and attempts to complete its range of development activities. The traditional approach to new product development (design first, engineer, and manufacture later) leads to problems including long development interval and a high incidence of engineering change (Putnam, 1985; Hayes et al., 1988). Alternative approaches identify similar variables, but varying in differing ways.

The benefits of 'integrated manufacturing' (Putnam, 1985) include shorter development interval and reduced engineering changes. On the other hand, in the 'alternative paradigm', proposed by Hayes et al. (1988), manufacturing has less complete information during the shorter development interval. Implied in this 'alternative paradigm' is an increase in engineering changes, and a reduction in the time available to engineering to complete its part of the project.

Manufacturability-related Engineering Change

Engineering change may occur at any time during a development project, or after launch of the product. However, poorly handled engineering changes create wasted material as well as increased reject rates (Hayes & Clark, 1985). Further, such change goes against the notion of 'design-right-first time', where manufacturability may be conceptualized as avoiding, on the one hand, production line stoppages, rework costs, and after-sales problems, and increasing, on the other hand, safety, quality of workmanship, cost savings, and process compatibility (Wood & Coughlan, 1988a).

Certain categories of change may be avoidable through the way in which engineering resources are deployed prior to the product launch. Further, change categories may be influenced more by one particular function than another. Conceptually, the change category most influenced by ME is that relating to product manufacturability. The product development process provides opportunities to evaluate the performance of the product and to make the necessary changes prior to start of volume production. These opportunities include value analysis sessions, manufacturability assessments, prototype building, and pilot production. Depending upon the way in which ME resources, are deployed, these activities may or may not be carried out, and may or may not be carried out well, with downstream consequences for the incidence of manufacturability-related change.

Rectification of the manufacturability-related difficulties may be accomplished through engineering change after the start of routine volume production. Manufacturability-related change may be independent of, derived from, or responsible for other engineering change relating to functional characteristics of the product. In particular, such change may include change in the total number of component parts, the specified tolerances, the materials in parts, the use of fasteners, the number of assembly directions, or the position and orientation of parts.

THE DEPLOYMENT OF MANUFACTURING ENGINEERING RESOURCES:

As a new product development project moves downstream towards start of volume production through the various development phases, resource acquisition and allocation decisions arise. These decisions are interwoven with aspects of manufacturing strategy. At the level of the firm, such decisions include the appropriate mix of human resources for the firm as a whole. At the level of the ME function, whether organized as a department in its own right or not, a similar decision on mix is required. This decision will be influenced by the portfolio of ongoing and planned projects involving ME. These projects may include development of new products and processes, and support and improvement of ongoing processes. Among these various demands priorities exist. These priorities may be imposed on the ME function from elsewhere in the organization through, for example, performance control objectives set as part of the strategic planning process (Mintzberg, 1979).

The resources to be planned, budgeted, and extended or otherwise used to carry out a new product development project include: time, money, engineering manpower, facilities, equipment and materials. The nature of each specific project dictates which resources are critical and to be estimated and scheduled with care (Archibald, 1976).

Manufacturing engineering manpower (or intellectual assets) is the resource of interest in this study. In Chapter Two, I identified two types of ME manpower sources as playing a part in new product development:

product design resources concentrating on value engineering, manufacturability assessment, and manufacturing standards;

process design resources concentrating on product planning/process engineering, plant layout, equipment engineering, production analysis and material handling.

The deployment of these ME resources during the new product development process has three major components:

level;
emphasis;
experience.

Level of ME Resources

Completion of each of the tasks carried out by ME during the new product development process requires the use of a certain amount of manpower resources. Over the course of a project, the ME manager will allocate a number of ME staff to support the development of the product. These staff will spend a certain amount of time engaged in activities related to the project, during differing stages or phases of the project. The manpower resource requirements may differ among stages of the development process and among projects, each based on the differences among the range of tasks to be completed. The expectation from the empirical studies reviewed would be that the earlier this time, or effort, is spent, the better the product performance (Gerstenfeld, 1976; Langowitz, 1988).

Emphasis by ME

Manufacturability is not implicit in the design of a product, and its achievement requires explicit emphasis from ME during the development process (Duck, 1986; Daetz, 1987; Langowitz, 1988). Ease of fabrication and handling of individual piece parts requires ME to place emphasis on physical features and properties, finishes and tolerances, molds and tooling during the new product development process. Ease of inspection and test of parts and assemblies requires ME to place emphasis on accessibility for instrumentation, visibility, fixturing and rework. Finally, ease of assembly and associated kitting and handling requires ME to place emphasis on the number of parts and how they are presented, oriented, inserted, and joined (Stoll, 1986; Hales, 1987).

Through developing and applying design rules, and though carrying out manufacturability assessments at differing stages of the new product development process, ME are able to emphasize the achievement of manufacturability (Walleigh, 1989). Inadequate ME emphasis on manufacturability may lead to problems in the area of assembly and test. Manufacture of designs with numerous parts may be characterized by part mix-ups, missing parts, and test failures:

> 'If some parts are very similar but not identical, the chances of an assembler using the wrong part in a given location may increase. Complicated assembly steps and/or tricky joining processes may lead to incorrect, incomplete, unreliable, or otherwise faulty assemblies' (Daetz, 1987: 65).

In sum, the expectation is that the greater and earlier emphasis, by ME on manufacturability, the better the product performance.

Experience of ME

In the process domain, the success of implementation and start-up of new process projects is related to technical and managerial experience (Henderson, 1974; McCutcheon, 1988). Manufacturing engineers have particular roles in relation to solving and avoiding problems as a product moves from development to full-scale production. These engineers, in their focus on manufacturability, build up, over time, a unique expertise, which may be lacking in both the development and manufacturing organizations (Szakonyi, 1985). Building ME staff experience and allocating experienced staff to a new product development project is within the control of the ME manager. Firms that are successful at new product development reassign individuals who have been key agents of change in previous developments to new projects. Through this process of osmosis, the firm transfers and accumulates experience in managing product development (Takeuchi & Nonaka, 1986). Building the technical and managerial abilities of an extended group of people who are assigned according to a careful plan can be used to enhance a firm's ability to plan and execute new product development projects (Hayes et al., 1988: 339).

DEVELOPMENT CONTEXT

The Manufacturing strategy of the firm defines differing development contexts in which the primary relationship of interest (ie. that between ME deployment and product performance) is expected to vary. Based on the strategic decision categories of Hayes and Wheelwright (1984), manufacturing strategy has two dimensions: structural, and infrastructural. These decision categories include the following elements:

Structural - technology: product complexity; product and process newness.

Structural - vertical integration: process position.

Infrastructural - organization: design-ME coordination.

I will discuss each of these elements in turn.

Product and Process Complexity

Products differ on bases other than function or appearance. A product may be thought of as a set of design concepts or particular approaches to basic functional parameters (Clark, 1985). The larger the set of design concepts, and the greater the difference among these concepts, the more complex is the product. Product complexity includes the range of technologies in the parts, that is, the physical material properties, process properties and the information base for the material in each constituent part of the product. In this sense complexity includes, in part, the intricacy or the number and interconnectedness of constituent parts (McCutcheon, 1988).

A process is a collection of tasks connected by a flow of goods and information that transforms various inputs into useful outputs. Manufacturing tasks vary in sequence, duration and interconnectedness, and operator skill requirements. A process has the capability to store both the goods and information during the transformation (Marshall, 1979). Process elements open to change, have been grouped into five inter-related categories: capital equipment and process technology, task characteristics and process structure, scale, material inputs, and labour (Abernathy & Wayne, 1974). Differences in these elements include layout, and use equipment of differing vintages and level of mechanization at differing process stages (Bright, 1958). Variation within these inter-related elements leads to more or less complexity in the process, in the Rogers' (1983) sense of perceived difficulty of use.

Product and process complexity differentiates among products and processes, with implications for the deployment of ME resources during the product development process. Development and integration of these technologies into a product requires ME to carry out product and process development tasks during the development of the product. These tasks concentrate on product planning, process engineering, plant layout, equipment engineering, production analysis and material handling. For ME, the complexity of the development task, may require the deployment of more or less manpower resources.

Product and Process Newness

The competitive emphasis of a new product may range from functional product performance, through product variation, to cost reduction, depending upon the character of the innovation (Abernathy & Utterback, 1982). 'Younger' members of a product family may be closer to the functional-performance end of the spectrum than 'older' products. Associated with the change in competitive emphasis of a new product is the emergence of a 'dominant design' for the product (Abernathy, Clark, & Kantrow, 1983). Movements down the design hierarchy are associated with refinement or extension of higher order concepts, and movements up the hierarchy are associated with departures from existing practices (Clark, 1985). The choice among competing design concepts also has substantial implications for production processes. As such, the activities carried out by ME, in both product and process development, may include some which are required for all projects, some which are unnecessary in later members of a product family, and some which are necessary only in later members of the family.

Earlier writers have conceptualized newness in a number of ways including:

> newness to the firm of customers, product class, needs served, production process, technology, distribution/sales force, advertising/promotion, and competitors (Cooper, 1981);
>
> style change, product line extensions, product improvements, new products for the current market, new products for a new market (Heany, 1983);
>
> incremental newness of the technology built into the product: minor improvement, major enhancement, new related technology, and new unrelated technology (Meyer & Roberts, 1988);
>
> original new products, reformulated new products (Yoon & Lilien, 1985);
>
> generic product development map: development work, engineering prototype, core product, enhanced product, customized product, cost-reduced product, hybrid product (Wheelwright & Sasser, 1989).

The degree of newness is one of the most important factors affecting a new product's success or failure (Yoon & Lilien, 1985). An assessment of product and process newness helps to set specifications and targets for individual projects, provides a context for relating concurrent projects, and indicates how the sequence of projects capitalizes on the company's previous investments (Wheelwright & Sasser, 1989). Products new to the firm very often require the acquisition of new technological resources, and take the firm into unfamiliar technological territory. Different categories of newness carry differing functional implications, and the combination of new human or capital resources, and increasing uncertainties heighten the risk of failure of the new product development project (Cooper, 1981; Heany, 1983). Compared with reformulated new products, original new products were developed by firms with higher production expertise (Yoon & Lilien, 1985).

As later members of a product family incorporate more common components, utilize pre-existing processes, and draw on more ME experience than earlier family members, newness should be associated with a reduction in the amount of confusion arising in relation to the development of new product and process technologies. This newness may also be associated with the mix of development activities carried out by ME and, so, ME resource deployment in later members of the product family.

A final dimension of product/process newness is the ME skill utilized in development relative to that used in other products within the family. A key concept in classifying corporate growth and diversification strategies is 'relatedness' (Wrigley, 1976). Relatedness of strategies is based upon the presence or absence of an underlying production or marketing logic among the product lines of a firm. Captured in these product lines is a core of technology, production, and marketing skill. This core skill is the collective skill which a group of managers acquire as they get to know each other, and the market and technologies they serve, as a result of competing against other firms. The degree of relatedness between the product lines of a firm or firms can vary in nature, that is by technology and market, and in degree, that is by being similar, related or different from others.

> 'When the carry over of learning from one product to another is recognized, it becomes clear that the full measure of a product's impact can only be determined by viewing it in the context of both the products that preceded it and those that followed...The product family incorporates the inter-relationships between products, the learning from failures as well as successes' (Maidique & Zirger, 1988: 330).

Those involved in product development projects engage in a constant process of learning and unlearning, across both levels and functions, where the know-how accumulated at the individual level is transferred to other divisions or to subsequent projects within the organization, becoming institutionalized over time (Imai et al., 1985). Correspondingly, development of an entirely new product has very different implications for deployment of ME skills than a less-new product: the new product requires 'skill making', the less-new product requires 'skill taking' (Wrigley, 1989).

Process Position

One of the most critical strategic decisions a firm faces is how to 'position itself' in its competitive environment. From the viewpoint of manufacturing, process positioning alternatives are expressed usually in terms of vertical integration and sourcing decisions (Hayes & Wheelwright, 1984). Process positioning comprises the width of a firm's internal span of process, the degree and direction of vertical integration alternatives, and its links and relationships, at either end of the process spectrum, with suppliers, distributors, and customers (Hill, 1989). Different process positions change the manufacturing task, and given the interrelationships between product and process technologies, different positions should also impact on the product development task. As such, my expectation is that process positioning moderates the relationship between ME deployment and product performance.

Design-ME Coordination

Integration of product and process design requires functional coordination, including that between design and manufacturing, and ME in particular. This coordination of multidisciplinary and multifunctional skills requires the creation and support of effective internal communication within the project team, and between the team and external organizations. The use of planning and management techniques has been identified as a success factor in new product development projects (Rothwell, 1977). Administrative innovations have also been identified which assist in functional coordination (Ettlie & Reifeis, 1987). These innovations include design for manufacture, and the promotion and development of engineering generalists, including ME staff.

Formalization of arrangements for ensuring closer cooperation between marketing, R&D, and other functions concerned with new products has been associated with product success (Hopkins, 1981). The type of coordination and control suited to the achievement of integration during the product development process, and improving the planning and monitoring of progress has long been a subject for conjecture. The debate centres on the tension between the necessity to formalize the product development task within the firm for efficiency and the advantages of keeping the process open and flexible to promote creativity (Johne & Snelson, 1988).

However, the essence of functional coordination is not in the application of individual procedures or techniques, but in the integration of these procedures to develop standard development model descriptions, phase-end technical and commercial criteria for transfer, and formal functional acceptance of designs (Zoppoth, 1972). Further, design-manufacturing coordination is achieved through mobility of personnel between design and ME, approval by ME of product design details, and acceptability of the notion of product change initiated by ME (Ettlie, 1988).

There is a second dimension to this concept of design-ME coordination: information quality. Projects must be provided with 'state-of-the-art' information on technologies they rely upon (Allen, 1984). Technological activity consumes and transforms information. As such the availability of primary information, often in the form of specifications, blueprints, in sufficient quantity, appropriateness, and timeliness throughout a project is important to achieving functional integration.

In sum, design-ME coordination may influence, not just ME resource deployment during the product development process, but also the performance of the new product. The more integrated design and ME, and the greater the quality of the information flow between the functions, the more effectively the ME resources may be deployed, with a corresponding positive impact on the product performance.

LIMITING THE SCOPE

The conceptual scheme outlines relationships among product and process complexity, ME resource deployment, and level of engineering change. Although important parts of the conceptual scheme, investigation of the relationships between product performance and ME resource deployment in a more or less complex development context will be left for future research. To include such an investigation as part of the current research would serve to broaden the scope of the study and detract from the primary relationship of interest. Only when a relationship between manufacturability-related product performance and ME deployment during the new product development process has been identified is an investigation of these wider relationships merited.

Similarly, the influence of other ongoing projects classed as new development or ongoing support, on ME deployment decisions will not be considered directly in this study. Such broadening of the study focus would bring into question the effectiveness of the resource allocation techniques employed and the appropriateness of the performance control objectives set. These issues, although important in the overall organizational context, are outside and central focus of this study.

RESEARCH PROPOSITIONS

Several propositions of difference and of association emerge from the conceptual framework.

Differences in Product Performance and ME Deployment

I will examine the differences among products, grouped by product newness, process position, and design-ME coordination, in the deployment of ME resources, and in product performance. In all cases, the null hypotheses are of no differences among the variables.

Product Newness: First, I will examine the differences among products, grouped by product newness, in the deployment of ME resources, and, in particular, the level of ME deployment during the new product development process, in ME emphasis on manufacturability during the development process, and in the levels of experience of the ME staff deployed. The null hypotheses are of no differences. The alternative hypotheses are as follows:

H1: newer products will be characterized by a higher level of ME deployment earlier in the product development process than less new products.

H2: newer products will receive a higher emphasis on manufacturability from ME earlier in the product development process than less new products.

H3: newer products will be characterized by lower levels of ME staff experience than less new products.

I will then examine the differences in product performance among products, grouped by product newness, including differences in manufacturability, in the length of the development interval, and in the incidence of manufacturability-related engineering change at the start of routine volume production. The null hypotheses are of no differences. The alternative hypotheses are as follows:

H4: less new products will have higher levels of manufacturability than newer products.

H5: newer products will be characterized by longer development intervals than less new products.

H6: newer products will have higher levels of manufacturability-related engineering changes at the start of routine volume production than less-new products.

Process Position: I will examine the differences among products, grouped by process position, in the deployment of ME resources, and, in particular, the level of ME deployment during the new product development process, in ME emphasis on manufacturability during the development process, and in the levels of experience of the ME staff deployed. The null hypotheses are of no differences. The alternative hypotheses are as follows:

> H7: for products characterized by more internal manufacture of product components, the level of ME deployment will be higher, earlier in the product development process than for products characterized by less internal manufacture of product components.
>
> H8: products characterized by more internal manufacture of product components, will receive a higher emphasis from ME on manufacturability earlier in the product development process than products characterized by less internal manufacture of product components.
>
> H9: products characterized by more internal manufacture of product components, will be characterized by higher levels of ME staff experience than products characterized by less internal manufacture of product components.

I will then examine the differences in product performance among products, grouped by process position, including differences in manufacturability, in the length of the development interval, and in the incidence of manufacturability-related engineering change at the start of routine volume production. The null hypotheses are of no differences. The alternative hypotheses are as follows:

> H10: products characterized by more internal manufacture of product components, will have higher levels of manufacturability than products characterized by less internal manufacture of product components.

H11: products characterized by more internal manufacture of product components, will be characterized by longer development intervals than products characterized by less internal manufacture of product components.

H12: products characterized by more internal manufacture of product components, will have lower levels of manufacturability-related changes at the start of routine volume production products characterized by less internal manufacture of product components.

Design-ME Coordination: Finally, I will examine the differences among products, grouped by management approach to design-ME coordination, in the level of ME deployment in the new product development process, in ME emphasis on manufacturability during the development process, and in the levels of experience of the ME staff deployed. The null hypotheses are of no differences. The alternative hypotheses are as follows:

H13: products, managed through a more formalized approach to design-ME coordination, will be characterized by a higher level of ME deployment earlier in the product development process than products managed through a less formalized approach.

H14: products, managed through a more formalized approach to design-ME coordination, will receive a higher emphasis from ME on manufacturability earlier in the product development process than products managed through the less formalized approach.

H15: products, managed through a more formalized approach to design-ME coordination, will be characterized by higher levels of ME staff experience than products managed through a less formalized approach.

I will then examine the differences in product performance among products, grouped by management approach to design-ME coordination, including differences in manufacturability problems, in the length of the development interval, and in the incidence of manufacturability-related engineering changes at the start of routine volume production. The null hypotheses are of no differences. The alternative hypotheses are as follows:

H16: products, managed through a more formalized approach to design- ME coordination will have higher levels of manufacturability than products managed through a less formalized approach.

H17: products, managed through a more formalized approach to design-ME coordination products will be characterized by shorter development intervals than products managed through a less formalized approach.

H18: products, managed through a more formalized approach to design-ME coordination will have lower levels of manufacturability-related changes at the start of routine volume production than products managed through a less formalized approach.

Association between Product Performance and ME Deployment

I will examine a series of hypothesised association between product performance and the deployment of ME staff during the new product development process.

Development Interval and Deployment of ME Staff: The null hypotheses are of no association among the performance and deployment variables. The basic alternative hypotheses of association are as follows:

Development Interval and Emphasis on Manufacturability:

H19: the greater the level of emphasis by ME on manufacturability during the new product development process, the shorter will be the development interval.

Development Interval and Phasing of Emphasis on Manufacturability:

H20: the earlier the phasing of emphasis by ME on manufacturability during the new product development process, the shorter will be the development interval.

Development Interval and Earlier ME Deployment:

H21: the greater the level of ME deployment earlier in the new product development process, the shorter will be the development interval.

Development Interval and Later ME Deployment:

H22: the greater the level of ME deployment later in the new product development process, the longer will be the development interval.

Development Interval and Level of ME Staff Experience:

H23: the greater the level of ME staff experience, the shorter will be the development interval.

Manufacturability and Deployment of ME Staff: The null hypotheses are of no association among the performance and deployment variables. The basic alternative hypotheses of association are as follows:

Manufacturability and Emphasis on Manufacturability:

H24: the greater the level of emphasis by ME on manufacturability during the new product development process, the greater will be the manufacturability of the product at the start of routine volume production.

Manufacturability and Phasing of Emphasis on Manufacturability:

H25: the earlier the phasing of emphasis by ME on manufacturability during the new product development process, the greater will be the manufacturability of the product at the start of routine volume production.

Manufacturability and Earlier ME Deployment:

H26: the greater the level of ME deployment earlier in the new product development process, the greater will be the manufacturability of the product at the start of routine volume production.

Manufacturability and Later ME Deployment:

H27: the greater the level of ME deployment later in the new product development process, the lower will be the ease of manufacture of the product at the start of routine volume production.

Manufacturability and Level of ME Staff Experience:

H28: the greater the level of ME staff experience, the greater will be the ease of manufacture of the product at the start of routine volume production.

Manufacturability-related Change and Deployment of ME Staff: The null hypotheses are of no association among the performance and deployment variables. The basic alternative hypotheses of association are as follows:

Manufacturability-related Change and Emphasis on Manufacturability:

H29: the greater the level of emphasis by ME on manufacturability during the new product development process, the lower will be the incidence of manufacturability-related engineering change after the start of routine volume production.

Manufacturability-related Change and Phasing of Emphasis on Manufacturability:

H30: the earlier the phasing of emphasis by ME on manufacturability during the new product development process, the lower will be the incidence of manufacturability-related engineering change after the start of routine volume production.

Manufacturability-related Change and Earlier ME Deployment:

H31: the greater the level of ME deployment earlier in the new product development process, the lower will be the incidence of manufacturability-related engineering change after the start of routine volume production.

Manufacturability-related Change and Later ME Deployment:

> H32: the greater the level of ME deployment later in the new product development process, the greater will be the incidence of manufacturability-related engineering change after the start of routine volume production.

Manufacturability-related Change and ME Staff Experience:

> H33: the greater the level of ME staff experience the lower will be the incidence of manufacturability-related engineering change after the start of routine volume production.

When these basic deployment-performance relationships are moderated by the manufacturing strategy variables (product/process newness, process positioning, and by the management approach to design-ME coordination), these hypotheses are expected to change.

SUMMARY

In this chapter, I developed a framework around the theme that the manufacturability-related performance of new products was associated with the deployment of manufacturing engineering (ME) resources during the new product development process. The context within which this new product development activity took place was defined by the manufacturing strategy of the firm. This framework was consistent with earlier studies on the performance of new product development projects. It proposed one set of performance-related factors, which were controllable by ME management, while a second set defined the development context. However, the framework differed from earlier studies as it identified specific functional resources, manufacturing engineering, as being associated with a specific dimension of product performance, manufacturability. Earlier studies had not investigated product performance from this perspective.

CHAPTER FOUR: A FIELD STUDY

The previous chapter developed a simple conceptual scheme that related the performance of new products to the deployment of manufacturing engineering resources during the new product development process. Propositions were presented that may be tested, given appropriate operationally defined variables for each of the constructs. This chapter outlines the research design and methods which were used to test the hypotheses.

RESEARCH DESIGN

The research was exploratory in nature: the objective was to identify and describe aspects of new product performance from the perspective of the ME function and to test some hypotheses of association and difference derived from the conceptual framework developed in the last chapter. Consequently, the methodology of choice was empirical field research. In general, research strategies have been categorized in many ways including:

experiment;
survey;
archival analysis;
history; and, case study (Yin, 1984).

In particular, field research strategies have been divided into a number of categories, as summarized in Table 4.1.

Table 4.1

Field Research Strategies

Field Research Strategy	Purpose
Field Survey	Gather data Suggest relationships
Single Case Study	Early tests of theory Preliminary exploration of theories explaining processes
Comparative Cases	Explicit comparison of events
Cross-sectional Field Study	Investigate specific propositions concerned with the state of the system, rather than processes.
Longitudinal Field Study	Investigate a process explanation Seek cause-and-effect relationships
Field Experiment	Determine cause-and-effect relationships where there are identified alternative explanations of phenomena.

(Douds & Rubenstein, 1978).

Even though each field research strategy has its distinctive characteristics, there are large areas of overlap among them. Each strategy can be used for exploratory, descriptive or explanatory research. However, some are more suited to particular purposes than others.

Many factors influence the selection of a research strategy:

the type of research question posed;

the extent of control over actual events;

the degree of focus on contemporary, as opposed to historical events;

the resources available to the researcher (Douds & Rubenstein, 1978; Yin, 1984).

The research questions posed in this study are 'how', 'what' and 'when' questions:

What specialist engineering resources are deployed in the development of manufacturable new products?

When, during the new product development process, are these engineering resources deployed?

Is the successful achievement of manufacturable new products associated with the way these engineering resources are deployed?

Is an association between the achievement of manufacturable new products and the way these engineering resources are deployed, contingent upon the development context?

To address these questions, specific hypotheses of difference and association were framed, and their investigation required explicit comparison of contemporary events in the new product development process over a number of projects. As such, a field survey, single case study or comparative studies were unsuitable for such hypothesis testing. However, the management of new product development projects, as an area for research, is not so well developed as to support investigation of causal relationships. Further, the relationships to be investigated could not be manipulated by the researcher, so ruling out a field experiment. As the relationships of interest in the new product development process were hypothesized to evolve over succeeding projects, the most appropriate field research approach was a cross-sectional field study, with a longitudinal dimension. Finally, this research strategy was consistent with the time and resources available to carry out the research.

The Choice of the Field Research Site

The potential for confusion or for improvement in manufacturing operations is implicit in new product performance. In particular, design for manufacture, short development intervals and accommodation or prevention of engineering change after commencement of routine volume production are live concerns of firms characterized by high rates of new product introduction, pressures toward cost reduction, and greater speed in new product development. As such, the research site chosen for this study was in an industry with a high percentage of [illegible]ent revenues derived from new products.

The research was conducted entirely within one company, a major competitor in the electronic equipment industry, with corporate offices located in the United States. The company developed, manufactured and marketed equipment in a number of product areas, including data terminals. In 1988, the company operated over forty manufacturing plants worldwide. R&D was conducted in over half of these facilities and by a subsidiary that operated R&D facilities in several locations worldwide. The selection of a single company as a field site, however, requires comment.

Examination of the relation between new product performance and ME deployment required consistent and detailed data. A sample of new product development projects drawn from different firms would have generated less consistent data and required a trade-off of depth of investigation with breadth. Few firms maintain data in strictly comparable fashion, even in the same industry. Hence, the significance of observed variations in product performance among different firms would be difficult to assess, and even suspect. Further, given the sensitive nature of the data sought, in a highly competitive industry, I judged that a company would be less willing to cooperate if they knew that the research was being replicated in competitors' plants.

The company presented a unique opportunity for the study of new product development because of the rate of change in its markets, its size, and the availability of comparable streams of business in different locations: an estimated eighty percent of current revenue was derived from products less than five years old. As such, the choice of this company for the study was consistent with a focus on the performance of new product projects in firms characterized by high rates of new product development.

Further, product design 'right-first-time' and product manufacturability were current strategic issues. A major challenge facing the company was sustaining and improving its agressive pattern of growth in an increasingly competitive market. The company's vision to the end of the century demanded delivery of products and systems 'of the highest quality and reliability, on time, tailored to the varying needs of our customers' (Annual Report, 1987). These products were to be economical to produce and supported by those who knew the product best. In 1985, the company developed and introduced the Stage Procedure (or Staging) as an innovative approach to management of the new product development process, and coordination of design and manufacturing engineering resources during the process. Staging was an integral part of the company's response to its competitive challenge. Utilization of Staging in all divisions after 1985 provided a unique opportunity to control for approach to design-ME coordination in the company: that in place before 1985, and Staging.

The Choice of New Product Development Projects

Product complexity has been identified as a factor related to risk in new product development (Cooper, 1981). However, the relationship between project complexity and project performance is not a simple one, being dependant upon the line of business or industry within which the project is taking place (Baker, Green & Bean, 1986). As such, the sample of products examined was selected to control for product or technological complexity. All products examined were drawn from a single product catagory, data terminals.

At its most general, the data terminals category included consumer and industrial terminals. While each of these terminals varied in purpose and range of features, many materials and processes were common to all systems. Several materials types were common to all terminals including plastics, metals, electronic components, circuit boards and cordage. Often, these material types were utilized in differing ways in each terminal. All terminals went through a basic process flow including main circuit board assembly, keyboard assembly, base assembly, cord assembly and packaging. The range of processes involved in the fabrication and assembly of each terminal type included injection molding, circuit board assembly, cord manufacture, assembly of major sub-assemblies and final assembly of the terminals.

The 12 new products studied were developed by four divisions of the company, and are summarized in Table 4.2.

Table 4.2

Sample of New Product Development Projects

Division	Terminal Family	Number of Projects
A	A Series	4
B	B Series	3
C	C Series	3
D	D Series	2

The terminals in Division A comprised the A series and included three consumer and one industrial terminal. The first member of the A series was developed in 1983 and the remaining three were developed between 1984 and 1987. In Division B, the first member of the B series was developed in 1987, and the remaining two were developed between 1987 and 1989. In Division C, the C series included three terminals which were developed between 1986 and 1988. Finally, in Division D, the two members of the D series were developed between 1985 and 1987.

These new product development projects were not selected at random. Rather, they were selected so that, within each division, all products were drawn from a single product family, which incorporated the inter-relationships among products, the learning from failures as well as successes (Maidique & Zirger, 1988). Within each product family, the objective was to include in the sample the first and second products of the family, and, if possible, the third and fourth products in the family. Selecting the products in this way allowed, in particular, the notion of newness to be anchored in relation to particular related products. This selection also introduced a desired longitudinal dimension into the study in that the products examined in each division (and family) were the outcome of serial development projects.

Control of Variables and Validity Considerations

The term control is used in several different senses in research design, and, so, precision is required regarding its usage as each sense of control involves ruling out threats to valid inference (Cook & Campbell, 1979). In this research study, I identified particular threats to valid inference identified, and ruled them out, either through research design, or by measuring the potential threat and using the measure in the data analysis to rule out the threat, as summarized in Table 4.3.

Table 4.3

Control of Variables & Validity

Variables Controlled	Means of Control	Trade-Off
Product Complexity	Elimination by design	Internal for external validity
Process Complexity	Elimination by design	Internal for external validity
Product Newness	Measurement & statistical control	Construct validity
Control Mechanism	Design, measurement & statistical control	Construct validity

First, product complexity and process complexity were controlled for through narrowing the focus of the study on one particular product category in one company setting. As such, these variables were eliminated from the study. Second, the control mechanism was controlled for, in part, through confining the study to one company. Further, because the control mechanism used by the company changed in 1985, the new product development projects studied were characterized by either one of two control mechanisms. As such, the control mechanism used for each produc as categorized and their influence identified using statistical methods. Similarly, product/process newness was measured and the influence identified using statistical methods.

Control of the above variables, and in particular, product complexity and process complexity, have implications for the validity of the study. Design of the study so as to focus on one particular product type in one company, increased the internal validity of the study, that is the relationship between the ME deployment and product performance variables. However, the external validity, that is the validity with which conclusions can be drawn about the generalizability of the relationship to and across populations of other products and company settings, is potentially reduced. This tradeoff of internal validity at the expense of external validity is defensible for an exploratory study.

The priority among validity types varies with the kind of research being conducted (Cook & Campbell, 1979). This study was designed to test hypotheses of difference and of association among variables based on the conceptual scheme proposed in the preceding section. As such, the study may be classified as theory building, and for such studies:

> '...the types of validity, in order of importance, are probably internal, construct, statistical conclusion, and external validity' (Cook & Campbell, 1979: p.83).

The primacy of internal validity relates to the costs of being wrong abo the magnitude and direction of inferred relations, and the often minimal gains in external validity that are achieved in moving from initial accidental samples of convenience, that belong in the class to which generalization is desired, to other types of samples:

> 'Consequently, jeopardizing internal validity for the sake of increasing external validity usually entails a minimal gain for a considerable loss' (Cook & Campbell, 1979: p.84).

In reality, the use of the company selected as the research site does not preclude the findings of the proposed research from being generalized to other firms in the electronic equipment industry, or to other firms in industries characterized by high rates of new product introduction. The company studied confronted a combination of dynamic, rapidly improving technologies, and high development costs. In committing large amounts of resources to the development process, the company faced management tasks similar to other multi-divisional firms operating in a high-technology industry. At its most general level this research addresses one set of these tasks, the timing and integration of engineering resources in relation to new product development in a multi-functional setting.

Information Sought

To study the performance of new products in relation to the deployment of manufacturing engineering resources, a number of different types of information are required. Each new product project went through a development process characterized by a sequence of phases. Data was required on ME involvement at each stage, and on the performance of the project after commencement of volume production.

First, descriptive qualitative information on the the particular new product being developed, and the on the management of the product development project was required. Second, quantitative information on ME deployment and on the incidence of engineering change for each project was required. The information sought included some of what might be categorized as manager's beliefs and attitudes.

Data Gathering Method

The field research was carried out two stages: the preliminary study and the final study. In the preliminary study, three new product development projects were investigated in two divisions within the company. In each division, discussions were held with manufacturing managers, manufacturing engineering managers, and manufacturing engineers. Data were gathered on the earliest two members of the A series in Division A, and on the first member of a new product family in another division. This other division was not included in the subsequent final study. In the final study, data on 12 new products were obtained using the interview protocol, included as Appendix III. Two of these products had been included in the preliminary study. Interviews were conducted with both the Manufacturing Director or Manufacturing Engineering Manager, and the Manufacturing Engineering project engineer assigned to the project of interest.

The Preliminary Study: The preliminary study was carried out in the period August to November 1988. The theoretical objective of the preliminary study was to identify the the specific activities carried out by ME in each phase of the new product development projects, and also the management procedures utilized to coordinate and control the development process. The understanding of these activities was reflected in the conceptual scheme developed in the previous chapter, and will be reflected in the operational scheme developed later in this chapter. The methodological objective of the preliminary study was to identify and evaluate data gathering issues and alternatives for the final study, and to validate the measurement scales developed. In the event, the preliminary study provided the basis for an interview protocol which allowed efficient data gathering for the final study.

The products selected as the focus of the preliminary study were of interest, not just for their substantive content, but as tests of the availability of reliable and valid data on products developed as far back as 1983. The preliminary interview protocol included questions which required specific descriptive qualitative or quantitative information. When asking such questions, the availability of archival data sources to supplement the interviewee's response was also investigated. Many archival sources of data were identified in this way.

In the preliminary study, the data gathering method utilized was personal interview of the Manufacturing Director, the Manufacturing Engineering Manager, the Manufacturing Project Manager for the project, or a senior Manufacturing Engineering Project Engineer on the project. The interviews were administered by this researcher and were guided by a preliminary inteview protocol comprised of open-ended and closed questions. The interview protocol also included measurement systems providing a single score for a variable for the project. These systems were based on 5-point scales (eg. much less emphasis to much more emphasis). Aggregated scores were based on the addition of ratings for each element of variable.

No one interviewee was required to address all topics in the interview protocol. However, many topics were addressed by only one interviewee, often the acknowledged expert on the topic within the division. In other cases, interviewees nominated other individuals within their division from whom clarification or confirmation of data was sought. Each interview took from two to three hours, and two to three interviews per individual were necessary to acquire the required data.

Interviews were coordinated with the assistance of the Manufacturing Director or Manufacturing Engineering Manager in each division. I gave interviewees one week's notice of the first interview, after which I set a date for subsequent interviews. Initially, I provided a copy of the interview protocol in advance, for information purposes. Later, it was apparent that interviewees were neither willing nor able to devote time to preparing for the interview. As a result, I provided only a one-page agenda for the interview in advance.

Second interviews with the same individual were often more productive than the initial meeting because of the rapport which had been established initially. Reference by the interviewee to written documents led to their study by the interviewer prior to the second interview. This second meeting resulted in an easier exchange of ideas and an opportunity to concentrate on particular areas of interest. Sometimes the separation between interviews was as short as a day and sometimes as long as several weeks.

The interviews took place in each individual's office. Early on in the data gathering process, it became apparent that some interviewees preferred to record their responses themselves on the interview protocol, rather than have the interviewer record the answers. One interpretation of this behaviour was that these interviewees were extremely active managers who were not accustomed to sitting in their offices and not writing. A marked improvement in the effectiveness of the data gathering process resulted from the change, with the focus of the interviewee's attention, less on the interview process, and more on the content of the protocol.

In many cases the interviewee indicated that he was not in a position to provide a response. In such cases, the interviewee was requested not to speculate, so that the repsonses that were received were carefully thought-out comments from people in a position to speak with validity on the specific topic. The responses were compared with written records wherever possible, and also checked with responses from other interviewees.

The archival sources of data identified were particularly important, not just as additional data, but also as primary data to be supplemented by the interviews rather than vice versa. These data included Manufacturing Engineering manhour records by job number, by engineer, by project on a monthly basis for each project, both before and after commencement of volume production. These records were available from the Design Cost Accounting function. The second major set of archival data comprised engineering change documentation for all projects. This documentation was available from the Design function. The third set of data was the manufacturing plan for each projects, and was available from the ME interviewees.

Where available, the archival data assisted in the interview process. In many instances such data were no longer available, having been destroyed in 'office-cleaning' exercises. These 'lost' data included detailed project schedules. In such instances, interviewees were invited to revise a copy of a similar project schedule drawn from a later project to reflect the characteristics of the project under investigation. Generally, interviewees experienced difficulty with this process, being unable to separate out the project under investigation from the many projects which had been developed since that time. In contrast, when faced with questions, based on 5-point scales, for the same projects, interviewees exhibited little difficulty or hesitation in assigning scores. This ease of response, in comparison with the difficulties described earlier, underscored the potential threats to validity and reliability when using such 5-point scales in a study requiring reflection on events or activities separated by time or other projects.

The scale-based measurement systems were revised, in the light of the experience of the preliminary study, in four specific ways. First, the areas where scale-based measurement systems were used were minimized. Second, areas where they were used were rephrased for clarity, especially with respect to the point in time of interest. Third, when assigning scores, interviewees were asked to provide a substantive comment in support of the score. Fourth, a number of measures of variables were taken, where possible. Finally, the revised scales were reviewed by the ME manager at Division A, for clarity, and for ability to discriminate among all products in the A series of terminals.

In sum, the preliminary study provided an opportunity to develop the proposed data gathering method in realistic research sites. The study indicated clearly that when investigating individual product members in a product family, in an environment characterized by new product introductions at a rate of even one per year, probability of interviewee responses not reflecting the product in question was high.

The Final Study: The final study was carried out in the period January to April 1989. The personal interviews, revised in the light of the experience on the preliminary study were repeated for the final study with the same range of individuals (ie. ME manager, project manager, project engineer). In addition, the archival data sources formed a major part of the data gathering effort method, so reducing the level of reliance on the personal interviews. However, while the form and format of these data were common or comparable throughout the company, the initial expectation of consistent quality was not realized: unfortunately, the accessibility, availability, and completeness of these archival data varied among the divisions included in the final study.

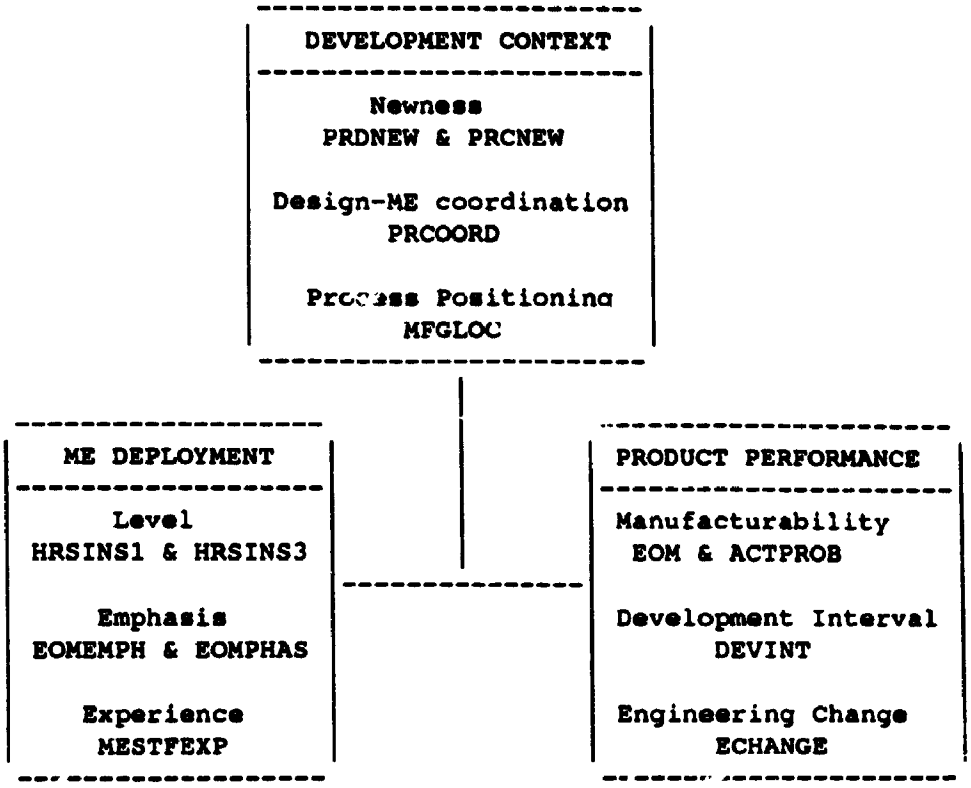
Although the carefully constructed and tested interview protocol was used in the final study, the range of questions usually discussed during the interviews was more encompassing than that included in the formal protocol. The flexibility of the interview method made it possible to expand discussion, as appropriate, on management practices relevant to the study.

THE OPERATIONAL MODEL

To test the research propositions, operational measures were defined for twelve variables developed for the research. Figure 4.1 shows the operational scheme with the names of the variables used for the operational measures.

Figure 4.1

Operational Framework



As in the conceptual model, three major blocks of variables are identified in the operational model:

product performance;
deployment of ME;
development context.

These variables, their constituent elements and internal consistency are summarized in Table 4.4.

2

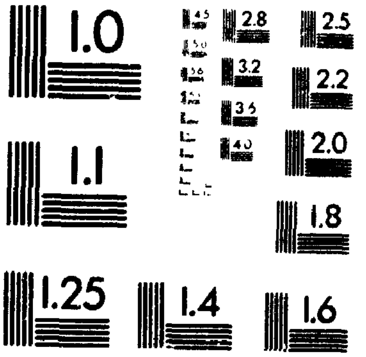


Table 4.4

The Variables

a) Product Performance

EOM (ordinal)	ease of manufacture of the product; 1 (poor) to 5 (outstanding); 11 items; Cronbach's alpha = .7371
ACTPROB (ordinal)	manufacturability-related problems; 1 (none) to 5 (major); four items; Cronbach's Alpha = .8343
DEVINT (cardinal)	development interval: number of months.
ECHANGE (cardinal)	number of manufacturability-related engineering changes.

b) Deployment of ME

HRSINS1 (cardinal)	Level of ME deployment in the definition stage of the new product development process: number of manhours
HRSINS3 (cardinal)	Level of ME deployment in the verification stage of the new product development process: number of manhours
EOMEMPH (ordinal)	ME emphasis on manufacturability during the development process; 1 (low) to 5 (high); 11 items; Cronbach's Alpha = .9590
EOMPHAS (ordinal)	Phasing of ME emphasis on manufacturability during the development process; 1 (early) to 5 (late); 11 items; Cronbach's Alpha = .9077
MESTFEXP (ordinal)	ME staff experience; 1 (poor) to 5 (outstanding); five items; Cronbach's Alpha = .8281

Table 4.4 (continued)

The Variables

c) Development Context

PRDNEW (ordinal)	Product newness; 1 (largely new) to 5 (no alteration); 10 items; Cronbach's Alpha = .8486
PRCNEW (ordinal)	Process newness; aggregation of EQUIPRED, TOOLRED, METHRED.
EQUIPRED (ordinal)	Process equipment newness; 1 (largely new) to 5 (no alteration); 8 items; Cronbach's Alpha = .6795
TOOLRED (ordinal)	Tooling newness; 1 (largely new) to 5 (no alternation); 10 items; Cronbach's Alpha = .9086
METHRED (ordinal)	Methods newness; 1 (largely new) to 5 (no alternation); 10 items; Cronbach's Alpha = .8188
PRCOORD (ordinal)	Control mechanism; 1 (Staging); 2 (other)
MFGLOC (ordinal)	Process position or location of component manufacture; 1 (external), 2 (internal); 10 items; Cronbach's Alpha = .7261

The measurement systems used for these variables relied on archival data supplemented by the interviewed managers' reports of the project events and the management procedures used. The measures were designed to use objective information whenever possible. The following section describes the measurement methods devised for each of the major variables in the operational scheme.

Product Performance

Manufacturability (EOM & ACTPROB): Manufacturability was conceptualized in terms of:

ease of fabrication and handling of individual piece parts;
ease of inspection and test of parts and assemblies;
ease of assembly and associated kitting and handling.

Two separate measures of ease of manufactured were contemplated at the outset, however only the second proved feasible. The first measure was based on the Boothroyd-Dewhurst design efficiency measure (1983); the second was based on attributes of ease of manufacture identified by Xerox (1983).

Common to the achievement of increased ease of manufacture is minimization of the total number of parts (Boothroyd & Dewhurst, 1983 a, b; Stoll, 1986; Daetz, 1987), which suggests that measurement of ease of manufacture may be carried out in terms of the total number of parts. At present, there are two quantitative evaluation methodologies available which focus on ease of assembly: Boothroyd - Dewhurst DFA method; and, Hitachi/GE Assemblability Evaluation Method. The Hitachi/GE methodology is proprietary. However, each methodology is used by major corporations (Daetz, 1987).

The Boothroyd-Dewhurst DFA methology includes an evaluation of 'design efficiency':

> 'Examination of the preliminary design answers two important questions: Can this part be eliminated or combined with other parts in the assembly? And how long will it take a worker to grasp, manipulate, and insert this part? With this information it is possible to estimate the total assembly time, compare it to the assembly time for an ideal design, and identify design features that result in high assembly cost' (Boothroyd & Dewhurst, 1983 b: 141).

Based on this analysis, the manual-assembly design efficiency is obtained from:

$$Em = 3Nm/Tm$$

where Em = design efficiency; Nm = minimum number of parts; Tm = total assembly time; 3 = 'ideal' assembly time of three seconds.

This measure of design efficiency was more extensive and demanding of data than was available in relation to the products investigated in this study. In particular estimation of both the minimum (as distinct from actual) number of parts, and the 'ideal' assembly time were not possible.

As an alternative, the following measure was used in the study. The measure drew on the Xerox (1983) approach to design for assembly, and the indicators used by Division A in describing design for manufacture at Division A. Xerox developed its set of design for assembly principles for application as 'key drivers of product design'. The resulting set of attributes of manufacturability included:

need for final assembly adjustments;
self-locating features;
standardization of fasteners, components, materials, and finishes

These attributes were rated on a 5-point scale, relative to earlier products in the new product family, or the previous product family if the product in question was the first of its family. The measurement system provided a single manufacturability score for each product. Each was an aggregate score, based on addition of the ratings of manufacturability. A low score indicated a low degree of manufacturability (EOM), and vice versa.

A second measure of manufacturability was also developed, based on interviewee assessment of severity of manufacturability-related problems at the commencement of volume manufacture (ACTPROB). Severity was assessed in relation to a five-point scale: none; minor; minor and major; major and minor; major. The problems were categorized as follows:

fabrication & handling of individual piece parts;
inspection & test of individual parts & assemblies;
assembly, kitting, & handling of individual parts;
process start-up.

Development Interval (DEVINT): The development interval included the total elapsed time over which ME carried out its development activities for a new product development project (DEVINT). Measurement of this variable required definition of when a project began and ended. In each new product development project, phases of development were marked by the passing of major milestones. The organization of these phases differed between the two approaches utilized by the company in the coordination of design and ME in the development process, as summarized in Table 4.5. Usually, the timing of these milestones was documented in project schedules and Stage review minutes.

Table 4.5

Organization of Major Milestones

Phases Prior to Staging	Corresponding Stage No.
Commercial Specification Approval	0: Initiation
New Product Sample and Review Capital Funds Appropriation R&D Project Approval Design Review Manufacturing Plan	1: Definition
Quality Plan Mechanical/Electrical Design Reviews	2: Development
Product Sample Review	3: Verification
Post Audit	4: Manufacture

A project began with approval of a new business opportunity, draft commercial and product specifications, draft project management plan, and draft strategic investment summary. In terms of the Stage Procedure in the company studied, approval of these items took place at Stage 0. The end of the development interval was marked by the release of the product to the market and the commencement of volume production. The final Stage, Stage 3, occurred just before the product was released to market. At this Stage, conformance to all original specifiations and plans, and issues of future product development and evolution were reviewed.

The three phases of interest in this study were those from Stages 0 to 1, 1 to 2, and 2 to 3. Prior to Stage 0 there was no basis for involvement of ME, as a new product was only at the conceptual stage. Stage 3 and Stage 4 were separated by approximately one year, during which time volume production was carried out. This phase was not of interest in this study. Accordingly, the development interval (DEVINT) includes the total elapsed time from the end of Stage 0 to the end of Stage 3, and was measured as the number of months covered by this interval.

Level of Engineering Change (ECHANGE): For the purposes of hypothesis testing, the level of engineering change was measured as the number of manufacturability-related engineering changes recorded after commencement of volume production (ECHANGE). A second measure, based on the number of ME manhours allocated to cost improvement activities after commencement of volume production, was considered but not used because of the unavailability of data. Other indicators of engineering change were identified, but were not amenable to statistical analysis. These indicators will be discussed in detail in Chapter Eight.

Engineering change control procedures in each division yielded documentation describing and classifying the engineering changes implemented for each new product development project. Each division in the company issued engineering change notices for authorized changes to manufacturing drawings, and classified these changes generally in accordance with a standard classification scheme. This scheme is summarized in Table 4.6.

Table 4.6

Company Standard Classification Scheme for Engineering Change

Class	Definition
1	An inoperative or potentially hazardous condition
1A	An inoperative or potentially hazardous condition in certain applications only
1B	An unsatisfactory condition which may be allowed to exist on a temporary basis
2	An improvement in design, but, in so doing, the design intent is affected
3	To introduce new features or to change the product rating
4A	Changes which do not affect design intent such as component substitutions, artwork recycles or cost reductions
4B	Changes which do not affect design intent that must be applied as soon as possible
4C	Changes which do not affect design intent but improve marginal design conditions

The gross number of manufacturability-related changes, class 4 changes, was measured. A ratio, such as the proportion of all engineering changes represented by changes to improve manufacturability, while potentially more informative, was not possible in this study. There was no theoretical basis to describe the behaviour of engineering changes other than those changes focused on manufacturability. There may be a relationship between the numerator and denominator in such a ratio, which if not understood would confound the relationships of interest.

ME Deployment

Level of ME Resource Deployment (HRSINS1 & HRSINS3): Each division estimated ME manpower allocations in advance for new product development projects, and they incorporated these estimates as part of the Manufacturing Plan. However, use of these estimates, as a basis for an operational definition of the level of ME resources, would open a threat to the construct validity of the variable. Engineering estimates preparation, as a budgetary preparation exercise, is open to budgetary slack. The concept of organizational slack characterizes the process through which the firm stabilizes the impacts of fluctuations in its economic environment (Cyert & March, 1963). Budgetary slack, drawn from empirical Accounting studies, arizes from imperfections in the organizational process of resource allocation, such as bargaining in the process of budget formation (Schiff & Lewin, 1970). Managers bargain for slack in the setting of budgets by understating revenues and overstating costs. Indications of this type of behaviour were observed in the preliminary study described earlier in relation to these estimates. As such, the use of these estimates as valid operationalizations of the level of ME resources deployed was limited.

An alternative measure of level of resource deployment was the actual number of manhours charged by ME staff to the project over the duration of the project, that is from the start of design to the commencement of volume manufacture. The use of these manhour charges as basis for an operational definition of the level of ME resource allocation was open also to a threat to its construct validity. Smoothing of charges among concurrent projects was practiced. However, these charges were subject to project and administrative control, and ultimately audited when used as the basis of claims for tax relief in respect of product development efforts. This level of control suggested that these hours were more representative of actual allocations than pre-project estimates.

Manhour charges were available for new products developed by Divisions A, B, and C, representing a total of 10 products. Where available, ME manhour charges, over the duration of each project, were grouped by phase based upon the phase or stage definitions described earlier. These groups of charges were used as the basis for measuring the level of ME deployment during the definition stage (HRSINS1) and in the verification stage (HRSINS3) of the development process.

Emphasis on Manufacturability by ME (EOMEMPE): Through carrying out manufacturability assessments at differing stages of the new product development process, ME were able to emphasize the achievement of manufacturability. Achievement of ease of fabrication and handling of individual piece parts required ME to place emphasis on physical features and properties, finishes and tolerances, molds and tooling during the new product development process. Similarly, achievement of ease of inspection and test of parts and assemblies required ME to place emphasis on accessibility for instrumentation, visibility, fixturing and rework. Finally, achievement of ease of assembly and associated kitting and handling required ME to place emphasis on the number of parts and how they were presented, oriented, inserted, and joined.

The dimensions of manufacturability used in the study formed the basis for measurement of the emphasis placed by ME on manufacturability (EOMEMPH). The degree of emphasis on each dimension of manufacturability was rated on a 5-point scale, relative to earlier products in the new product family, or the previous product family if the product in question was the first of its family. The measurement system provided a single emphasis score for each product. Each was an aggregate score, based on addition of ratings of emphasis. A low score indicated a low degree of emphasis on manufacturability, and vice versa.

Phasing of emphasis on manufacturability by ME (EOMPHAS) was measured through identification of the phases of the product development process, as described earlier, in which ME placed emphasis on each dimension of manufacturability. The measurement system provided a single phasing score for each product. Each was an aggregate score, based on addition of ratings of phasing. A low score indicated emphasis on manufacturability early in the development process, and vice versa.

ME Staff Experience (MESTFEXP): Manufacturing engineers, in their focus on manufacturability, build up, over time, experience in the anticipation, avoidance, and rectification of manufacturability-related problems as a new product design moves through the various stages of the development process to volume production. Building of ME staff experience and allocation of experienced staff to a new product development project was within the control of the ME manager.

Measurement of ME staff experience (MESTFEXP) included the degree to which ME staff, as a group who were identified as involved in a new product development project, were experienced in relation to:

Experience on Related Project(s);
Experience on Similar Project(s);
Experience of Working with Multi-Disciplinary Colleagues;
Technical Expertise;
Academic Qualification.

Rating scores for experience were based on a 5-point scale, with lower scores given for 'poor' experience and higher scores for 'outstanding' experience. The measurement system provided a single experience score for the ME group involved in each new product development project. Each score was an aggregate score, based on addition of ratings for each dimension of experience. A low score for each dimension of experience indicated a low level of experience, and vice versa.

Development Context

Product and Process Newness (PRDNEW & PRCNEW): Newness was the degree of similarity of a product to other members of its product family. Product and process newness were measured in relation to earlier product developments within a product family. McCutcheon (1988), as part of his study, posed the question:

> Did products have to be altered or redesigned to be used in the new system?
> to which the response was one of the following: no alteration; minor; considerable; major; largely new product.

This measurement system was adapted for the purposes of this study. The measures of product and process newness reflected each product's relatedness to other products in the family in the areas of constituent elements, process equipment, tooling and manufacturing methods.

Measurement of newness included the degree to which pre-existing product parts (PRDNEW), process equipment, tooling and manufacturing methods (PRCNEW) were altered or redesigned to suit the requirements of the new product under development. The basis for this measurement system was a set of major product elements or parts common to all terminals. Ten product elements were identified, comprising of electronic and mechanical/plastic parts.

Rating scores for newness were based on a 5-point scale, with lower scores given for newer elements and higher scores for less-new elements. The measurement system provided a single newness score for each product and process. Each was an aggregate score, based on addition of ratings for each dimension of newness. The overall product newness score (PRDNEW) was the sum of the scores for each of the product elements. The overall process newness score (PRCNEW) was the sum of the scores for the manufacturing processes tooling and manufacturing methods. A low score for each dimension of newness indicated a high level of newness or low relatedness to other products in the family, and vice versa.

While conceptually I identified two dimensions of newness, product and process newness, in practice I found these dimensions to be indistinguishable as operationalized. The two dimensions were nearly perfectly correlated: a Spearman rank order correlation was calculated as 0.9632 ($p=0$, one-tailed; $n=12$). Of itself, this result could form the basis for discussion and further investigation. However, I rationalized the operationalization of newness to that based upon product newness (PRDNEW) for the analysis which follows in the later chapters.

Process Positioning (MFGLOC): Process positioning comprises the width of a firm's internal span of process, the degree and direction of vertical integration alternatives, and its links and relationships, at either end of the process spectrum, with suppliers, distributors, and customers (Hill, 1989). Process positioning (MFGLOC) was measured as the manufacturing location, either internal or external relative to the division, for a set of major product elements or parts common to a terminal. Eleven product elements were identified, comprising of electronic and mechanical/plastic parts.

The measurement system provided a single position score for each product. Each was an aggregate score, based on addition of ratings for the location of manufacture of each product element. A low score indicated a greater propensity to source major product elements externally; a high score indicated a greater propensity to manufacture major product elements internally.

Design-ME Coordination (PRCOORD): In 1985, the company developed and introduced the Stage Procedure as an innovative approach to management of the new product development process, and coordination of design and manufacturing engineering resources during the process. While traditional financial controls remained in place, Staging was to facilitate divisions in expanding their views of quality in new product development to include absence of defects, ease of manufacture and operation, and timeliness of market availability. By highlighting cost, time and quality objectives for each project, and conducting formal reviews of progress at distinct stages, Staging was designed to correct the difficulties of unsuccessful projects by placing an increased emphasis on cost avoidance. The intention was to provide a basis for managing the integration of new product development activities from which all divisions would experience continuous learning and adaptation.

In sum, Staging was to provide guidance to all divisions on identification and achievement of an evolving system of technical and commercial objectives at each stage of the new product development process. Utilization of the Stage Procedure in all divisions after 1985 provided a unique opportunity to control for approach to design-ME coordination in the company: that in place before 1985, and Staging. Accordingly, design-ME coordination (PRCOORD) was measured as the use of Staging or of the set of procedures which predated the introduction of Staging.

STATISTICAL TECHNIQUES FOR TESTING THE PROPOSITIONS

The research design was characterized by a convenience sample of twelve new product development projects, a small sample. The distributions of the data obtained in the research could not be assumed to be normal. Further, the measures used in gathering the data included many ordinal scales. As such, non-parametric techniques were used to carry out the statistical analysis of the hypothesized relationships among the variables.

In testing the hypotheses of association, I used the Kendall rank-order correlation coefficient, T. One advantage of this coefficient over the Spearman rank-order correlation coefficient, is that T can be generalized to the Kendall partial rank-order correlation coefficient. The Kendall and Spearman coefficients utilize the same amount of information in the data, have the same sensitivity to detect the existence of association in the population. However, as each coefficient has a different underlying scales, numerically they are not directly comparable to each other (Siegel & Castellan, 1988).

To test hypotheses of difference, I performed the Mann-Whitney U test (MW-U). As at least ordinal measurement was achieved, this test was used to test whether two independent groups had been drawn from the same population. This test is one of the most powerful nonparametric tests, having a power-efficiency close to 95 per cent when applied to data which might properly be analysed by the most powerful parametric test, the t-test (Siegel & Castellan, 1988).

Given the exploratory nature of the research, I concluded from the analysis of the data that an hypothesis was supported in the following circumstances, summarized in Table 4.7:

Table 4.7
Hypothesis Investigation Criteria

Direction ot Association or Difference	Significance Level (one-tail test)	Conclusion
As hypothesized	$0<p<=.2$	Support for the hypothesis
	$.2<p<=.25$	Some support for the hypothesis
	$p>.25$	No support for the hypothesis
Not as hypothesized	Unimportant	No support for the hypothesis

DESCRIPTIVE RESULTS FOR EACH PRODUCT FAMILY

In all, twelve new product development projects were investigated in four divisions of the one company. The product development dates ranged from 1983 to 1989. In the following four sections I summarize and comment briefly upon the measures of the performance, deployment, and manufacturing strategy variables observed in each division. These data will form the basis of our investigations of the propositions arising from the conceptual framework, which will be reported in Chapters Five, Six, Seven, and Eight.

The A Series: In Division A, four products were investigated. Characteristics of products A1, A2, A3 and A4 are compared in Table 4.8. In general, the A1 was newest of the four products, both in relation to product and process. The extent of in-house and external manufacture was similar in each product, with A3 sharing manufacturing facilities more than the other products. The emphasis on manufacturability was similar in all except A4, and that emphasis took place earliest for A3, and latest for A4. In the event, A3 was the most manufacturable set, while A4 was even less manufacturable than A1.

Table 4.8

Product Characteristics: Division A

Characteristic	Product A1	A2	A3	A4
Development interval (months)	14	12	9	13
Ease of manufacture (the lower the less)	39	41	45	33
Severity of manufacturability-related problems (the lower the less)	10	13	9	14
Number of manufacturability-related changes	7	11	7	5
Proportion of ME manhours in the definition stage	25.90	23.04	27.80	5.88
Proportion of ME manhours in the verification stage	36.76	33.31	23.15	33.45
ME emphasis on manufacturability (the lower the less)	46	46	47	42
Phasing of ME emphasis on manufacturability (the lower the earlier)	30	32	24	33
ME staff experience (the higher the more)	13	18	21	20
Product newness (the lower the newer)	14	20	33	19
Process newness including:	50	83	121	96
equipment	15	26	35	32
tooling	10	13	37	18
methods (the lower the newer)	25	44	49	46
Manufacturing location (the higher the more vertically integrated)	23	26	28	25
Design-ME coordination (1: Staging; 2: pre-Staging)	2	2	1	1

The B Series: In Division B, three products were investigated. Characteristics of products B1, B2 and B3 are compared in Table 4.9. The B Series terminals were high volume (in relation to previous Division B production levels). The B1 and B2 sets were manufactured at a combined rate of 10000/week, while the B3 set was to be manufactured at 5000/week. In general, the B1 set was newer than either the B2 or B3 sets, both in relation to product and process. The extent of in-house and external manufacture was similar in each product. The emphasis on manufacturability was greater in the newest product, the B1 set and that emphasis took place early in the development process, relative to the B2 set. In the event, the B1 set was less manufacturable than either the B2 or B3 sets.

The C Series: In Division C, three products were investigated. Characteristics of products C1, C2 and C3 are compared in Table 4.10. In general, the C1 set was newer than either the C2 or C3 sets, both in relation to product and process. The extent of in-house and external manufacture was similar in each product. The emphasis on manufacturability was greater in the newest product, the C1, and that emphasis took place earliest of the three products. In the event, the C1 was less manufacturable than C2 set, but more than the C3 set.

Table 4.9

Product Characteristics: Division B

	Product		
Characteristic	B1	B2	B3
Development interval (months)	16	15	14
Ease of manufacture (the lower the less)	35	41	46
Severity of manufacturability--related problems (the lower the less)	14	13	9
Number of manufacturability--related changes	13	14	0
Proportion of ME manhours in the definition stage	8.10	8.10	23.49
Proportion of ME manhours in the verification stage	25.85	25.85	24.76
ME emphasis on manufacturability (the lower the less)	34	14	22
Phasing of ME emphasis on manufacturability (the lower the earlier)	37	45	36
ME staff experience (the higher the more)	18	18	21
Product newness (the lower the newer)	27	43	39
Process newness including:	98	132	129
equipment	30	38	36
tooling	28	45	45
methods (the lower the newer)	40	49	48
Manufacturing location (the higher the more vertically integrated)	16	20	20
Design-ME coordination (1: Staging; 2: pre-Staging)	1	1	1

Table 4.10

Product Characteristics: Division C

	Product		
Characteristic	C1	C2	C3
Development interval (months)	21	n/a	9
Ease of manufacture (the lower the less)	42	44	32
Severity of manufacturability--related problems (the lower the less)	15	4	18
Number of manufacturability--related changes	2	5	3
Proportion of ME manhours in the definition stage	0.48	n/a	6.46
Proportion of ME manhours in the verification stage	38.18	n/a	32.55
ME emphasis on manufacturability (the lower the less)	28	11	35
Phasing of ME emphasis on manufacturability (the lower the earlier)	47	64	39
ME staff experience (the higher the more)	23	23	23
Product newness (the lower the newer)	30	42	37
Process newness	109	139	129
including:			
equipment	33	40	36
tooling	38	49	45
methods	38	50	48
(the lower the newer)			
Manufacturing location (the higher the more vertically integrated)	17	18	18
Design-ME coordination (1: Staging; 2: pre-Staging)	2	2	2

The D Series: In Division D, two products were investigated. Characteristics of products D1 and D2 are compared in Table 4.11. In general, the D1 set was newer than the D2 set, both in relation to product and process. The extent of in-house and external manufacture was similar in each product. The emphasis on manufacturability was similar in the each product, but for D2, that emphasis took place earlier. In the event, D1 was less manufacturable than the D2 set.

Table 4.11

Product Characteristics: Division D

Characteristic	Product D1	Product D2
Development interval (months)	n/a	19
Ease of manufacture (the lower the less)	41	46
Severity of manufacturability--related problems (the lower the less)	7	8
Number of manufacturability--related changes	4	8
Proportion of ME manhours in the definition stage	n/a	n/a
Proportion of ME manhours in the verification stage	n/a	n/a
ME emphasis on manufacturability (the lower the less)	52	51
Phasing of ME emphasis on manufacturability (the lower the earlier)	33	23
ME staff experience (the higher the more)	23	23
Product newness (the lower the newer)	18	29
Process newness	97	106
including:		
equipment	36	31
tooling	31	34
methods	30	41
(the lower the newer)		
Manufacturing location (the higher the more vertically integrated)	18	17
Design-ME coordination (1: Staging; 2: pre-Staging)	1	1

SUMMARY

In this chapter I outlined the research design and methods which were used to test the hypotheses in the conceptual framework developed in Chapter Four. This design featured the investigation of twelve new product development projects in four divisions of one company. I summarized and commented briefly upon the measures of the performance, deployment, and manufacturing strategy variables observed in each division. These data will be integrated with our interview data, and will be reported in Chapters Five, Six, Seven and Eight.

CHAPTER FIVE: DEVELOPMENT CONTEXT OF ME DEPLOYMENT & NEW PRODUCT DEVELOPMENT

In the previous chapter, I developed operational measures for each of the constructs in the conceptual framework relating new product performance to the deployment of the manufacturing engineering function during the new product development process. I described the features of the field study to investigate the relationships in the conceptual framework. I summarized the measures of the performance, deployment, and manufacturing strategy variables observed in each division. This chapter is the first of four chapters in which I report the results of the field study.

In many respects, this chapter prepares the ground for the subsequent chapters, providing a description of each of the company divisions, their associated products and manufacturing engineering organizations. However, this chapter also provides detailed description of the activities carried out by ME, and explores relationships between manufacturing engineering deployment and manufacturing strategy, and between new product performance and manufacturing strategy. In the remaining three chapters, I explore the relationships observed between each of the three dimensions of new product performance, development interval, manufacturability and engineering change, and the deployment of ME during the new product development process.

This chapter has several major sections. The first section introduces the manufacturing engineering function, describing the development, support and improvement activities carried out by ME, and detailing the activity content of each stage of the new product development process. With this understanding of the identity of ME through the activities performed, the second section explores the organization and staffing of the function in relation to manufacturing strategy in each division. The final section outlines differences in product performance, and in ME deployment during the new product development process for differing manufacturing strategies.

MANUFACTURING ENGINEERING ACTIVITIES

Before investigating the organizational responses to differing manufacturing strategies, I will discuss the range of activities carried out by the ME groups in each of the four divisions, in order to define the boundaries of this function. These results were originally reported by Coughlan (1989).

In each division, ME focused, not only on process, but also on product development, support and improvement. This finding adds to our conceptualization of ME: focus and emphasis on product support and improvement had not been suggested by the writers discussed earlier. Table 5.1 summarizes the focus and emphasis of ME activities.

Table 5.1

Manufacturing Engineering Activities by Focus and Emphasis as reflected in Divisions A and B

ME EMPHASIS	ME FOCUS	
	Process	Product
Development	prodn. planning tool design work stds./methods equipt. spec., dev., installn. & startup plant layout manfng. standards operator training documentation advanced techniques facilities planning test set development	manufacturability assessment value engineering prototype building
Support	prodn. planning work stds./methods equipment disposal reproduction/records plant layout manfng. standards tool room management facilities maintenance safety ENGINEERING CHANGE EMPLOYEE SUGGESTIONS	ENGINEERING CHANGE EMPLOYEE SUGGESTIONS
Improvement	plant layout tool design work stds./methods equiptment improvement manfng. standards ENGINEERING CHANGE COST REDUCTION	ENGINEERING CHANGE COST REDUCTION

Product-focused activities, after completion of the product development, included initiation, review and implementation of:

cost reduction projects,
manufacturability-related engineering changes,

and employee suggestions.

These later product-focused activities were carried out by sections of the ME groups, whose involvement in product development was less than other sections, such as, in Division A, the assembly engineering rather than new product development section.

The sources of technology or the degree of vertical integration differed among the divisions, with implications for the ME activities carried out. Although new process specification, installation and support was carried out in all divisions, process R&D was carried out only by Division C, for itself and for other divisions. Similarly, while new product development was supported by ME groups in each division, only in Division A were products fully developed inhouse for manufacture. The other divisions sourced their product designs from an external design agency. Finally, Division A manufactured components, for assembly into products, while Division C, an assembly and test operation, sourced components from A.

In sum, the degree of vertical integration differed among divisions along three dimensions:

product development;
process development;
component manufacture

Along each of these three dimensions, the more backward-integrated the division, the more ME carried out activities in greater technical depth than the ME groups in less integrated divisions. These other ME groups compensated for less technical depth by facilitating transfer of product and process technologies into their divisions through integration of their development activities with those of external suppliers.

ME Activities in the New Product Development Process

The focus of this research is on the performance of new products in relation to the deployment of manufacturing engineering resources during the new product development process. The classification of ME activities developed earlier represents an overview of all activities performed by the ME function. In terms of this classification, the research is focused, in part, on the implications of the execution of development activities for support and improvement activities. However, this classification did not provide an indication of the phasing of the product development activities during the development process in order to achieve a manufacturable product in a minimum development interval. In order to examine this issue, I must describe the new product development process in the various divisions, and, in particular, the disciplined approach utilized to manage this process, the Stage Procedure.

The Stage Procedure: The Stage Procedure was introduced in 1985 to generate problem correction before launch through a focus on quality, cost, and manufacturability. A set of four stages was defined, at the end of which there was a formal review of progress, and formal transfer of 'prime responsibility' for achievement of targets for the next Stage. A fifth, and final, stage began with the commenecement of volume manufacturing. While this stage always occurred, no instance of a review during, or at the end of, this stage was observed. Table 5.2 summarizes the features of the Stage Procedure.

Table 5.2

The Stage Procedure

Item	Stage 0 Initiation	Stage 1 Definition	Stage 2 Development	Stage 3 Verification
Prime department	Marketing	Marketing	Design	Manufactur'
Product features activities	Product description	Commercial & Technical specifications	Technical trial units	Field trial units
Product cost activities		Value analysis Yield target Subsystem cost target	Product cost Manufacturability New process qualification	Product cost
Product delivery activities	Program development plan Schedules & risks	Project mgmt plan Marketing delivery commitment Design priorities Manufacturing/test plan	First ship dates Field trial plan	

Saren (1984) proposed a classification scheme for models of the intra-firm innovation process:

departmental-stage models;
activity-stage models;
decision-stage models;
conversion process models;
response models.

In terms of this taxonomy, the model of the intra-firm innovation process underlying the Stage Procedure spans a number of classes, and could be classified as an Activity-Department-Stage model. Each stage required multifunctional involvement, but only one function had 'prime' responsibility for achievement of targets in each stage.

The Initiation stage (Stage 0) was focused on development of the product concept. Prime responsibility for completion of this stage was held by Marketing. If the project successfully passed review at the end of Stage 0, it proceeded to the Definition stage (Stage 1). During the Definition stage, the development focus was on product features, cost/price parameters, and backward compatibility with pre-existing products. Again, Marketing held prime responsibility for completion of this stage. If the project passed review at the end of Stage 1, then the Development stage (Stage 2) commenced.

R&D (or product design) held prime responsibility for completion of the Development stage. The focus in this stage was on development of technical specifications for the approved product concept. To complete Stage 2, a field - tested, bench-built unit should be available to manufacturing for evaluation complete with technical specifications. On completing Stage 2, the project proceeded to the Verification stage (Stage 3). At this final stage, the development focus was on verification of conformance to product specifications and to product cost targets in a pilot volume production run. Manufacturing held prime responsibility for completion of this stage. Projects were rarely rejected in Stage 3, and, when successful, they commenced routine volume production. After Stage 3, the division released the product to the market.

The Development Focus of Manufacturing Engineering: The development focus of ME changed over the course of the new product development process. ME had no involvement in the earliest stage, Initiation. However, the next stage, Definition, required the 'delivery' of the following items by ME at Stage 1:

Manufacturing/test plan
Value analysis results
Yield targets
Subsystem cost targets
Capital equipment and capacity requirements

During the Development stage, ME carried out activities in order to complete the following 'deliverables' by Stage 2:

New Process qualification
Product costs
Manufacturability assessment
Manufacturing start-up programme
Inventory requirements (short term)
Yield predictions

During the Verification stage, ME was responsible for achievement of the following 'deliverables' by Stage 3:

Manufacturing yield update
product costs update
manufacturability update

Finally, after start of routine volume production, that is, post Stage 3, the following deliverables were required from ME:

manufacturing yields;
product costs.

ME Activity Content of Development Stages: In Divisions A and B, I investigated the phasing of the activities carried out by ME in order to achieve the 'deliverables' required at the end of each stage of the development process. I used, as a basis, the stages of the Stage Procedure described earlier.

The activities carried out by the ME groups in the divisions were comprised of activities started and completed entirely within single stages of the development process, and activities which spanned one or more stages of the process. Figure 5.1 summarizes the phasing of these activities, which are then quantified in Table 5.3.

Figure 5.1
ME Activities carried out during the New Product Development Process

Activity Categories	New Product Development Stage 1	2	3	Post 3
PRODUCTION PLANNING & PROCESS ENGINEERING:				
Manufacturing specification	x			
Machine selection	x			
Machine and tool specification	x			
Machine and tool cost estimating	x			
Manufacturability assessment	x-----	x		
Operations sequencing	x-----	x		
Non-productive material specification		x		
Assistance in production difficulties			x-----	x
TOOL DESIGN:				
Tool requirements analysis	x-----	x		
Checking & proving of vendors machine & tool design work	x-----	------	x	
Design of machines, equipment & tools		x-----	x	
TOOL ROOM:				
Tool maintenance		x		
Die, fixture, gauge construction		x-----	x	
Tool modification		x-----	x	
EQUIPMENT ENGINEERING:				
Equipment cost estimating	x			
Process equipment specification & selection	x-----	------	x	
Process specification preparation	x-----	------	x	
Equipment coordination for shop trials		x-----	x	
PLANT LAYOUT:				
Production flow analysis	x-----	x		
Plant layout		x-----	x	
MATERIALS HANDLING:				
Analysis of product design, process layout & materials requirements	x-----	------	x	
Materials handling system development		x		

Figure 5.1 (continued)
ME Activities carried out during the New Product Development Process

Activity Categories	New Product Development Stage			
	1	2	3	Post 3
WORK STANDARDS/METHODS:				
Establish direct labour standards	x-----	------	-----x	
Prepare direct labour estimates	x			
Verify standards			x-----	x
Determine bases for labour authorization			x	
Periodic study of production operations				x
Correct off-standard conditions				x
Evaluate employee suggestions				x
PRODUCTION ANALYSIS:				
Develop data for make/buy analysis	x			
Prepare & review project control records	x-----	------	-----x	
Obtain & distribute advance information on new parts	x-----	------	-----x	
Analyse & coordinate product change requests	x-----	------	-----x	
Prepare cost analyses & presentations	x-----	------	-----x	
REPRODUCTION and RECORDS:				
Maintain up to date tool drawings, releases & planning records	x-----	------	-----x	
Process work orders & procurement requests		x		
Distribute process sheets			x-----	x
MANUFACTURING STANDARDS:				
Make proposals for company standards	x			
Develop local standards	x-----	------	-----x	
Publish and distribute standards	x-----	------	-----x	

Note:
Stage 1: Definition Stage
Stage 2: Development Stage
Stage 3: Verification Stage
Post Stage 3: Manufacturing Stage

Table 5.3
ME Activity Content of Development Stages

Class of ME Activity	DEVELOPMENT STAGES Stage 1	Stage 2	Stage 3	Post Stage 3
Number of activities started	24 (60%)	9 (22.5%)	4 (10%)	3 (7.5%)
Number of activities in process	24 (60%)	25 (62.5%)	21 (52.5%)	6 (15%)
Number of activities completed	8 (20%)	8 (20%)	18 (45%)	6 (15%)

Examination of the activities in process in the various stages of the development process indicated that the concentration of activities in the three stages was roughly similar. If there was a tendency towards greater concentration in any one stage, it was in Stage 2. An estimated 62.5% of the ME activities carried out by ME were in process during this stage. However, nearly two thirds of these activities commenced during Stage 1, while completion of activities was concentrated in the verification stage, Stage 3..

In general, activities from all categories, except Tool Room, were carried out during each stage of the process. However, some categories of activities were concentrated in the earlier stages; of the eight activities in the Production Planning/Process Engineering category, six commenced in Stage 1, four were completed in Stage 1, and a further three were completed in Stage 2. In contrast, of the seven activities in the Work standards/Methods category, five commenced after Stage 2, and four of these activities continued after Stage 3.

In sum, the three stages of the development process were characterized by differing sets of activities carried out by ME. Many of these activities commenced during Stage 1, but the period of heaviest concentration of ME activity was during the development stage, Stage 2. However, a mere count or description of activities performed by ME during the new product development process only goes part way to describing the involvement of ME in the process. A second element of the involvement was the level of effort expended in the achievement of the required deliverables in each stage. An indicator of this effort was the distribution of the actual time spent by ME staff on development activities during each stage. This time was gauged from the manhours charged by the ME staff to the various development projects. Analysis of these manhour charges confirmed the activity-based findings.

ME manhour data were available for [illegible] of the twelve products included in this study. Of these data, only those relating to nine projects were usable. These manhour data are summarized in Table 5.4. I investigated characteristics of ME deployment using Kruskal-Wallis one-way analyses of variance by ranks. The level of ME deployment in each stage of the new product development process, as measured by the percentages of total ME manhours expended in Stages 1,2, and 3 respectively, differed among the three stages of the development process (chi-square = 20.562; p = 0.000).

Table 5.4
Level of ME Deployment in Development Stages

Division	Place in Product Family	Percentage of ME Manhours per Stage		
		Definition Stage 1	Development Stage 2	Verification Stage 3
A	1*	25.90	37.33	36.76
	2*	23.04	43.66	33.31
	3*	27.80	38.82	23.15
	4	5.88	60.67	33.45
B	1	8.1	66.05	25.85
	2	8.1	66.05	25.85
	3	23.49	51.75	24.76
C	1*	0.48	61.34	38.18
	3	6.46	60.99	32.55
	$\bar{X}$ =	14.36	54.07	30.43
	S.D =	10.48	11.50	5.38

(Note: * - these products were not managed through the Stage Procedure. However, the dates at which the projects reached the equivalent of the three Stages were identified from project records by the manufacturing engineer with responsibility for the ME aspects fo the project).

I then grouped the products by their places in their respective product families, that is, first-in-family, second-in-family, and so on. I examined the differences among the groups of products in ME manhours expended in each of Stages 1,2, and 3. The results are summarized in Table 5.5. The results indicate that there was no evidence to suggest that ME deployment in Stages 1,2, or 3 differed among products grouped by place in product family. As such, although the actual number of ME manhours expended may differ between earlier or later members of the product families, the distribution of those manhours over the three development stages was similar.

Table 5.5
Differences in Level of ME Deployment in Development Stages among Products grouped by Place in Family

Development Stage	Chi-Square	p<
1	2.0448	0.5632
2	0.6555	0.8836
3	4.1064	0.2502

I then grouped the products by the Division in which they were developed and assembled. I examined the differences among the groups of products in ME deployment in each of Stages 1,2, and 3. The results are summarized in Table 5.6.

Table 5.6
Differences in ME Deployment in Development Stages among Products grouped by Division

Development Stage	Chi-Square	p<
1	3.3053	0.1915
2	4.9412	0.0845
3	2.8235	0.2437

The results indicate that there was some evidence that ME manhours expended in Stages 1,2, and 3 differed among products grouped by division. As such, ME deployment in the three development stages may differ among divisions. These differences may be explained in terms of the relative extent to which the divisions carried out product development activities. In particular, Division A manufactured a greater proportion of the components and subassemblies used in its products than the other divisions. Correspondingly, the differing degrees of vertical integration is one factor in the divisional differences in ME deployment.

In sum, these results illustrate the notion of early involvement of manufacturing engineering resources during the development process, and provide a detailed picture of the nature of this involvement. While ME became involved in the new product process after the initiation of the projects, once the product concept was approved ME was faced with an evolving set of technical deliverables, which required the expenditure of manhours on differing sets of activities throughout the development process. These activities were both product and process focused. Many of these activities were not confined to individual stages of the development process. Rather, they spanned one or more stages, and their description adds substance to the notion of overlapping phases of development, as described by Imai et al. (1985).

MANUFACTURING STRATEGY AND ME ORGANIZATION

Changes in the competitive environment of manufacturing companies imply changing roles for manufacturing engineering. In this section, I used a manufacturing strategy model as a basis for interpretation and understanding these changing roles and the corresponding organization of the ME function in each of the four divisions in this study.

Manufacturing Strategy

In the four Divisions under study there were no explicit statements of manufacturing strategy although there were de-facto policies reflected in the certain decisions, summarized in Table 5.7.

Division A, a high volume producer of standardized terminals, competed in a price-dominated market. Manufacture of components and subassemblies for terminals, and final assembly of terminals accounted for nearly 100 percent of the manufacturing activity in A. Many of the components and subassemblies were distributed to other divisions for inclusion in their terminals products. Division A invested in automated facilities for low cost assembly of new products, and designed subsequent new products for assembly on these facilities. Each division established an annual cost reduction budget and set of objectives against guidelines established by the Corporate Vice-President of Manufacturing. Cost improvement dominated in A, with substantial emphasis on improvement and support of existing processes.

Table 5.7
Comparison of the Four Divisions

Manufacturing Policy	Division A	Division B	Division C	Division D
Product volumes	High	Medium	Low	Low
Product variety	Low, standardized	High, customized	High, customized	High, customized
Order handling	Make for stock	Make to order	Make to order	Make to order
Run lengths	Long	Medium	Short	Short
Basis of competition	Price	Flexibility, Price	Flexibility	Flexibility
New product introduction	One/year	One/year	40/year	180/year
Cost reduction	9% of Sales (1987 target)	8% of Sales (1987 target)	Not available	4% of Sales (1987 target)
New product--process linkage	Parallel development	Parallel development	Products designed for existing equipment	Parallel development
Production process	Machine-paced assembly line	Machine-paced assembly line	Worker-paced assembly line	Worker-paced assembly line
Equipment	Specialized	Specialized	General purpose	General purpose
Capacity additions	Large and costly	Large and costly	Incremental	Incremental
Vertical integration	Manufacture and assembly	Assembly only	Assembly only	Assembly only
Relative sales	1.0 (1986)	0.60	Not available	5.0
Relative no. of employees	1.0 (1987)	0.2	1.33	2.0
ME staff/all employees	5.6% of total (1987)	4.5% of total	7.7% of total	6% of total

Division B, a rapidly growing medium volume producer of many products, including customized terminals, competed in a performance-dominated but price-sensitive market. Assembly of terminals accounted for over 50 percent of the total manufacturing activity in B. Many of the components and subassemblies were sourced externally for inclusion in their terminals products. B invested in automated facilities with flexibility to assemble both the existing and new products at low costs and with short throughput times. In 1986, B shifted emphasis from product cost reduction after commencement of volume manufacture to cost avoidance through design, before manufacture.

Division C, a short run producer of many products, including customized terminals, competed on the technical performance of its products. Assembly of terminals accounted for less than 20 percent of the total manufacturing activity in C. In C, speed of new product introduction and cost avoidance dominated. In general, C introduced new products at an approximate rate of 40 per year. Many of the components and subassemblies were sourced from Division A for inclusion in their terminals products. C assembled all terminals manually.

Division D, a short run producer of many products, including customized terminals, competed on the technical performance of its products. Assembly of terminals accounted for less than 20 percent of the total manufacturing activity in D. Many of the components and subassemblies were sourced from Division A for inclusion in their terminals products. While D invested in automated assembly and test facilities with flexibility to assemble both existing and new products at high yield levels and with short throughput times, assembly of terminals was largely manual. In D, speed of new product introduction and cost avoidance dominated. In general, D introduced new products at an approximate rate of 180 per year.

Only Division D showed a long-run focus on process research, development, and improvement of externally-built equipment and process technology. Division A had moved to a policy of contracting-out equipment innovation, design and development. This trend represented a change from past practice of internal process design and external sourcing. Divisions B and C contracted-out equipment innovation, design and development.

The four Divisions differed in timing of their investments in new equipment and process technology. Divisions A and B made their most recent investments in radical new process technologies at the same time as they were developing new products. B's investment was made as the Division was developing its first new product family to eventually replace the existing product family (which had been developed by, and transferred from, another division). Division D made its investment after development of a new product, and in anticipation of future related products. There was no evidence of recent investment in equipment and process technology in Division C, in the area of assembly of terminals.

In sum, the four Divisions differed in their de-facto policies, which, however, reflected accurately the competitive realities of the particular product-markets served. These policies corresponded, for the most part, to those which would be predicted from the use of a manufacturing strategy model to relate corporate and marketing objectives to engineering and operations. However, the rationale behind assembly of terminals in Divisions C and D was questioned in each of these divisions. In all except Division A, terminals were not the mainstay of the division's operations. In Divisions B,C and D, the terminals were functionally and technologically related to other products developed and manufactured in these divisions. However, except for Division B, the volumes and differing manufacturing specifications for terminals were anomalous relative to the main manufacturing focus of each of these three divisions.

Strategic Role of Manufacturing Engineering

I explored the mechanism by which these manufacturing policies were set in these divisions, for an indication of the roles played by ME in formulating manufacturing strategy. These results were originally reported by Wood & Coughlan (1988 b). The planning - programming - budgeting system, used in the three Divisions, corresponded closely to the 'classic' planning - programming - budgeting system described by Mintzberg (1979). Overall performance control objectives led to the development of overall strategic plans, which were converted into specific operating plans and budgets, including those for manufacturing.

The inputs of the ME Depts. in each division to the planning - programming - budgeting system are compared in Table 5.8.

Manufacturing objectives were produced through either a 'bottom up' or a 'top down' process. I observed both. In the former process, the ME Dept. manager developed and submitted to the Manufacturing Director a set of objectives backed by action plans for achievement. In the latter process, the objectives were developed by the Manufacturing Director and translated by the ME Dept. into specifics for their particular responsibilities.

The rolling three year Operating Plan detailed projections on capacity, costs, process capabilities, and engineering capital investment required to implement the rolling five year Product Line Plan. In formulating the Operating Plan, the ME Dept. was both a service group supporting other groups, and also a source of input in its own right. As a service group, ME assisted other groups in meeting their objectives through supply of engineering staff. Detailed process engineering and cost improvement proposals constituted the direct ME input.

Table 5.8
Input of Manufacturing Engineering to Manufacturing Strategy Formulation in Divisions A, B and D

Item	Division A	Division B	Division D
Objectives-			
input of ME Dept to formulation of objectives at Division level:	ME objectives selected by the Manufacturing Director	no input	ME objectives selected by the Manufacturing Director
input to objectives at Manufacturing function level:	ME objectives selected by the Manufacturing Director	no input	ME objectives selected by the Manufacturing Director
input to objectives at ME Dept. level:	priority actions identified by ME Dept	no input (set by Mfng. Director)	priority actions identified by ME Dept
constraints:	Divisional financial	Divisional financial	ME Dept. resources
Product Line Plan-			
input of ME Dept to formulation of Plan at Division level:	Cost projections	Cost projections	Cost projections
Operating Plan-			
input of ME Dept to formulation of Plan at Division level:	Development of cost, labour, capacity, and process capability analyses related to capital assets, capacity and direct labor utilization changes	Identification of the number of engineers which the Division can support at the break-even point allocated to current failures and areas for improvement in manufacturing operations	Proposal of an engineering direction based on ME Dept experimentation
involvement with Manufacturing Director	Interactive development	Interactive development	Interactive development

Comparison of the nature and timing of ME input into the strategy formulation process indicated differences in the roles of ME in each Division. In Division B, ME was the least proactive of the four divisions, with little input into decisions about strategic issues, not just at Division level, but also at ME department level. However, while ME in Division B reacted to defined manufacturing requirements, there was evidence of change in this role, with the appointment of a new manager to the function. In Division D, ME was the most proactive of the three. ME input into the setting of objectives was based on its own assessment of ME staff and skill availability. Further, input into the Operating Plan was based on ME experimentation with such approaches as JIT/TQC. ME in Division A, while less proactive than in Division B, was more reactive than in D. The distinction between A and D rested on the more obvious constraint in Division A of divisional financial objectives.

Manufacturing Engineering Organization

I investigated the grouping of ME resources and the ME profile, defined as the number of ME staff, and the depth in technical skills. Depth in skill was measured as the ratio of ME engineers to technicians. I expected that ME profile would be dependent on manufacturing strategy, being an outcome of policy decisions on engineering support levels.

Grouping of ME Resources: The ME function in each division incorporated manufacturing, test and industrial engineering specialties within the group, as summarized in Table 5.9.

Table 5.9
Grouping of ME Resources

Responsibilities of the ME function:	DIVISION A	B	C	D
Process Engineering	*	*	*	
Process Technology				*
New Product Introduction	*	*	*	*
Industrial Engineering	*		*	*
Test Engineering	*			*
Assembly Engineering	*		*	
Maintenance Engineering	*		*	

Although many of the areas of responsibility were common to each division, there were two organizational approaches to coordination of these responsibilities, as indicated in Figure 5.2. In Divisions A and B, a single manufacturing engineering department was headed by an individual ME manager. This department incorporated all of the sub-areas of ME represented in the division. The ME department manager reported directly to the director of manufacturing, as did the production and materials managers.

Figure 5.2
ME Grouping and Relative Volume and Variety
in Divisions A, B, C and D

Grouping of Manufacturing Engineering Resources		
Time & Product-based	Division C Division D	
Function-based		Division A Division B
	low volume/ high variety	high volume/ low variety

Relative Product Volume
and Variety
(all products)

The second organizational approach to coordination of ME responsibilities was evidenced in Divisions C and D. This approach was characterized a split manufacturing engineering department, each with an individual ME manager. The split was based upon the timing of the work done by the respective ME groups. The central engineering or manufacturing technology department incorporated all of the sub-areas of ME related to the development and start-up of new products and manufacturing processes. The department manager reported directly to the director of manufacturing. A second type of ME department was responsible for the support of individual products and their associated manufacturing processes after start of routine volume production or operation. There were as many of these 'support' departments as there were major product groups. Each 'support' department manager reported directly to the production manager for the product group.

Four basic criteria are used by organizations to select the bases for grouping organizational units: interdependencies in the workflow, in the work process, of scale, and in social relationships (Mintzberg, 1979). The functional approach in Divisions A and B reflected a concern for reciprocal and sequential interdependencies of workflow in the development, support and improvement of products and processes. These products were characterized by relatively high volumes and low variety. As such, grouping of the ME resources under a single manager minimized the coordination and communication costs.

The time-based approach in Divisions C and D reflected separation of concerns for interdependencies of workflow between the development of products and processes, and the support and improvement of those products and processes. With high rates of new product introduction, relatively low volumes and high variety, grouping of the development and support/improvement resources under a single manager would have resulted in major coordination problems. As such, coordination of the groups was carried out from further up in the organization. However, a second approach to grouping was observed in Divisions C and D, not for product and process development, but for product support and improvement. Support and improvement was grouped by product type, reflecting differences in manufacturing processes and standards among the products.

The differing approaches to grouping of ME resources in the divisions each had costs. ME in Divisions A and B, grouped into a single function, appeared to be large enough to function efficiently. However, the apparent size of the single group masked resource shortfalls, particularly when new products and processes were under development at the same time as existing products were in volume production. ME in Divisions C and D, organized in differing groups, lacked an organizational connection allowing the ME staff involved in product and process development to follow through to volume production. Rather, integration of development, support and improvement of products and processes was dependent upon formal procedures for transfer of responsibility, supplemented by previous working relationships and personal interactions.

The question arises, where should ME resources be placed in the organization: all together, split by development and support/improvement responsibilities, or split by product? The basic tradeoff is between workflow interdependencies and the need for specialization and economies of scale. Each development, support or improvement activity carried out by a manufacturing engineer may have implications beyond the product under development or production, or after that product has moved from its current status (ie. in development or in production). Identification of these implications, defined in terms of manufacturability and reduction of the newness of a product, is an objective of this study. However, it seems that to split an ME group by development and support/improvement responsibilities, is to introduce an artificial split in the organization which may result in a new variation of the notion of 'throwing the design over the wall'. As such, where the interdependencies among the development, support and improvement activities carried by ME are strong, there may be a case for grouping the ME resources by product, such that for each product an identifiable ME group exists.

ME Profile: I then compared, for Divisions A, B and D, the ratio of manufacturing engineers to technicians with the ratio of total ME staff (engineers plus technicians) to total division employees. Measures were taken for the year 1987 and prior years, where available. These measures are summarized in Table 5.10, and plotted in ratio form in Figure 5.3. Comparable data were not available for Division C. These results were originally reported by Wood & Coughlan (1988 b).

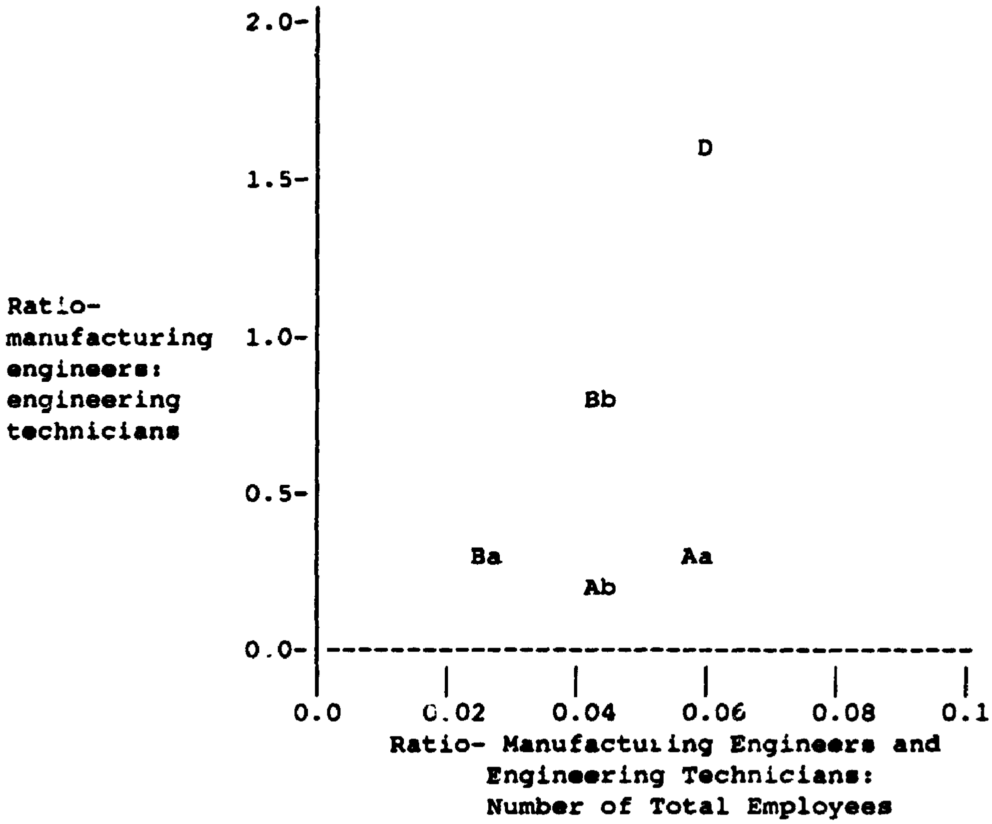
The ME function in Divisions A, B and D differed in terms of size, staff mix, and scope of responsibility. In 1987, Division D had the largest ME staff in overall terms. D also had the highest proportion of engineers. These indicators reflected both D's process R&D activities and higher rate of new product introduction relative to Divisions A and B.

In 1982, Division A was substantially vertically integrated. By 1987, A's sourcing policy had changed and more components were bought rather than made. This change, in combination with budget constraints, led to substantial reductions in total employees and in ME staff numbers. The reductions in ME staff were organized to minimize risks of extended unemployment for those laid off, and, so, included more engineers than engineering technicians. These changes are illustrated by data points Aa (1982) and Ab (1987) in Figure 5.3.

Table 5.10
Comparison of the ME Profile in Divisions A, B and D

	Division		
ME Profile	A	B	D
Relative Number of Employees:	1.0	0.2	2.0
ME staff (% of total employees)	5.6% (1987) 6.5% (1982)	4.5% (1987) 2.6% (1984)	6% (1987)
ME staff ratios (engineers : technicians):			
Overall ratio (1987)	0.22 : 1	0.80 : 1	1.34 : 1
Overall ratio (1984)		0.30 : 1	
Overall ratio (1982)	0.30 : 1		
ME staff ratios (1987) (engineers : technicians):			
Process engineering	0.83 : 1	0.66 : 1	2.50 : 1
Industrial eng.	0.20 : 1		1.00 : 1
New product introduction	0.25 : 1}	1.00 : 1	0.75 : 1
Test engineering	}		1.75 : 1
Assembly Engineering	0.00 : 1		
Maintenance	0.00 : 1		

Figure 5.3
Evolution in Manufacturing Engineering Profiles



Notes:

Aa: Division A as organized in 1982;
Ab: Division A as organized in 1987;
Ba: Division B as organized in 1984;
Bb: Division B as organized in 1987;
D: Division D as organized in 1987.

In Division B, poor sales in 1984 resulted in a reduction of employment levels, with changes in ME staff numbers, calculated on the basis of the number which could be supported at the plant breakeven point. These changes are illustrated by data points Ba (1984) and Bb (1987) in Figure 5.3. In general terms, the ratios in Division B, as illustrated by data points Ba (1984), and Bb (1987) did change substantively, and for the better. However, in 1987 they were still inadequate to achieve required shifts in emphasis towards new product and process developments without reductions in emphasis on existing products and processes. Division B attempted to develop a new product and an associated process simultaneously, but was forced to slow the development effort after finding that support of existing products and processes had fallen below acceptable levels.

The ratios in Division A, on the other hand, as illustrated by data points Aa (1982), and Ab (1987), did not change as extensively as in Division B, but more than in Division D. These ratios did change for the worse, however, leaving Division A unable to develop further robotic assembly processes without reducing support to existing products and processes. In 1988, Division A decided to increase the proportion of engineers in the ME group.

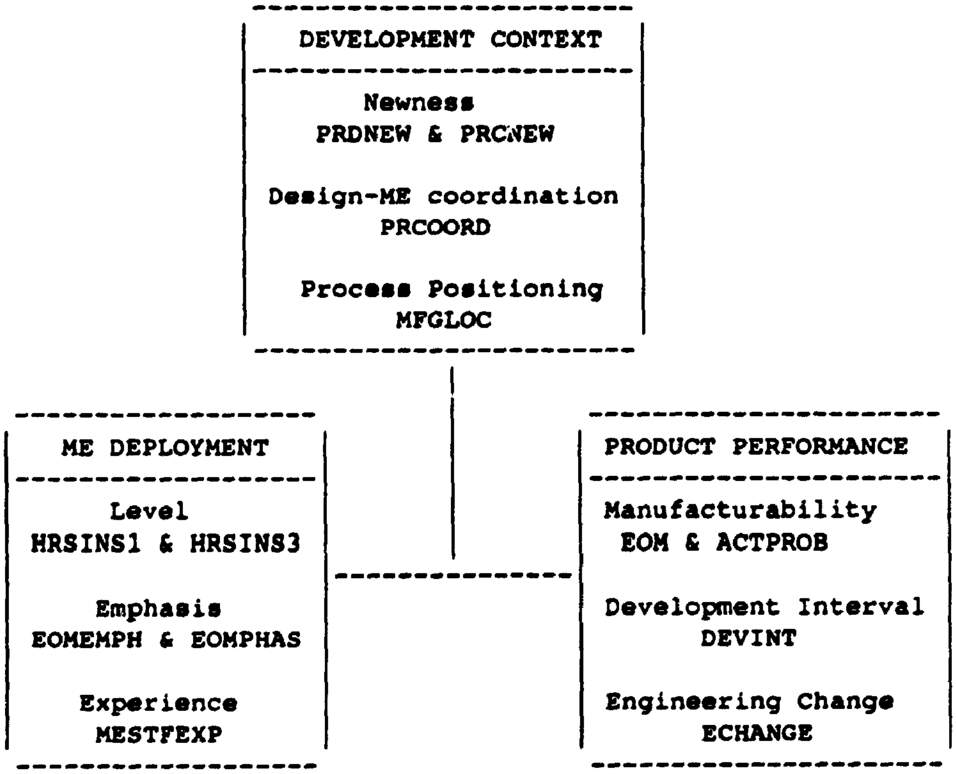
While there was no explicit statement of manufacturing strategy, each division had de-facto policies which reflected the particular product - markets served and their competitive realities. However, in Divisions A and B, operational pressures strongly influenced the implementation of one such policy, in terms of ME profile levels. As such, this short-term response to operational pressures led to 'swings' affecting the ME establishment, both in size and mix of engineers and technicians, sometimes resulting in inconsistency between the size of the ME staff and the Division's long-run objectives.

ME DEPLOYMENT, PRODUCT PERFORMANCE AND MANUFACTURING STRATEGY

In the conceptual framework developed for this study, the hypothesized relationship between product performance and ME deployment was moderated by various elements of manufacturing strategy. The framework is shown in Figure 5.4.

Figure 5.4

Operational Framework



Three major blocks of variables are identified in the model:

Product performance;
deployment of ME;
development context.

Product performance reflects the activity of the ME function. The deployment of ME is a variable over which the ME manager has control. The development context, defined by the manufacturing strategy of the firm, reflects differing situational or environmental settings in which the primary relationship of interest (ie. that between ME deployment and product performance) might be expected to vary. Based on the strategic decision categories of Hayes and Wheelwright (1984), manufacturing strategy has two dimensions: structural, and infrastructural. These decision categories include the following elements:

Structural - technology: product newness.

Structural - vertical integration: process positioning.

Infrastructural - organization: design-ME coordination.

I examined the differences among products, grouped by product newness, process position, and design-ME coordination, in the deployment of ME resources, and in product performance. In all cases, the null hypotheses were of no differences among the variables.

Product Newness

First, I examined the differences among products, grouped by product newness, in the deployment of ME resources, and, in particular, the differences in the proportions of ME manhours expended during Stages 1 and 3 of the new product development process, in the levels of emphasis and timing of emphasis on manufacturability during the development process, and in the levels of experience of the ME staff deployed. The null hypotheses were of no differences. The alternative hypotheses were as follows:

> H1a: newer products will be characterized by a higher proportion of ME manhours expended in Stage 1 of the product development process than less new products.
>
> H1b: newer products will be characterized by a lower proportion of ME manhours expended in Stage 3 of the product development process than less new products.
>
> H2a: newer products will receive a higher emphasis on manufacturability from ME during the product development process than less new products.
>
> H2b: newer products will receive earlier emphasis on manufacturability from ME during the product development process than less new products.
>
> H3: newer products will be characterized by lower levels of ME staff experience than less new products.

To test these hypotheses, I grouped the products as newer and less new relative to the median value (of 29.5) of the measure of product newness, PRDNEW. I then calculated Mann-Whitney U statistics for the differences in the median values of the deployment between groups, and corresponding significance levels based upon a one-tailed test. These results are summarized in Table 5.11.

Table 5.11
Differences in Deployment of Manufacturing Engineering for differing levels of Product Newness (PRDNEW)

Variable	No. Cases	Median Value	Mean Rank	M-W U	1-tail Prob.	Conclusion
HRSINS1				9.5	.4524	No support for H1a
newer products	4	15.57	5.13			
less new prods	5	8.1	4.90			
HRSINS3				5.5	.1428	No support for H1b
newer products	4	33.38	6.13			
less new prods	5	25.85	4.10			
EOMEMPH				5.0	.0206	Support for H2a
newer products	6	46.0	8.67			
less new prods	6	25.0	4.33			
EOMPHAS				6.0	.0325	Support for H2b
newer products	6	32.5	4.50			
less new prods	6	42.0	8.50			
MESTFEXP				11.0	.1203	Support for H3
newer products	6	19.0	5.33			
less new prods	6	22.0	7.67			

I then examined the differences in product performance among products, grouped by product newness, including differences in ease of manufacture, in the severity of manufacturability-related problems, in the length of the development interval, and in the incidence of manufacturability-related engineering changes at the start of routine volume production. The null hypotheses were of no differences. The alternative hypotheses were as follows:

H4a: less new products will have higher levels of manufacturability than newer products.

H4b: less new products will have lower severity of manufacturability-related problems at the start of routine volume production than newer products.

> H5: newer products will be characterized by longer development intervals than less new products.
>
> H6: newer products will have higher levels of manufacturability-related engineering changes at the start of routine volume production than less-new products.

To test these hypotheses, I grouped the products as newer and less new relative to the median value of the measure of product newness, PRDNEW (median = 29.5). I then calculated Mann-Whitney U statistics for the differences in the median values of the product performance between groups, and corresponding significance levels based upon a one-tailed test. These results are summarized in Table 5.12.

In sum, the company experienced lower manufacturability and more manufacturability-related engineering changes for newer products, in spite of ME placing greater emphasis on manufacturability earlier in the product development process. Further, there was some evidence to suggest longer development intervals for newer products. However, ME did not expend an increased proportion of manhours on newer products during Stage 1 of the development process, relative to less new products, although they expended a greater proportion of manhours during Stage 3. Further, the experience level of the ME staff engaged in newer products was lower than for less new products.

Table 5.12
Differences in Product Performance for differing levels of Product Newness (PRDNEW)

Variable	No. Cases	Median Value	Mean Rank	M-W U	1-tail Prob.	Conclusion
EOM				11.5	.1548	Support for H4a
newer products	6	40.0	5.42			
less new prods	6	43.0	7.58			
ACTPROB				16.5	.4091	No support for H4b
newer products	6	11.5	6.25			
less new prods	6	11.0	6.75			
DEVINT				10.5	.3371	No support for H5
newer products	5	14.0	5.90			
less new prods	5	14.0	5.10			
ECHANGE				10.0	.1785	Support for H6
newer products	6	7.5	6.83			
less new prods	5	5.0	5.00			

These findings are suggestive of a very different development task for newer rather than less-new products. By definition, newness implies diminished use or availability of existing experience both built into product and process elements, and captured in the ME staff allocated to the development project. Accordingly, the ME staff placed more emphasis on manufacturability earlier, because there were more new components and assemblies which had not been previously assessed for manufacturability. However, because of the newness, these components and assemblies had not been proven in volume production, as components and assemblies in less-new products would have been, and so required engineering change to effect necessary improvements.

Process Position

I examined the differences among products, grouped by process position, in the deployment of ME resources, and, in particular, the differences in the proportions of ME manhours expended during Stages 1 and 3 of the new product development process, in the levels of emphasis and timing of emphasis on manufacturability during the development process, and in the levels of experience of the ME staff deployed. The null hypotheses were of no differences. The alternative hypotheses were as follows:

> H7a: for products characterized by more internal manufacture of product components, ME will expend a higher proportion of manhours in Stage 1 of the product development process than for products characterized by less internal manufacture of product components.
>
> H7b: for products characterized by more internal manufacture of product components, ME will expend a lower proportion of manhours in Stage 3 of the product development process than for products characterized by less internal manufacture of product components.
>
> H8a: products characterized by more internal manufacture of product components, will receive a higher emphasis from ME on manufacturability during the product development process than products characterized by less internal manufacture of product components.
>
> H8b: products characterized by more internal manufacture of product components, will receive earlier emphasis from ME on manufacturability during the product development process than products characterized by less internal manufacture of product components.
>
> H9: products characterized by more internal manufacture of product components, will be characterized by higher levels of ME staff experience than products characterized by less internal manufacture of product components.

To test these hypotheses, I grouped the products as externally and internally manufactured relative to the median value of the measure of process position, MFGLOC (median = 15). I then calculated Mann-Whitney U statistics for the differences in the median values of the deployment between groups, and corresponding significance levels based upon a one-tailed test. These results are summarized in Table 5.13.

Table 5.13
Differences in Deployment of Manufacturing Engineering for differing levels of Process Position (MFGLOC)

Variable	No. Cases	Median Value	Mean Rank	M-W U	1-tail Prob.	Conclusion
HRSINS1				5.0	.1428	Support for H7a
external mfr.	5	8.10	4.00			
internal mfr.	4	24.47	6.25			
HRSINS3				8.0	.3651	No support for H7b
external mfr.	5	25.85	4.60			
internal mfr.	4	33.38	5.50			
EOMEMPH				8.0	.1071	Support for H8a
external mfr.	8	31.0	5.50			
internal mfr.	4	46.0	8.50			
EOMPHAS				4.5	.0242	Support for H8b
external mfr.	8	38.0	7.94			
internal mfr.	4	31.0	3.63			
MESTFEXP				5.5	.0309	No support for H9
external mfr.	8	23.0	7.81			
internal mfr.	4	19.0	3.88			

I then examined the differences in product performance among products, grouped by process position, including differences in ease of manufacture, in the severity of manufacturability-related problems, in the length of the development interval, and in the incidence of manufacturability-related engineering changes at the start of routine volume production. The null hypotheses were of no differences. The alternative hypotheses were as follows:

> H10a: products characterized by more internal manufacture of product components, will have higher levels of manufacturability than products characterized by less internal manufacture of product components.
>
> H10b: products characterized by more internal manufacture of product components, will have lower severity of manufacturability-related problems at the start of routine volume production products characterized by less internal manufacture of product components.
>
> H11: products characterized by more internal manufacture of product components, will be characterized by longer development intervals than products characterized by less internal manufacture of product components.
>
> H12: products characterized by more internal manufacture of product components, will have lower levels of manufacturability-related changes at the start of routine volume production products characterized by less internal manufacture of product components.

To test these hypotheses, I grouped the products as externally and internally manufactured relative to the median value of the measure of process position, MFGLOC (median = 15). I then calculated Mann-Whitney U statistics for the differences in the median values of the product performance between groups, and corresponding significance levels based upon a one-tailed test. These results are summarized in Table 5.14.

In sum, the company experienced lower manufacturability, shorter development intervals and more manufacturability-related engineering changes for products characterized by a greater degree of internal manufacture of components. During the development of these 'internal' products, ME expended a greater proportion of manhours during stage 1, and placed greater emphasis on manufacturability earlier. However, the ME staff was not as experienced in the development of internal products as they were for 'external' products.

Table 5.14
Differences in Product Performance for differing levels of Process Position (MFGLOC)

Variable	No. Cases	Median Value	Mean Rank	M-W U	1-tail Prob.	Conclusion
EOM				12.0	.2848	No support
external mfr.	8	41.5	7.00			for H10a
internal mfr.	4	40.0	5.50			
ACTPROB				14.5	.4040	No support
external mfr.	8	11.0	6.31			for H10b
internal mfr.	4	11.5	6.88			
DEVINT				4.0	.0431	No support
external mfr.	6	15.5	6.83			for H11
internal mfr.	4	12.5	3.50			
ECHANGE				11.5	.3175	No support
external mfr.	7	5.0	5.64			for H12
internal mfr.	4	7.0	6.63			

These findings are suggestive again of a very different development task for internal rather than external products. For internal products, the span of responsibility of the ME staff in the development of 'internal' products was greater than for 'external' product, and included the matching of individual component designs, rather than higher level sub-assemblies, with existing and new manufacturing processes. Accordingly, ME could not afford to assume that component designs were manufacturable - they had to ensure their manufacturability, but did not get it 'right first time' - maybe because of newness.

Design-ME Coordination

Finally, I examined the differences among products, grouped by management approach to design-ME coordination, in the deployment of ME resources, and, in particular, the differences in the proportions of ME manhours expended during Stages 1 and 3 of the new product development process, in the levels of emphasis and timing of emphasis on manufacturability during the development process, and in the levels of experience of the ME staff deployed. The null hypotheses were of no differences. The alternative hypotheses were as follows:

> H13a: products, managed through the Stage procedure, will be characterized by a higher proportion of ME manhours in Stage 1 of the product development process than products not managed through the Stage procedure.
>
> H13b: products, managed through the Stage procedure, will be characterized by a lower proportion of ME manhours in Stage 3 of the product development process than products not managed through the Stage procedure.
>
> H14a: products, managed through the Stage procedure, will receive a higher emphasis from ME on manufacturability during the product development process than products not managed through the Stage procedure.
>
> H14b: products, managed through the Stage procedure, will receive earlier emphasis from ME on manufacturability during the product development process than products not managed through the Stage procedure.
>
> H15: products, managed through the Stage procedure, will be characterized by higher levels of ME staff experience than products not managed through the Stage procedure.

To test these hypotheses, I grouped the products by management approach to design-ME coordination, PRCOORD. I then calculated

Mann-Whitney U statistics for the differences in the median values of the deployment between groups, and corresponding significance levels based upon a one-tailed test. These results are summarized in Table 5.15.

Table 5.15
Differences in Deployment of Manufacturing Engineering for differing approaches to Design-ME Coordination (PRCOORD)

Variable	No. Cases	Median Value	Mean Rank	M-W U	1-tail Prob.	Conclusion
HRSINS1				8.0	.3651	No support
staged	5	8.1	3.40			for H13a
non-staged	4	14.75	4.50			
HRSINS3				2.0	.0317	Support
staged	5	25.85	3.40			for H13b
non-staged	4	35.035	7.00			
EOMEMPH				13.0	.2651	No support
staged	7	42.0	7.14			for H14a
non-staged	5	35.0	5.60			
EOMPHAS				11.0	.1717	Support
staged	7	33.0	5.57			for H14b
non-staged	5	39.0	7.80			
MESTFEXP				16.0	.3993	No support
staged	7	21.0	6.29			for H15
non-staged	5	23.0	6.80			

I then examined the differences in product performance among products, grouped by management approach to design-ME coordination, including differences in ease of manufacture, in the severity of manufacturability-related problems, in the length of the development interval, and in the incidence of manufacturability-related engineering changes at the start of routine volume production. The null hypotheses were of no differences. The alternative hypotheses were as follows:

H16a: products, managed through the Stage procedure, will have higher levels of manufacturability than products not managed through the Stage procedure.

H16b: products, managed through the Stage procedure, will have lower severity of manufacturability-related problems at the start of routine volume production than products not managed through the Stage procedure.

H17: products, managed through the Stage procedure, products will be characterized by shorter development intervals than products not managed through the Stage procedure.

H18: products, managed through the Stage procedure, will have lower levels of manufacturability-related changes at the start of routine volume production than products not managed through the Stage procedure.

To test these hypotheses, I grouped the products by management approach to design-ME coordination, PRCOORD. I then calculated Mann-Whitney U statistics for the differences in the median values of the product performance between groups, and corresponding significance levels based upon a one-tailed test. These results are summarized in Table 5.16.

In sum, the performance of products managed through the Stage Procedure differed less conclusively from those managed through the set of procedures which pre-dated Staging, than in the other two manufacturing strategy contexts. Some evidence of higher manufacturability for non-Staged products was countered by evidence of lower severity of manufacturability-related problems for Staged products. Further, contrary to expectations, the incidence of engineering change was greater for Staged products, and development intervals were longer. On the input side, a less experienced ME staff did not expend higher proportions of manhours on Staged products during

Stages 1 or 3 of the development process, relative to non-Staged products. However, the emphasis by ME on manufacturability was earlier, but not conclusively greater, for Staged products than for non-Staged products.

Table 5.16
Differences in Product Performance for differing approaches to Design-ME Coordination (PRCOORD)

Variable	No. Cases	Median Value	Mean Rank	M-W U	1-tail Prob.	Conclusion
EOM				13.0	.2651	No support for H16a
staged	7	41.0	7.14			
non-staged	5	41.0	5.60			
ACTPROB				12.5	.2159	Support for H16b
staged	7	9.0	5.79			
non-staged	5	13.0	7.50			
DEVINT				10.0	.3338	No support for H17
staged	6	14.5	5.83			
non-staged	4	13.0	5.00			
ECHANGE				8.0	.0996	No support for H18
staged	6	7.5	7.17			
non-staged	5	5.0	4.60			

These findings are suggestive of a very different outcome from the introduction of Staging than that expected. Staging was introduced to facilitate the improvement of manufacturability and the reduction of development intervals. However, the opposite conclusion could be drawn from the differences examined: the Procedure failed to facilitate the development of new products as desired. Yet, this Procedure included elements which should facilitate the faster development of more manufacturable products. As such, it may not be the Procedure but the sample of products examined, or the familiarity of the development teams with the use of the Procedure. First, two of the six products which were Staged suffered major and unexpected technology-related problems late in the development process which extended the development interval. Second, three of the four divisions investigated introduced changes to the timing and content of manufacturability assessments after their initial experiences with the Procedure. As such, the differences observed in this manufacturing strategy context may be confounded by variables which were not controlled for in this study.

Summary Characteristics: ME Deployment & Product Performance

In summary, the analysis illustrates differences in product performance and ME deployment in differing manufacturing strategy contexts. The differences are summarized in Table 5.17. The differing contexts were defined by the newness of the product, the process position, and the management approach to design-ME coordination.

These findings are suportive of the inclusion of manufacturing strategy as a moderating variable in the conceptual framework for this study. The manufacturing strategy context of a new product development project makes a difference in the deployment of the manufacturing engineering resources, and in the performance of the resulting product. While these manufacturing strategy variables are not directly influenced by the new product development team, on an individual project basis, the potential for change exists during the strategy setting process.

Further, individual decisions, such as whether to make or buy a subassembly, reinforce or change the context of a new product development project, and, correspondingly, both the deployment of ME during the project and the ultimate product performance.

Table 5.17
Summary Characteristics: ME Deployment & Product Performance

Variable	Characteristic	For products which are:	Sig. (p<)
HRSINS1	Higher	Newer	.45
		Internal	.14
		Non-Staged	.36
HRSINS3	Higher	Newer	.14
		Internal	.37
		Non-Staged	.03
EOMEMPH	Higher	Newer	.02
		Internal	.10
		Staged	.26
EOMPHAS	Earlier	Newer	.03
		Internal	.02
		Staged	.17
MESTFEXP	Higher	Less-New	.12
		External	.03
		Non-Staged	.40
EOM	Higher	Less-New	.15
		External	.28
		Non-Staged	.27
ACTPROB	Lower	Less-New	.40
		External	.40
		Staged	.22
DEVINT	Shorter	Less-New	.34
		Internal	.04
		Non-Staged	.33
ECHANGE	Lower	Less-New	.18
		External	.32
		Non-Staged	.10

CHAPTER SIX: ME DEPLOYMENT FOR DEVELOPMENT INTERVAL REDUCTION

Reduction of development intervals in new product development, just as improvement of manufacturability, was a conscious and major priority for the company, the divisions investigated, and for the ME groups within those divisions. The company implemented the Stage Procedure, in part, to achieve reductions in development intervals. In addition, the divisions, independently of each other, evolved distinct approaches to facilitate reduction of the development interval. Underlying each of these approaches, at company and divisional levels, were issues of tradeoffs, and adherence to rules. In general, however, manufacturing engineering was not a key group in the achievement of shorter development intervals. Especially for newer products, technology and marketing concerns dominated, which were outside the control of ME.

Of the five deployment decisions open to ME managers, only two were consistently associated with shorter development intervals: when to become involved in the development process, and when to withdraw from the process. Except for newer products, shorter development intervals were associated with earlier ME involvement during the definition stage of the development process, and earlier withdrawl during the verification stage. For newer products, it did not seem to matter when ME was involved.

The newness of the product and the process position each defined development contexts, within which different relationships between the development interval and ME deployment emerged. For less new products and for products based largely upon components and subassemblies manufactured inhouse ('internal products'), the relationships were similar: shorter intervals were associated with greater and earlier ME involvement in the development process, and with greater and earlier ME emphasis on manufacturability. In contrast, for newer products, ME deployment was not related to the interval length, while for products based largely on externally sourced components and subassemblies ('external products'), only early involvement was associated with shorter development intervals.

Despite the expectations of the company concerning the impact of the Stage Procedure, its use did not seem to change the virtual absence of a relationship between length of interval and ME deployment. Rules were broken by managers, at all levels, in order to shorten the development interval. However, the exact direction of causation remains a question: were the managers reacting to Staging as a formal procedure which got in the way of the development task, through its requirements for documentated progress against detailed checklists, and resisting the imposition of a greater degree of formalization on their development activities? Or, were they committed to the objectives of Staging, but reacting to its inadequacies in a constructive way?

The next section describes the company and divisional approaches to development interval reduction, starting with the Stage Procedure and concludes with a discussion of implicit and explicit rule-breaking at divisional level to facilitate reduction in the development interval. I then discuss the relationship observed between the length of the development interval and each of the five ME deployment decisions.

MANAGEMENT FOR DEVELOPMENT INTERVAL REDUCTION

Frequent, Short-cycle Projects: The Stage Procedure Response

In the early eighties, the company faced a need to manage the development of new products with ever-more ambitious schedules, specifications, and cost objectives. The growing importance of product variety and technological sophistication as competitive factors, and the increasing cost of maintaining that sophisticated variety, were pressuring the company to improve the manufacturability of all of their product designs, through integrated product and process development. Further, development schedule overruns were resulting in greater loss of profit opportunities for the company than cost overruns by either Manufacturing or R&D. The company recognized the need improve their management of new product development projects.

Until the early eighties, procedures for the management of new product development in the company were characterized by many checkpoints and division-level reviews of progress. The company emphasized both cost control and wise investment as essential for improved profitability. Correspondingly, as management decision-making emphasized finance, new product development was viewed largely in investment terms.

The company gave each division, and each project team within it, responsibility for managing new product developments in their own way, as long as financial criteria were met and the product was competitive in the market. In Division A, the development of product A1 had been managed successfully through appointment of a senior manager as project manager, cross-functional teamwork, application of design-for-automation and value analysis techniques, and an enthusiasm born of the need to survive. However, a successful outcome would be difficult to repeat, especially in the context of frequent, short-cycle new product development projects. The elements of a sustainable management approach were present in the A1 development project (and in projects in the other divisions); the company saw that it needed some means of harnessing and formalizing the management and technical experience which the development team had gained, in order to achieve the similar results over shorter development intervals, without such concentrated involvement of senior management.

In 1985, the company introduced the Stage Procedure. to facilitate divisions in expanding their views of quality in new product development to include absence of defects, ease of manufacture and operation, and timeliness of product availability to the customer. Throughout the new product development process, the Stage Procedure emphasized the achievement of delivery schedules. Explicit commercial and technical milestones and new, formal, event-driven reviews were to help impress on the cross-functional team members the urgency of their work. These reviews would allow team members to foresee the impact of delays through the development process, and to control progress so that those dependent on deliverables late in the process would have adequate time to meet their deadlines. However, in each of the divisions, these corporate procedures and guidelines were by-passed by project teams in efforts to reduce the development intervals and achieve ambitious delivery dates.

Division-level Management for Development Interval Reduction

In the divisions, management of new product development projects for development interval reduction was characterized by informal responses to Staging, including rule-breaking at both project and senior management levels. The nature of the markets for which the products were targeted was such that the product development teams were under severe pressure to introduce the products in the shortest possible time. In each of these markets windows of opportunity had been identified. These windows were perishable and available for only defined periods of time. The pressure was heightened by the perceived importance of the products to the survival and image of the division and the corporation. As such, time-based pressures were often dominant in the development projects, forcing the achievement of an introduction date with a functional but less than cost effective product. In many ways, the project teams could do little to overcome these pressures as they were competing in markets where product distributors required agreement on a specific date for release of the product to the market, and required up to six months to set up the distribution channels in time for that date.

The divisions broke the Stage Procedure rules in one of three ways: through release of products to customers before completion of the verification stage; in spite of rejection at the verification stage; or conditional upon implementation a cost reduction case. The end results of these infringements were products delivered to the customer, which often required design recycling or retro-fitting of redesigned parts to equipment in service. While design recycling resulted in bringing a product closer to the design intent, it also had wider implications for manufacturability which only showed up in volume production.

For example, when product A4 was returned to the drawing board for redesign, the changes resulted in an increase in component density which had adverse implications for manufacturability. These implications were neither assessed nor addressed until after the verification stage. As a consequence of these experiences, Division A, in common with other divisions, subsequently introduced the requirement that if a product design was 'recycled', then this redesign had to be 'proven-in', and a 'mini-end-of-Stage review' held to review the results.

Further rule-breaking by project teams in order to reduce the development interval took various forms. In some cases, long lead-time activities, such as tool development or equipment acquisition, started without the necessary capital funding approvals in place. In order to provide cover for these interval-reducing activities, project groups isolated themselves from senior divisional or corporate management. As such, management were not informed of the process by which certain project deliverables were completed.

In addition to explicit rule-breaking, project groups also engaged in implicit rule breaking. In these cases, the ME group knowingly accepted transfers of incomplete design information. As such, and in the interests of the development schedule, ME took the risk that they would be able to meet their project objectives, even with incomplete design information. Such risk-taking sometimes had costly consequences. While product A4 met its rescheduled market release date, it did not meet its cost objectives. Similarly, in the case of the product D2, ME were left with a display design which was difficult to manufacture, and which was ultimately changed.

However, the exact direction of causation remains a question: were the managers reacting to Staging as a formal procedure which got in the way of the development task, or were they committed to the objectives of Staging, but reacting to its inadequacies in a constructive way? The view, expressed in one division was that if rules were not broken, projects would not be completed on time. However, another manager commented that rule-breaking was not indiscriminate - the skill was in knowing which rules to break and when to break them. When these comments are taken in relation to the decision by Division A to introduce a requirement for a 'mini-end-of-Stage review' of a redesign, in spite of the pressures for development interval reduction, the picture emerges of a management group committed to getting the best product out in the time available. These managers were willing to learn, but they recognised that corporate procedures did not relieve them of the necessity to manage the projects. In effect, they were committed to the objectives of Staging, but reacting to its inadequacies in constructive ways.

LENGTH OF DEVELOPMENT INTERVAL AND ME DEPLOYMENT

After achieving an understanding of corporate and divisional approaches to management of development interval reduction, I then examined how the length of the development interval was associated, if at all, with the deployment of ME resources during the development process.

The development interval included the total elapsed time over which ME carried out its development activities for a new product development project (DEVINT). I defined this interval as the number of months between the definition and verification of the product design. I then examined the nature of the associations between the length of the development interval and each of the deployment decisions available to the ME manager, both with and without control for the development context. Kendall tau-B rank correlation coefficients, and corresponding significance levels based upon a one-tailed test were calculated.

Development Interval and Emphasis on Manufacturability

The results of the analysis of the association between the development interval and the level of emphasi [illegible] on manufacturability will be reported first. This report will be followed by the results of the analysis of the association between the development interval and the phasing of emphasis by ME on manufacturability.

Development Interval and Level of Emphasis

The length of the development interval was the outcome of the completion of development activities by many functional groups interacting during the new product development process. One of these groups was manufacturing engineering, by whom a major emphasis was on manufacturability. My general expectation was that the greater the emphasis on manufacturability, the shorter the development interval. Stated formally, the expected association was as follows:

> H19: the greater the level of emphasis by ME on manufacturability during the new product development process, the lower will be development interval.

Without controlling for any moderating variables, there was some support for this expectation. The results are summarized in Table 6.1.

Table 6.1

Association between Development Interval (DEVINT) and Emphasis on Manufacturability (EOMEMPH)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	-.2299	.183	As hypothesized	10
Newer products	+.1054	.400	Not as hypothesized	5
Less new products	-.5270	.103	As hypothesized	5
Less internal manufacture	+.0667	.425	Not as hypothesized	6
More internal manufacture	-.5477	.139	As hypothesized	4
Staging	-.0667	.425	As hypothesized	6
Pre-Staging	-.1826	.359	As hypothesized	4

In each of the divisions, ME reviewed alternative component, feature, and manufacturing options, in part, through manufacturability assessment. The greater the emphasis by ME on manufacturability, the shorter was the development interval. Through this greater emphasis on manufacturability, ME did not have to spend time addressing problems which might otherwise have arisen later. In this sense, ME emphasis on manufacturability was akin to preventive maintenance and, as such, associated with greater 'up-time' of the development process, with consequently shorter cycle times. However, this association strengthened for internal and less-new products. In all other contexts, the associations were weak or non-existent.

As noted in Table 5.17 in Chapter Five, ME emphasis on manufacturability was greater for internal products than for products characterized by less internal manufacture of components and subassemblies ('external' products). The wider range of components to be manufactured using internal facilities required a greater degree of input from ME during the development process. This level of input placed ME in a position of control over the pace of the development process. Correspondingly, for such 'internal' products, greater emphasis on manufacturability was associated with shorter intervals.

By definition, the development agenda for less-new products was limited relative to that for newer products. Less-new products incorporated fewer new features, components and sub-assemblies, and many of the product-process relationships were established. As such, where the development agenda was limited, the achievement of functionality drove the schedule less than manufacturability. Accordingly, for less-new products, greater emphasis by ME on manufacturability was associated with shorter development intervals.

The absence or weakness of the relationship for external or new products supported an observed lack influence by MF on the development interval in these contexts. For products developed in these contexts, I observed incidents in some of the product development projects, which were acknowledged to have extended the development interval, and which were outside of the control of ME. In two particular cases, products A4 and D2, the project was on schedule and the specification targets set for and by ME were within view, when major problems occurred with the product technology. Resolution of these problems extended the development interval, rather than any emphasis or lack of emphasis from ME.

Development Interval and Phasing of Emphasis

Resolution of manufacturability-related problems which arose during the development process had the potential to extend the development interval. However, building on the notion of emphasis on manufacturabiity as preventive maintenance of the new product development process, the general expectation was that the earlier that emphasis was placed, the shorter the development interval. More formally:

> H20: the earlier the phasing of emphasis by ME on manufacturability during the new product development process, the shorter will be the development interval.

Reducing the development interval required, not only an emphasis by ME on manufacturability, but also earlier rather than later placement of that emphasis, in particular, for less new products, and for products characterized by more internal manufacture of components, as summarized in Table 6.2.

Table 6.2
Association between Development Interval (DEVINT)
and Phasing of Emphasis on Manufacturability (EOMPHAS)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	+.2501	.161	As hypothesized	10
Newer products	-.2000	.312	Not as hypothesized	5
Less new products	+.7379	.038	As hypothesized	5
Less internal manufacture	+.0667	.425	As hypothesized	6
More internal manufacture	+.3333	.248	As hypothesized	4
Staging	+.2000	.287	As hypothesized	6
Pre-Staging	.0000	.500	Not as hypothesized	4

One objective of the Stage Procedure was the reduction of the development interval. In discussion, ME managers in each division suggested that Staging facilitated that reduction, through greater discipline and accountability, more than the earlier approach to design-ME coordination. The development schedule was more explicit for Staged products than for non-Staged products. For example, during the field research, the quality of the available project documentation, in terms of content and completeness, was higher for Staged than non-Staged products. However, these positive indicators found little support in terms of association between phasing of ME emphasis on manufacturability and length of development interval. This observation was consistent with the absence of association between the length of the development interval and ME emphasis on manufacturability, reported earlier in Table 6.1.

As discussed in relation to the level of emphasis on manufacturability, less-new products and internal products provided ME with a more visible role in the development process. In the case of less-new products, the technology was more stable, so providing ME with more complete design information earlier. Further, by definition, ME had experience of volume manufacture of many of the product components and subassemblies, based upon earlier members of the product families. Correspondingly, for less-new products, the earlier that emphasis, the shorter was the development interval.

All internal products received early emphasis on manufacturability, and the earlier that emphasis, the shorter was the development interval.

For internal products, the necessity to integrate the product design with new or existing manufacturing processes cast ME in the role of a key gatekeeper for process information. For both less-new and internal products, ME knew more about the integration of the process design with the evolving product design. By becoming involved in the development process earlier, ME marshalled this information to the overall benefit of the product, as substantiated here in terms of shorter development intervals.

ME was not as involved in the development of products with a large proportion of sourced components and subassemblies. This observation is consistent with the existence of vendor engineering groups in the three divisions characterized as less vertically integrated. In these divisions, the vendor engineering groups appeared to act in much the same way in relation to design and (external) manufacturing as ME did in relation to design and (internal) manufacturing. The emerging picture of ME with less influence in the case of external products is consistent with this division of responsibility.

Development Interval and Level of ME Deployment

The results of the analysis of the associations between the development interval and the level ME deployment in the definition stage of the new product development process will be reported first. This report will be followed by the results of the analysis of the associations between the development interval and the level ME deployment in the verification stage.

Development Interval and ME Deployment in the Definition Stage

ME manhours were expended on more activities than manufacturability assessment. The more of these manhours expended earlier in the development process, the earlier these activites were started. The expectation was that the earlier the manhour expenditure, the shorter the development interval. Stated more formally:

> H21: the greater the level of ME deployment in the definition stage of the new product development process, the shorter will be the development interval.

This expectation was borne out for all except newer and non-Staged products, where there was no evidence of association. These results are summarized in Table 6.3.

Newer products were characterized by greater risks and uncertainities, as they required the development, integration and start-up of new product and process technologies. Many of these risks and uncertainties were outside the area of responsibility of ME. Correspondingly, there was no association between the length of the development interval and the deployment of ME in the definition stage.

In effect, the length of the interval may have been determined more by the context, in this cases the newness of the technology, than by ME management decisions on deployment of ME resources.

Table 6.3
Association between Development Interval (DEVINT)
and ME Deployment in the Definition stage (HRSINS1)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	-.3189	.122	As hypothesized	9
Newer products	0.0000	.500	Not as hypothesized	4
Less new products	-.5270	.103	As hypothesized	5
Less internal manufacture	-.3162	.224	As hypothesized	5
More internal manufacture	-.3333	.248	As hypothesized	4
Staging	-.3162	.224	As hypothesized	5
Pre-Staging	0.0000	.500	Not as hypothesized	4

Less-new products were developed in a context of greater technological stability, were more amenable to management influence. Correspondingly, the length of the development interval was associated with the deployment of ME in the definition stage. For newer products, the absence of association contrasts sharply with the strong association evident in less-new products. This contrast adds to the gradually emerging picture of ME as a function which had little influence on the length of the development interval for newer products, but may have had a key role in development interval reduction in less-new products.

A second picture emerging from this analysis of the development interval in relation to the deployment of ME is a consistent relationship in the case of internal products. While the associations observed in relation to deployment in the definition stage were not moderated by the process position, the emerging relationship was not contradicted. The length of the development interval may be more amenable to ME deployment for internal products, than for external products.

In the more structured context defined by the Stage Procedure, the concerns of functions like ME, gained more prominence earlier than previously, with positive implications for the length of the development interval. For products not managed through the Stage Procedure, the absence of an association contrasts with the association evident in Staged products. This contrast adds to the notion of Staging as a procedure which added greater structure and visibility to the development process, rather than additional tasks. However, as discussed earlier in terms of the divisional responses to Staging, the procedure did not provide 'the answer' to the problem of developing a manufacturable product in the shortest interval. The weakness of the association between the development interval and ME deployment in the definition stage is consistent with the positive but limited impact of Staging on the development process.

Development Interval and ME Deployment in the Verification Stage

As summarized in Table 5.2 of Chapter Five, the Stage Procedure formally assigned 'prime responsibility' for completion of each stage of the development process to a nominated function. Manufacturing was 'prime' for the verification stage, when the development focus was on verification of conformance to product specifications and to product cost targets in a pilot volume production run. ME were key Manufacturing representatives on the development team. The expectation was that the activities performed by ME at this stage of the process were on the 'critical path'.

ME manhours were expended in the verification stage of the development process on a set of activities which included verifying work standards, equipment coordination for shop trials, and assistance in pilot production difficulties. As reported earlier in Table 5.3 of Chapter Five, 17 out of the 21 activities in process in this stage were commenced prior to this final stage. Accordingly, the fewer manhours expended in the verification stage, the shorter should be the development interval, corresponding with fewer activites performed by ME. More formally,

> H22: the greater the level of ME deployment in the verification stage of the new product development process, the longer will be the development interval.

In general, this expectation was borne out, and, in particular, for all except newer products, as summarized in Table 6.4. This finding is important as it suggests that, with one exception, later deployment of ME in the development process was associated with longer development intervals.

Table 6.4
Association between Development Interval (DEVINT)
and ME Deployment in the Verification stage (HRSINS3)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	+.3189	.122	As hypothesized	9
Newer products	0.0000	.500	Not as hypothesized	4
Less new products	+.5270	.103	As hypothesized	5
Less internal manufacture	+.3162	.224	As hypothesized	5
More internal manufacture	+1.000	.021	As hypothesized	4
Staging	+.3162	.224	As hypothesized	5
Pre-Staging	+1.000	.021	As hypothesized	4

When these associations are examined in relation to those on ME deployment in the earlier definition stage, ME seems to have come off the critical path, or shortened the time it was on the critical path, by completing its development task sooner rather than later. However, an alternative explanation, which I could not verify, was that the shorter development intervals were achieved through 'rule-breaking', where ME accepted transfers of design information from design in a form known to be incomplete. However, in the interests of the development schedule, ME took the risk that they would be able to meet their project objectives based upon the incomplete design information. The absence of completely complementary results in relation to the deployment of ME in the definition and verification stages, suggests that some rule-breaking may indeed have occurred in parallel with earlier deployment

For newer products, there was no evidence of association between development interval and the ME deployment in the verification stage. However, as observed earlier in relation to the level of ME deployment in the definition stage, this absence of a relationship contrasts sharply with the strong association evident in less-new products. Taken together, these two sets of observations suggest that for newer products, it did not seem to matter, in terms of the length of the development interval, when ME resources were deployed. In contrast, for less-new products, the earlier in the definition stage the resources were deployed and the earlier in the verification stage they were withdrawn, the shorter was the development interval.

The implication is that in the more technologically stable context of the less-new product, ME made a greater contribution to product performance, measured in terms of development interval. The development task was more limited, the prominence given to the concerns of other functional groups was less, and the quality of the product and process information with which ME had to work was higher. As such, earlier deployment, when carried out, was effective.

Development Interval and ME Staff Experience

By definition, ME experience was based on volume manufacture of product components and subassemblies, many of which were derived from earlier members of the product family. The ability of ME, based upon experience, to integrate the product design with new or existing manufacturing processes, allowed ME to perform better in the role of a key gatekeeper for process information. The general expectation was that shorter development intervals would be associated with greater ME staff experience. More formally:

> H23: the greater the level of ME staff experience, the shorter will be the development interval.

This expectation was not borne out. Except for newer products and products characterized by a greater degree of internal manufacure of components, there was little support for relationships between interval length and experience. This finding suggests a general lack of impact which ME had on the development interval. No explanation is offered for the non-hypothesized relation between ME staff experience and development interval for new products. These results are summarized in Table 6.5.

For products characterized by internal manufacture of components, the development interval was shorter for greater staff experience. This finding is consistent with our earlier observations in relation to ME emphasis on manufacturability. ME experience contributed to the performance of the product, in terms of shorter development intervals.

The apparent importance of ME staff experience in this context raises questions about the staffing of the function for the development, maintenance and utilization of that experience.

Table 6.5
Association between Development Interval (DEVINT) and ME Staff Experience (MESTFEXP)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	+.0495	.426	Not as hypothesized	10
Newer products	+.3162	.224	Not as hypothesized	5
Less new products	-.1179	.394	As hypothesized	5
Less internal manufacture	+.0778	.419	Not as hypothesized	6
More internal manufacture	-.6667	.087	As hypothesized	4
Staging	-.0716	.423	As hypothesized	6
Pre-Staging	-.1826	.359	As hypothesized	5

LENGTH OF DEVELOPMENT INTERVAL AS CONTEXT

In development contexts characterized by less-new products or a greater dependence upon internal sources for the supply of components, I observed consistent relationships between the length of the development interval and the deployment of ME in the development process. In other development contexts, the length of the development interval was not as clearly related to the deployment of the ME function. In keeping with the exploratory nature of the study, I hypothesized from these findings that the development interval, as well as being related to the deployment of ME, also played a role in defining the context within which new products were developed.

Hypotheses of Difference: As with the other 'context' variables, I examined the differences among products, grouped by length of development interval, in the deployment of ME resources during the new product development process. The null hypotheses were of no differences. The alternative hypotheses were as follows:

H34a: products, with shorter development intervals, will be characterized by a higher proportion of ME manhours in the definition stage of the product development process than products with longer development intervals.

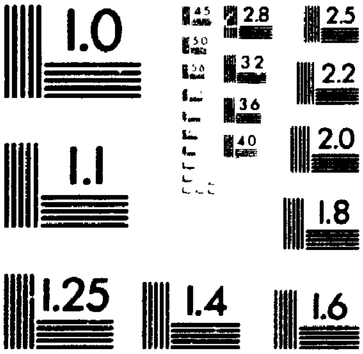
H34b: products, with shorter development intervals, will be characterized by a lower proportion of ME manhours in the verification stage of the product development process than products with longer development intervals.

H35a: products, with shorter development intervals, will receive a higher emphasis from ME on manufacturability during the product development process than products with longer development intervals.

H35b: products, with shorter development intervals, will receive earlier emphasis from ME on manufacturability during the product development process than products with longer development intervals.

H36. products, with shorter development intervals, will be characterized by higher levels of ME staff experience than products with longer development intervals.

3



To test these hypotheses, I grouped the products by length of development interval, DEVINT. I then calculated Mann-Whitney U statistics for the differences in the median values of the deployment between groups, and corresponding significance levels based upon a one-tailed test. These results are summarized in Table 6.6.

Table 6.6
Differences in Deployment of Manufacturing Engineering for differing lengths of Development Interval (DEVINT)

Variable	No. Cases	Median Value	Mean Rank	M-W U	1-tail Prob.	Conclusion
HRSINS1				4.0	.1309	Support for H34a
short interval	6	23.265	5.83			
long interval	3	8.10	3.33			
HRSINS3				8.0	.4524	No support for H34b
short interval	6	32.93	4.83			
long interval	3	25.85	5.33			
EOMEMPH				14.0	.2605	No support for H35a
short interval	6	44.0	7.17			
long interval	6	31.0	5.83			
EOMPHAS				9.5	.0863	Support for H35b
short interval	6	32.5	5.08			
long interval	6	41.0	7.92			
MESTFEXP				11.0	.1203	No support for H36
short interval	6	20.5	5.33			
long interval	6	23.0	7.67			

I then examined the differences in product performance among products, grouped by length of development interval, including differences in manufacturability, in the severity of manufacturability-related problems, and in the incidence of manufacturability-related engineering changes at the start of routine volume production. The null hypotheses were of no differences. The alternative hypotheses were as follows:

H37a: products, with shorter development intervals, will have lower levels of manufacturability than products with longer development intervals.

H37b: products, with shorter development intervals, will have higher severity of manufacturability-related problems at the start of routine volume production than products with longer development intervals.

H38: products, with shorter development intervals, will have higher levels of manufacturability-related changes at the start of routine volume production than products with longer development intervals.

To test these hypotheses, I grouped the products by length of development interval, DEVINT. I then calculated Mann-Whitney U statistics for the differences in the median values of the product performance between groups, and corresponding significance levels based upon a one-tailed test. These results are summarized in Table 6.7.

Table 6.7
Differences in Product Performance for differing lengths of Development Interval (DEVINT)

Variable	No. Cases	Median Value	Mean Rank	M-W U	1-tail Prob.	Conclusion
EOM				13.5	.2336	Some support for H37a
short interval	6	40.0	5.75			
long interval	5	41.5	7.25			
ACTPROB				13.0	.2105	Some support for H37b
short interval	6	11.5	7.33			
long interval	5	10.5	5.67			
ECHANGE				13.5	.3916	No support for H38
short interval	5	7.0	5.70			
long interval	5	6.5	6.25			

Discussion: In sum, the performance of products with longer development intervals was better than those developed in shorter intervals. There was some evidence of higher manufacturability, lower severity of manufacturability-related problems, and a lower incidence of engineering change for products developed in longer intervals. On the input side, the ME staff placed greater emphasis on manufacturability earlier for products developed in shorter intervals. Correspondingly, ME expended higher proportions of manhours during the definition stage of the development process for these products. Finally, for short-interval products, the ME staff were less experienced than those engaged in products developed over longer intervals.

The differences in ME deployment and product performance among products developed in shorter or longer intervals suggest that the length of the development interval defined differing task environments. That both the deployment of ME resources and the performance of the products differed in these environments is not surprising. What is remarkable, however, is the similarity of these differences to those observed in the cases of newer and less-new products, reported and discussed earlier, in Chapter Five.

While a number of newer products were developed in shorter intervals, and, so, may have influenced both the deployment and the outcome, shortening the development interval seemed to result in a development context similar to that surrounding newer products. Each context was characterized by uncertainty, although the origin of the uncertainty differed. For newer products, the uncertainty was more technological: the operating characteristics and manufacturing requirements of components and subassemblies were unknown, and some remained unknown until the start of volume production. To offset this uncertainty, ME became involved earlier in the development process and to a greater extent than when more information on operating characteristics and manufacturing requirements was available. In the event, however, while products performed to the functional specification, they did not perform as well in manufacturability terms, the outcome of a tradeoff between conflicting objectives.

Similarly, for short-interval products, while the operating characteristics and manufacturing requirements were known, ME was not be capable of integrating them in the time allowed, resulting in technological uncertainty at the start of volume production. Again, to offset this uncertainty, ME became involved earlier in the development process and to a greater extent than when more time was available. In the event, however, while products achieved their tighter production dates, they did not perform as well in manufacturability terms, the outcome, again, of a tradeoff between conflicting objectives.

In summary, there were differences in product performance and ME deployment for products developed in strategic contexts defined by short and long development intervals. These differences support the inclusion of the length of the development interval as a moderating variable in the conceptual framework for this study. The length of this interval in a new product development project made a difference in the deployment of the manufacturing engineering resources, and in the performance of the resulting product.

Summary: ME Deployment for Development Interval Reduction

The length of the development interval was not generally influenced by the ME group in the product development team. However, in development contexts characterized by greater technological stability (less-new products) or greater control by ME over the integration of product and process technologies (internal products), ME helped reduce the interval. Figure 6.1 outlines these context-contingent associations between the development interval and ME deployment which have emerged.

Figure 6.1
Association between Development Interval and ME Deployment

```
 ------------------
| Emphasis on      |        -
| Manufacturability |---------------------
 ------------------                       |
 ------------------                       |
|    Phasing of     |        +            |
|    Emphasis on    |------------------   |
| Manufacturability |                  |  |
 ------------------                    |  |
 ------------------               -------------
|    Level of ME    |        -       | Development |
| Deployment Earlier|----------------|   Interval  |
|  in the Process   |                 -------------
 ------------------                    |  |
 ------------------                    |  |
|    Level of ME    |        +         |  |
| Deployment Later  |------------------   |
|  in the Process   |                     |
 ------------------                       |
 ------------------                       |
|    ME Staff       |        -            |
|    Experience     |---------------------
 ------------------
```

Notes: positive association denoted by '+'
       negative association denoted by '-'

CHAPTER SEVEN: ME DEPLOYMENT FOR MANUFACTURABILITY

The company recognised the need for product designers to work to the customer's specific needs and requirements. Further, they also recognised potential benefits from ensuring that product designs could be effectively accommodated by the manufacturing processes through utilization, where possible, of standard components, sourced or manufactured at high quality and optimum costs. Through this combination of design for need and design for manufacture, they expected to achieve a profitable balance between quality and productivity.

In 1985, the company implemented the Stage Procedure, in part, to facilitate the development of manufacturable new products. In addition, the divisions, independently of each other, evolved distinct approaches to assessment and achievement of manufacturability. Underlying each of these approaches, at company and divisional levels, were issues of standards, tradeoffs, and organizational change. In general, manufacturing engineering was key in the achievement of manufacturability.

All five deployment decisions open to ME managers were associated with improved manufacturability: when to become involved in the development process, when to withdraw from the process, when and how much emphasis to put on manufacturability, and what staff to assign.

However, the combinations of decisions associated with improved manufacturability varied with the development context.

In all contexts, higher manufacturability was associated with greater involvement of ME in the definition stage of the new product development process. In all contexts, except that defined by newer products, higher manufacturability was associated with a lower level of deployment in the verification stage of the process. For newer products, higher manufacturability was associated with a greater level of deployment in this final stage of the process. The fundamental deployment strategy seemed to be to get involved early in the definition stage, and to remain involved into the verification stage.

In addition to decisions on the level of ME deployment, in all contexts, at least one other deployment decision was associated with improved manufacturability. However, this additional decision did not always concern the emphasis or the phasing of ME emphasis on manufacturability. Two questions were raised by this observation: did the achievement of manufacturability require that ME do a little more than be involved in the development process and emphasise manufacturability? Alternatively, were there some contexts in which manufacturability was not amenable to the efforts of ME?

In three particular development contexts, similar combinations of deployment decisions were associated with improved manufacturability: newer products, products characterized by internal manufacture of components and subassemblies, and products developed in shorter intervals. The common feature of each of these contexts was the uncertainty within which the products were developed. For newer products, the product and process concepts were still in formation. For internal products, each project featured some new relationship between product and process technologies, thus requiring ME's detailed attention. For products developed in shorter intervals, there was not enough time to utilise all the information which was available.

The greater degree of formalization in the Stage Procedure recognised a definitive role for ME in the development process. In particular, this role emphasized manufacturability. As planned by the company, in development contexts defined by use of the Stage Procedure, all five deployment decisions were associated with improved manufacturability, in contrast to the outcome for products developed before the introduction of Staging.

In the next section of Chapter Seven, I will describe the company and divisional approaches to management for manufacturability, starting with a description of divisional responses to the Stage Procedure, and concluding with the evolution of division-level approaches to this issue. I will then discuss the relationship observed between the manufacturability and each of the five ME deployment decisions.

The Stage Procedure: Divisional Responses

In 1985, the company attempted to replace cost reduction during the volume production phase with cost avoidance during the development phase. In effect, the company required project groups to design products 'right first time'. In order to support this thrust, the company introduced the Stage Procedure as a disciplined approach to the management of new product developments. The Procedure divided the new product development process into a number of stages, including: Stage 1 - definition; Stage 2 - development; Stage 3 - verification.

The company instituted the Stage Procedure to obtain impact beyond project management; it was to become a way of thinking within the company. They intended to create an environment of continuous learning and adaptation. Accordingly, the Stage Procedure was not intended to be rigid, recognising that no individual set of management procedures could provide a unique and satisfactory solution to every problem. Since 1985, most products introduced in the company had been managed through Staging.

Each division was required, as part of the Stage Procedure, to carry out manufacturability assessments at specified stages of the development process. In addition, the Stage Procedure also required value analysis by Stage 1. In operation, however, the divisions changed the timing of these Stage deliverables, as summarized in Table 7.1. Even though the Stage Procedure aimed specifically to achieve earlier consideration of manufacturing requirements, divisional experiences revealed that the original steps underestimated how soon those considerations had to be addressed. While the detail of each division's adjustments to the Stage Procedure reflected its specific competitive and operational circumstances, each division subsequently moved their assessment of product manufacturability to a stage earlier than originally specified. Accordingly, the first products managed through Staging were not felt to be as manufacturable as those developed after adjustment of the Procedure.

Table 7.1
Stage Procedure Changes Initiated by Three Divisions

Change	Division A	Division B	Division D
Changed numbers of Stages:	No	No	One extra Stage between Stages 1 & 2.
Motivation for change:	Not applicable	Not applicable	Need to estimate yield and cost targets based on earlier pilot manufacture.
Basis for change:	Not applicable	Not applicable	Experience on earlier projects
Changed performance targets at Stages:	New pilot volume production run before Stage 2.	New value analysis session before Stage 1.	Establishment of manufactur--ability targets at Stage 2.
Motivation for change:	Need for data, experience, and early opportunity to higlight manufactur--ability issues.	To evaluate product layout and definition, and to secure agreement of all functions on design stability after Stage 1.	Need for targets against which to assess the product at Stage 3.
Basis for change:	Experience on an earlier project	Experience on an earliur project	Experience on earlier projects
Changed transfer qualifications at Stages:	No	Final assembly feasibility criteria.	Definition of prototype, eng. sample, and pre--production unit
Motivation for change:	Not applicable	Need for reduced cost, quality, safety, rework, & installation problems.	Need for agreed, measurable goals for manufactur--ability
Basis for change:	Not applicable	Experience on an earlier project (pre-Staging) with designs from Corp. R&D	Differences in opinion within Division and with Corporate R&D.

Manufacturability Assessment

Guidelines: Management of new product manufacturability during development also evolved independently of Staging, and to differing degrees among the divisions. Common to all divisions were checklists of manufacturability guidelines developed by ME for product designers. These guidelines were based upon corporate procedures, but reflected individual divisional differences. The guidelines were most detailed in the area of PCP assembly, and less so in mechanical assembly. For divisions which manufactured industrial equipment products other than terminals, the guidelines for terminals were less stringent than those for the industrial equipment, reflecting the less onerous customer demands for terminal operating life. However, in other respects, terminals were more difficult products to manufacture: they were designed with aesthetic considerations, resulting in uneven shapes, and, sometimes, severe challenges in space utilization.

In all divisions the manufacturability guidelines were applied to products formally in manufacturability assessments. Each division had its own particular form of assessment, of which the system of demerit points developed by ME in Division D was the most sophisticated. This system was characterized by a cut-off point above which the product failed the manufacturability assessment. This cut-off point had been lowered each year since establishment.

The Assessment Process: Each of the four divisions formalized the responsibility for manufacturability assessment and allocated specific members of the ME group to carry out the assessments. However, both Division C and Division D went further in formalising the manufacturability assessment process. These two divisions differed from the others in their dependence on external groups for their product designs. In each case, they developed process flow charts which detailed tasks, flows, information sources, and functional responsibilities for achievement of manufacturability. The objective in each case was, through clarification of the responsibilities of each functional group, to bring the content, timing, and duration of the manufacturability assessment process under the control of ME. Further, the external design group and the ME group in Division D did not just interact earlier and place greater emphasis on manufacturability, they also exchanged design files electronically, and agreed a forty-eight hour turnaround for assessment and comment on these files.

Training: Division D went furthest in its approach to management for manufacturability. Realising that earlier and more intensive interaction between design and ME staff, mandated by their particular approach to manufacturablity assessment, placed strains upon the skills of each group, they initiated training programs to upgrade these skills. The ME group drew up a budget to develop their circuit design skills, while members of the design group were required to visit and acquaint themselves with the operating processes in the Division D manufacturing plant.

Validity of Assessment: The acceptability of design information to ME, or of a manufacturability assessment to manufacturing depended upon the trust which ME, design or manufacturing had for each other. Part of that trust related to the extensiveness of the pre-transfer checks carried out on development models. The quality of these checks depended in part upon the sample size of the various development models. Sample size was a particular concern in Division A, the division with the largest production volumes and the least tolerance of product changes during volume production. The Manufacturing Director felt that the sample sizes used in the pilot runs during the development process were not large enough to identify the ranges of the variables which might influence product performance. These variables included supplier batches, process setups and test methods. The ME Manager saw that estimation of the number of samples required judgement.

However important, the sample size of the development models is only part of the issue of acceptability of information. The results of pilot runs also depended upon the control exerted over the manufacturing and assembly processes utilized in the production of development models. Such control came from developing and checking specifications of key process parameters for parts manufacture such as solder, flux, freon and equipment set up, as developed by Division A in 1986.

Further, assessment of a sample required that the sample was made with the specified materials, by the specified process, and tested with proven test equipment and methods against an explicit statement of design intent. In sum, the validity of the assessment of a given development model depended on the availability of complementary technologies. These technologies depended upon one another and interacted with one another. Yet, often, they did not all come together at the same time in order to give validity to the test.

For example, all products investigated were new products, but an assessment of newness yielded distinctions among the products - some were newer than others, and newer products were less manufacturable than less new products. However, even for the less new products, there were product features which distinguished them from earlier members of their product families. These features included displays, processing capabilities, and components with low electro-static discharge features. For these products, based on otherwise stable product elements derived from earlier members of the product family, these newer elements consistently gave problems during development which continued into the volume production phase. These problems resulted in the need to make product design changes, source alternative materials, or implement new assembly methods.

In effect, many products did not represent syntheses of established component technologies. Rather, the component technolgies themselves were evolving just as the products were, and the new product development projects were characterized by the development of a revised version of the product in parallel with the original version. The original was then introduced into volume production, before being superceded by the revised version. In some cases, this type of development was outside the control of the product development team and linked more to the use of component technology which was at an early stage of its development. In the event, the components selected, although transparent to the ultimate users, were, soon after the start of volume production, neither the most cost nor technologically effective means to satisfy the design intent.

Each division also provided evidence of three types of obstacle to the timely availability of process technologies for assessment of manufacturability while products were under development:

process development independent of product development;
process implementation dependent upon product development;
product design 'proofing manually.

First, some process change was implemented simultaneously for a number of products. Among these products were some older vintage products, which had been in volume production for over a year. As such, process automation was being implemented not so much for any particular product, but for the family of related products.

Second, development of planned automation of stages of the manufacturing process also took place in parallel with the product development activities. However, implementation of the process automation was delayed until after the start of volume production: the division had limited engineering resources to assign to simultaneous product and process development, such that startup of the process was delayed.

Third, even where an automated process was available coincident with the start of volume production, divisions assembled the early volume units manually in order to, in their terms, 'proof' the design. Behind this manual build was a desire to meet the initial product volume requirements while managing the risk of process-based difficulties.

MANUFACTURABILITY AND DEPLOYMENT OF ME STAFF

With an understanding of the evolution of the corporate and divisional approaches to management for manufacturability, I then examined how the manufacturability of products was associated, if at all, with the deployment of ME resources during the new product development process. I investigated two dimensions of manufacturability: ease of manufacture (EOM) and the severity of manufacturability-related problems (ACTPROB).

I measured the ease of manufacture of a product and the severity of manufacturability-related problems in terms of each manufacturing engineer's rating of these dimensions of manufacturability. I then examined the nature of the associations between manufacturability and each of the deployment decisions available to the ME manager, both with and without control for the development context. Kendall tau-B rank correlation coefficients, and corresponding significance levels based upon a one-tailed test were calculated.

Manufacturability and Emphasis on Manufacturability

This section of the chapter is in two parts. In the first part I report on the associations observed between manufacturability and the level of emphasis by ME on manufacturability. In the second part I report on the associations observed between manufacturability and the phasing of emphasis by ME on manufacturability.

Manufacturability and Level of Emphasis on Manufacturability

The two dimensions of manufacturability which were investigated, ease of manufacture (EOM) and the severity of manufacturability-related problems (ACTPROB), differed in their relationships with the level of emphasis placed by ME on manufacturability during the development process (EOMEMPH). The general expectation was the greater the emphasis, the better the manufacturability. More formally:

> H24a: the greater the level of emphasis by ME on manufacturability during the new product development process, the greater will be the ease of manufacture of the product at the start of routine volume production.
>
> H24b: the greater the level of emphasis by ME on manufacturability during the new product development process, the lower will be the severity of manufacturability-related problems at the start of routine volume production.

Without controlling for the development context, there was no evidence of association between EOMEMPH and EOM. In contrast, for ACTPROB, the greater the emphasis on manufacturability, the less severe the manufacturability-related problems. However, the relationship between emphasis and manufacturability was contingent upon the development context. These results are summarized in Tables 7.2 and 7.3.

Table 7.2
Association between Ease of Manufacture (EOM)
and Level of Emphasis on Manufacturability (EOMEMPH)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	+.0158	.472	As hypothesized	12
Newer products	+.6429	.040	As hypothesized	6
Less new products	-.0667	.425	Not as hypothesized	6
Less internal manufacture	-.2224	.225	Not as hypothesized	8
More internal manufacture	+.9129	.035	As hypothesized	4
Staging	+.0501	.439	As hypothesized	7
Pre-Staging	-.5270	.103	Not as hypothesized	5
Short interval	+.2760	.222	As hypothesized	6
Long interval	-.1380	.351	Not as hypothesized	6

Table 7.3
Association between
Severity of Manufacturability-related problems (ACTPROB)
and Level of Emphasis on Manufacturability (EOMEMPH)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	-.2500	.134	As hypothesized	12
Newer products	-.9286	.066	As hypothesized	6
Less new products	+.4140	.126	Not as hypothesized	6
Less internal manufacture	+.0714	.402	Not as hypothesized	8
More internal manufacture	-.9129	.035	As hypothesized	4
Staging	-.5507	.045	As hypothesized	7
Pre-Staging	+.1054	.400	Not as hypothesized	5
Short interval	-.3571	.165	As hypothesized	6
Long interval	-.0667	.425	As hypothesized	6

First, manufacturability was amenable to improvement through emphasis by ME during the development process, only in the case of newer products: the manufacturability of newer products was better for greater emphasis on manufacturability. However, for less-new products, there was, on the one hand, no relation between emphasis and ease of manufacture, and, on the other hand, greater severity of problems for greater emphasis. Two competing explanations are offered for this finding: the first is that ME emphasis on manufacturability interfered with the manufacturability built into less-new products from earlier experience, and resulted in severe manufacturability-related problems. Alternatively, less-new products tended to incorporate new features and individual components and sub-assemblies which resulted in particularly severe problems requiring greater emphasis by ME on achieving their manufacturability.

In the first explanation, manufacturability was a product characteristic which existed in degree and was built into the relationship of the component parts and subassemblies to each other, and to their respective manufacturing processes. For newer products, these relationships were still in formation and, so, amenable to the emphases by ME. For less new products, these relationships among parts, components and manufacturing processes were largely fixed, through use of pre-existing parts, components and processes. Emphasis by ME on manufacturability could have resulted in unnecessary change which upset established relationships between product and process concepts. As such, for less new products, manufacturability may not have been so much amenable to change by ME, as it was vulnerable to interference by ME.

Alternatively, building new components into a product always required ME emphasis on manufacturability. For less-new products, some components were entirely new and, so, had difficulty being absorbed into the already largely fixed product and process designs. The resulting problems required ME to become involved and address the manufacturability problems which had arisen. This second explanation is largely consistent with the nature of the problems observed and the areas where they occurred, such as in products C3 and D2.

Second, manufacturing engineering was largely internal in its focus on new product development: if a component part or subassembly was to be manufactured in their plant, the ME staff assessed its manufacturability. Correspondingly, the manufacturability of products characterized by internal manufacture of components and subassemblies was greater for greater emphasis on manufacturability.

In contrast, if a part or subassembly was sourced externally from a supplier, the ME staff did not assess its manufacturability. This is not to say that manufacturability was not of concern when parts or subassemblies were sourced externally. On the contrary, vendor engineering functions operated more or less formally in the divisions in a liaison role similar to that of ME between design and manufacturing. Correspondingly, for products characterized by external manufacture of components and subassemblies, manufacturability was not associated with ME emphasis on manufacturability. While, vendor engineering efforts and emphases may have been associated with improved manufacturability of sourced parts and subassemblies, they may also the reduced need for emphasis by ME on those sourced items. However, these vendor engineering functions were not the subject of detailed research.

Third, the manufacturability of products managed through the Stage Procedure was not conclusively higher or lower than that of products not managed through Staging. This result is not necessarily an indication of ineffectiveness of Staging, relative to its objective of improving manufacturability. Rather, the result may have been confounded by the selection of products. Staging was introduced in 1985, and of the seven products on which it was used, four were classified as newer and three as less new relative to the median value of product newness (PRDNEW). Correspondingly, for the products not managed through Staging, two were newer and three were less-new. As such, the groups; of Staged and non-Staged products comprised of mixed groups of new and less-new products between which no clearcut relationships would be expected given the earlier observations on newness as a moderator. In addition, divisional responses to Staging altered the timing and number of manufacturability assessments over the period of interest. These changes were summarized in Table 7.1, earlier. As such, the context, as defined by the Stage procedure was not fixed, which may have led also to the inconclusive results.

Finally, in order for these products to achieve their tighter production dates, manufacturability was traded-off, and the product subsequently subjected to cost reduction. However, the level of manufacturability to be achieved was still within the control of the ME group: for products developed in shorter intervals, manufacturability was greater for greater emphasis by ME on manufacturability. While ME may have been challenged to integrate the product and process requirements in the short time allowed, greater emphasis on manufacturability paid off in terms of product performance.

Manufacturability and Phasing of Emphasis on Manufacturability

The previous section considered the relationship between amount of emphasis on manufacturability and the manufacturability of the product. This section looks at the relationship between the phasing of that emphasis, categorized as earlier or later in the development process, and manufacturability. The general expectation was that the earlier the emphasis, the better the manufacturability. More formally:

> H25a: the earlier the phasing of emphasis by ME on manufacturability during the new product development process, the greater will be the ease of manufacture of the product at the start of routine volume production.
>
> H25b: the earlier the phasing of emphasis by ME on manufacturability during the new product development process, the lower will be the severity of manufacturability-related problems at the start of routine volume production.

This expectation was borne out in part: without controlling for development context, the severity of problems was less for earlier phasing of emphasis. However, without controlling for the context, there was little evidence to support this expectation regarding ease of manufacture and phasing of emphasis. These results are summarized in Tables 7.4 and 7.5.

As with the emphasis on manufacturability, the relationship between manufacturability and phasing of emphasis was contigent upon the newness of the product, the process position, the approach to design-ME coordination and the length of the development interval. First, the manufacturablity of newer products was higher for earlier emphasis on manufacturability. However, for less-new products, there was little evidence to-suggest that manufacturability was related to phasing of emphasis. The implication of this finding is that manufacturability was amenable to improvement through earlier emphasis by ME, only in the case of newer products. As a new product evolved from concept to verifiable design, the time to consider manufacturability was not in the final stage, when the only option open to ME was verification of the manufacturability built into the design. Such late phasing of emphasis was equivalent to the situation described by the much-used phrase 'throwing the design over the wall', and was associated with lower manufacturability.

Table 7.4
Association between Ease of Manufacture (EOM)
and Phasing of Emphasis on Manufacturability (EOMPHAS)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	-.1103	.313	As hypothesized	12
Newer products	-.5000	.087	As hypothesized	6
Less new products	-.0667	.425	As hypothesized	6
Less internal manufacture	-.0741	.401	As hypothesized	8
More internal manufacture	-.6667	.087	As hypothesized	4
Staging	-.3078	.176	As hypothesized	7
Pre-Staging	+.6000	.071	Not as hypothesized	5
Short interval	-.3333	.174	As hypothesized	6
Long interval	+.1380	.351	Not as hypothesized	6

Table 7.5
Association between
Severity of Manufacturability-related problems (ACTPROB) and Phasing of Emphasis on Manufacturability (EOMPHAS)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	+.2813	.106	As hypothesized	12
Newer products	+.5000	.087	As hypothesized	6
Less new products	0.0000	.500	Not as hypothesized	6
Less internal manufacture	+.2143	.229	As hypothesized	8
More internal manufacture	+1.000	.021	As hypothesized	4
Staging	+.4104	.107	As hypothesized	7
Pre-Staging	0.0000	.500	Not as hypothesized	5
Short interval	+.5521	.063	As hypothesized	6
Long interval	+.0667	.425	As hypothesized	6

Second, the manufacturability of products characterized by internal manufacture of components and subassemblies was greater for earlier emphasis. This result is consistent with the earlier finding on level of emphasis. Further, internal products were characterized by earlier emphasis, while external products were characterized by later emphasis. As such, ME did not become involved in assessment of manufacturability of sourced parts and subassemblies, in some cases, until the building of prototype units on the volume manufacturing processes. At that stage, while problems did occur, they were outside the control of ME.

Third, the Stage Procedure was more disciplined in its approach to the coordination of design and ME, and in the requirement for specific manufacturability-related deliverables early in the process. The procedures in place pre-Staging were not as formalized in their requirements for these deliverables. However, where Staging was used in the coordination of ME and design, the ease of manufacture was higher and the severity of problems was lower for products receiving earlier emphasis. For non-Staged products, there was no relation between problem severity and phasing of emphasis, although ease of manufacture declined with earlier emphasis.

Finally, for products developed in shorter intervals, manufacturability was greater for earlier emphasis by ME on manufacturability. This finding is consistent with that reported earlier in relation to the level of emphasis on manufacturability. Taken together, although the level of manufacturability achieved for products developed in shorter intervals was lower, manufacturability was still somewhat within the control of the ME group.

The findings on ME emphasis on manufacturability, both level and phasing, add depth to the contingent nature of the emerging relationship between product performance and ME deployment. Product performance has many dimensions, and differing factors are associated with different dimensions of 'good' performance. In Chapter Six, I reported a consistent relationship between the length of the development interval and ME deployment for internal products. A similar consistency now emerges in the relationship between the manufacturability and ME deployment. This consistency underscores the importance of ME in relation to both length of development interval and manufacturability for internal products.

A very different picture is emerging in relation to newer and less-new products. For less-new products, greater and earlier deployment was associated with shorter development intervals, while for newer products, the same deployment strategy was associated, not with the length of the development interval, but with manufacturability. These findings suggest that while, in general, it appears that earlier and greater deployment of ME was associated with improved performance, the performance measure which was improved was contingent upon the context.

MANUFACTURABILITY AND LEVEL OF ME DEPLOYMENT

This section of the chapter is in two parts. In the first part I report on the relationships observed between manufacturability and the level of ME deployment in the definition stage of the new product development process. In the second part I report on the relationships observed between manufacturability and the level of ME deployment in the verification stage.

Manufacturability and Level of ME Deployment in the Definition Stage

As noted earlier, nearly two thirds of all activities carried out by ME commenced during the definition stage of the development process. This earliest stage, definition, required the 'delivery' of the following items by ME as complete at the end of the definition stage.

Manufacturing/test plan;
value analysis resultz;
yield targets;
subsystem cost targets;
capital equipment and capacity requirements.

Achievement of these deliverables required the start and execution of the following activities during this stage of the development process, summarized in Table 7.6.

Table 7.6
Activity Content of the Definition Stage of the New Product Development Process

Activity Category	Activity Category
PRODUCTION PLANNING/ PROCESS ENGINEERING	Manufacturability assessment Operations sequencing Machine selection Manufacturing spec. preparation Machine and tool spec. Machine and tool cost estimating
TOOL DESIGN	Checking/proving/of vendors machine/tool design work Tool requirements analysis
EQUIPMENT ENGINEERING	Process Equipment specification /selection Equipment cost estimating Process specification preparation
PLANT LAYOUT	Production flow analysis/ determination
MATERIALS HANDLING	Analysis of product design, process layout, materials, packaging and supply requirements
WORK STANDARDS/METHODS	Establish direct labour budget standards Prepare direct labour estimates for price studies
PRODUCTION ANALYSIS	Prepare/review project control records Obtain/distribute advance information on new parts/programs Analyse/coordinate product change requests Develop data for make-or-buy determination Prepare cost analyses
REPRODUCION & RECORDS	Maintain up to date tool drawings, releases, and planning records
MANUFACTURING STANDARDS	Development of local standards Development of proposals for company standards Standards publishing & distribution

The scope of these activities was far wider than manufacturability assessment, but their impact on manufacturability was collectively significant. More formally:

> H26a: the greater the level of ME deployment in the definition stage of the new product development process, the greater will be the ease of manufacture of the product at the start of routine volume production.
>
> H26b: the greater the level of ME deployment in the definition stage of the new product development process, the lower will be the severity of manufacturability-related problems at the start of routine volume production.

Except in the cases of products coordinated through the set of procedures which pre-dated Staging, and products characterized by longer development intervals, the greater the proportion of manhours expended in the definition stage of the product development process, the better was the manufacturability of the products. This relationship, while consistent with those between each of emphasis and phasing of emphasis on manufacturability, and manufacturability, is more general and less context-specific. These results are summarized in Tables 7.7 and 7.8.

This greater generality may be understood in terms of a wider range of activities, than simply emphasis on manufacturablity, incorporated in ME deployment, as measured by manhour expenditures. Another explanation of the less context-specific relationship between ME deployment and manufacturability, is the type of data on which it is based. Measurement of emphasis or phasing of emphasis on manufacturability was based upon reflective and subjective assessments by key individual members of the manufacturing engineering staff. Measurement of ME manhours expended in the definition stage was based upon audited records of manhour charges, a more objective source of data. While the key individual assessments were more subjective, they reflected, non-the-less, the experience of key ME staff who participated actively in the new product development process.

Table 7.7
Association between Ease of Manufacture (EOM)
and Level of ME Deployment in the definition stage (HRSINS1)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	+.3429	.103	As hypothesized	9
Newer products	+.6667	.087	As hypothesized	4
Less new products	+.4000	.164	As hypothesized	5
Less internal manufacture	+.3162	.224	As hypothesized	5
More internal manufacture	+.6667	.087	As hypothesized	4
Staging	+.7379	.038	As hypothesized	5
Pre-Staging	-.3333	.248	Not as hypothesized	4
Short interval	+.4667	.094	As hypothesized	6
Long interval	-.8165	.110	Not as hypothesized	3

Table 7.8
Association between
Severity of Manufacturability-related Problems (ACTPROB) and Level of ME Deployment in the definition stage (HRSINS1)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	-.7650	.003	As hypothesized	9
Newer products	-.9129	.035	As hypothesized	4
Less new products	-.7379	.038	As hypothesized	5
Less internal manufacture	-.7379	.038	As hypothesized	5
More internal manufacture	-1.000	.021	As hypothesized	4
Staging	-.8250	.030	As hypothesized	5
Pre-Staging	-.6667	.087	As hypothesized	4
Short interval	-.6901	.028	As hypothesized	6
Long interval	-.8165	.110	As hypothesized	3

In sum, achievement of manufacturable products required, in addition to simple emphasis on manufacturability, the execution of a range of complementary activities, on which ME manhours were deployed in the definition stage of the development process.

Manufacturability & Level of ME Deployment in the Verification Stage

ME manhours were expended in all three stages of the new product development process. In the verification stage, the general expectation was that the higher the proportion of manhours expended the lower would be the manufacturability of the product. More formally:

> H27a: the greater the level of ME deployment in the verification stage of the new product development process, the lower will be the ease of manufacture of the product at the start of routine volume production.
>
> H27b: the greater the level of ME deployment in the verification stage of the new product development process, the greater will be the severity of manufacturability-related problems at the start of routine volume production.

This expectation was based upon the assumption that ME resources not deployed during the earlier definition stage of the new product development process, would be deployed in the verification stage. Correspondingly, reduced involvement of ME in the earlier stages of the development process would lead to a greater likelihood of ME receiving aless manufacturable design design from 'over the wall'.

This expectation was borne out in general. However, for new and less new products, the relationships were less clear. For newer products, there was no evidence of association between ease of manufacture and the level of ME manhours expended in the verification stage. However, the severity of problems was less for higher levels of ME deployment in the verification stage. For less new products, the relationships were generally as expected. These results are summarized in Tables 7.9 and 7.10.

Table 7.9
Association between Ease of Manufacture (EOM) and Level of ME Deployment in the Verification Stage (HRSINS3)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	-.2286	.200	As hypothesized	9
Newer products	0.0000	.500	Not as hypothesized	4
Less new products	-.4000	.164	As hypothesized	5
Less internal manufacture	-.3162	.224	As hypothesized	5
More internal manufacture	-.6667	.087	As hypothesized	4
Staging	-.7379	.038	As hypothesized	5
Pre-Staging	+.6667	.087	Not as hypothesized	4
Short interval	-.3333	.174	As hypothesized	6
Long interval	+.8165	.110	Not as hypothesized	3

Table 7.10
Association between
Severity of Manufacturability-related Problems (ACTPROB) and Level of ME Deployment in the verification stage (HRSINS3)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	+.4119	.068	As hypothesized	9
Newer products	-.5477	.139	Not as hypothesized	4
Less new products	+.7379	.038	As hypothesized	5
Less internal manufacture	+.7379	.038	As hypothesized	5
More internal manufacture	+.3333	.248	As hypothesized	4
Staging	+.8250	.030	As hypothesized	5
Pre-Staging	+.3333	.248	As hypothesized	4
Short interval	+.2760	.222	As hypothesized	6
Long interval	+.8165	.110	As hypothesized	3

Again, it seems that both new and less-new products presented very differing management challenges to the ME function. While the performance of each category of product required early expenditure of manhours by ME, the same was not true for the timing of the fall-off in ME manhour expenditure. During the verification stage, activities were carried out in order to complete the following 'deliverables':

Manufacturing yield update;
product costs update;
manufacturability update.

Achievement of these deliverables required the start and execution of the following activities during this stage of the development process, summarized in Table 7.11.

Many of these activities were not required for less-new products, while most of them were required for newer products. As such, the level of activity in the verification stage was higher for newer products than for less-new products. However, where the level of activity was reduced for newer products, the severity of problems increased, as, for example, in the development of product B1. In this case, the development was characterized by competing simultaneous demands on ME resources, and by the installation of a new flexible manufacturing system, which compromised the ability of the ME manager to maintain ME resources on the B1 project. What is suggesed here is that the severity of the problems was associated with the lower level of expenditure of ME manhours during the final stage of the new product development process.

Table 7.11
ME Activity Content of the Verification Stage of the New Product Development Process

Activity Category	Activity Category
PRODUCTION PLANNING/ PROCESS ENGINEERING	Assistance in Production difficulties
TOOL DESIGN	Design of special machines/ equipment/tools Checking/proving/of vendors machine/tool design work
TOOL ROOM	Die, fixture, gage construction Tooling modification
EQUIPMENT ENGINEERING	Process Equipment specification /selection Process specification preparation Equipment coordination for shop trials
PLANT LAYOUT	Location of machines, equipment, storage facilities, aisles, shipping/receiving
MATERIALS HANDLING	Analysis of product design, process layout, materials, packaging & supply requirements
WORK STANDARDS/METHODS	Establish direct labour budget standards Standards verification Determination of bases for authorization of direct labour
PRODUCTION ANALYSIS	Prepare/review project control records Obtain/distribute advance information on new parts/programs Analyse/coordinate product change requests
REPRODUCION & RECORDS	Maintain up to date tool drawings, releases, and planning records
MANUFACTURING STANDARDS	Development of local standards Publishing and distribution of standards

Manufacturability and ME Staff Experience

ME staff experience was measured as the level of experience on related and similar new product development projects, working with multi-disciplinary colleagues, technical expertise, and academic qualification. The general expectation, that manufacturability would be greater for greater ME staff experience, was borne out. More formally:

> H28a: the greater the level of ME staff experience, the greater will be the ease of manufacture of the product at the start of routine volume production.
>
> H28b: the greater the level of ME staff experience of the new product development process, the lower will be the severity of manufacturability-related problems at the start of routine volume production.

These basic relationships were maintained for newer products, for Staged products, and for products developed over longer intervals. These results are summarized in Tables 7.12 and 7.13.

For both newer and Staged products, each of the contexts was characterized by newness, both technological and organizational, in which greater experience was an asset. Staging as an approach to the management of new product development projects had been recently introduced and was still evolving at the time the products studied were introduced, as summarized earlier in Table 7.1. Further, in parallel with the divisional responses to Staging, the divisions were developing guidelines, formalising assessment processes, tightening up process standards, and cross-training their design and ME groups. As such, greater experience in relation to working with multi-disciplinary colleagues would have assisted in the implementation of these new organizational approaches to achieving manufacturability. The implication of this finding is that a change in organizational approach to manufacturability should be accompanied by deployment of ME staff with experience, not just technological, but also in relation to interaction and integration of ME activities with other functional groups.

Table 7.12
Association between Ease of Manufacture (EOM) and Level of ME Staff Experience (MESTFEXP)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	+.2290	.171	As hypothesized	12
Newer products	+.2925	.214	As hypothesized	6
Less new products	-.2335	.269	Not as hypothesized	6
Less internal manufacture	+.1427	.330	As hypothesized	8
More internal manufacture	+.3333	.248	As hypothesized	4
Staging	+.4326	.102	As hypothesized	7
Pre-Staging	+.3586	.203	As hypothesized	5
Short interval	0.0000	.500	Not as hyothesized	6
Long interval	+.6614	.050	As hypothesized	6

Table 7.13
Association between
Severity of Manufacturability-related Problems (ACTPROB)
and Level of ME Staff Experience (MESTFEXP)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	-.1922	.212	As hypothesized	12
Newer products	-.2965	.214	As hypothesized	6
Less new products	+.0806	.417	Not as hypothesized	6
Less internal manufacture	-.2292	.234	As hypothesized	8
More internal manufacture	0.0000	.500	Not as hypothesized	4
Staging	-.8111	.009	As hypothesized	7
Pre-Staging	+.3586	.203	Not as hypothesized	5
Short interval	+.1429	.349	Not as hypothesized	6
Long interval	-.3651	.177	As hypothesized	6

The manufacturability of newer products was associated with greater ME staff experience, while for less-new products, the relationship was weak to non-existent. It seems that less-new product development projects were less demanding of ME; the experience of ME in product development was really used in the development of newer products. There was a practice in all divisions of appointing ME staff of lower organizational seniority and experience to positions in the product development teams for less-new products, otherwise held by more senior staff on newer products.

In Division A, this practice resulted in a mismatch between the level of experience assigned to the development of product A4. The product was the fourth in the A-series of products. The product was not expected to be very different from the earlier members of the series. As such, less senior and less experienced ME staff were assigned to the project. However, the newness of the product was underestimated, and the product was the first to be managed through the Stage Procedure in the Division. The ME staff did not have the technical or organizational strength to address the manufacturability-related problems which arose in a challenging context of new product concepts and a new approach to the coordination of design and ME. These problems subsequently dominated the early years of the volume manufacture of the product. The implication of this finding is that an assessment of product newness should be made early in the development process in order to match the experience level of the ME staff to be deployed to the development task required.

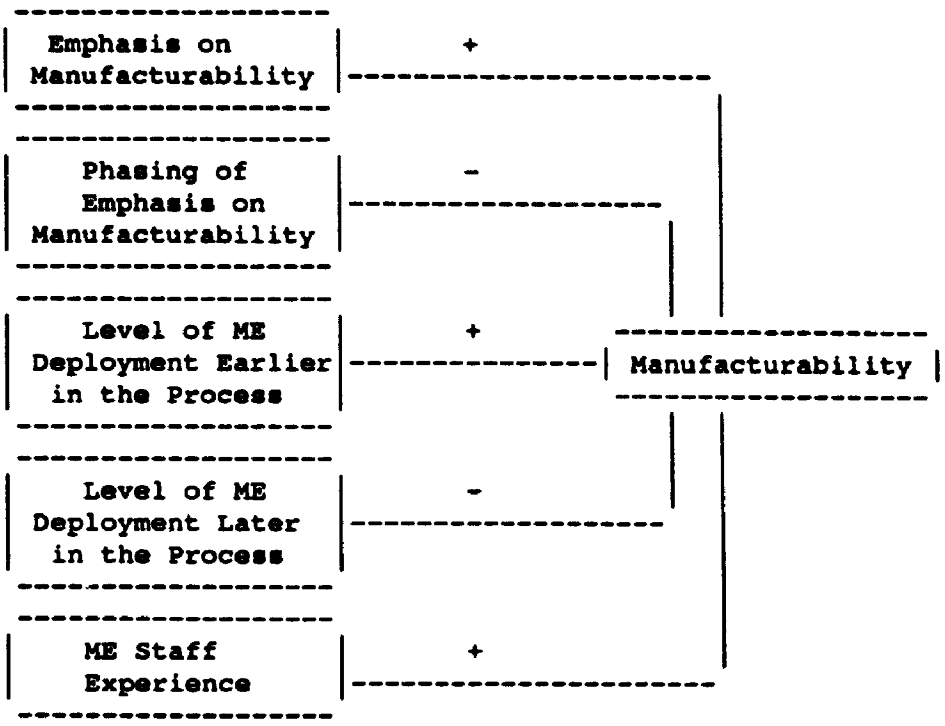
For products developed in shorter intervals, the relationship between ME experience and manufacturability was weak to non-existent. In contrast, for products developed over longer intervals, the relationships were strong: the greater the experience, the greater the manufacturability. It is difficult to conclude that ME experience did not matter in projects developed under tighter time-pressures. Further, it is difficult to reconcile these observations with those reported earlier in relation to ME emphasis on manufacturability, and level of ME deployment. ME had consistently strong associations with manufacturability for short-interval projects: the greater and earlier the deployment, the greater the manufacturability. I explained these relationships in terms of ME deployment making a difference when the development context was challenging. Such an explanation is inconsistent with the findings in this section. I can offer no explanation for this inconsistency.

Summary: ME Deployment for Manufacturability

I investigated two dimensions of manufacturability in relation to ME deployment: ease of manufacture; and, the severity of manufacturability-related problems at the start of routine volume production. The association between manufacturability and the deployment of ME resources was contingent upon the development context. In particular, manufacturability was associated with greater and earlier deployment of ME staff for newer products, and for products using by more internal manufacture of components and subassemblies. Figure 7.1 outlines the associations between manufacturability and ME deployment which have emerged, and which are contingent upon the development context.

Figure 7.1

Association between Manufacturability and Deployment of ME Staff



Notes: positive association denoted by '+'
negative association denoted by '-'

CHAPTER EIGHT: MANUFACTURABILITY-RELATED CHANGE AND ME DEPLOYMENT

Managing engineering change was a major challenge for the company: nominal cost savings were often less than the cost of implementing individual changes, while the sheer number of changes often led to materials management problems. The president had become involved in a critical evaluation of the change process and the whole rationale behind the incidence of engineering change. Correspondingly, the company was changing its approach and attempting to limit the scale and scope of changes permitted after startup.

The company operated a change classification process, which grouped all engineering changes according to specific criteria. This system operated in all divisions, and provided an efficient entry into the research on engineering change management. However, it emerged that the change classification system did not capture all dimensions of the change activity within the divisions. The system focused on changes to product specifications. Consistent with the exploratory nature of the research, discussions with managers on engineering change, as captured on the engineering change notices, helped to identify additional indicators of engineering change.

Unfortunately, unlike the change notices, the data from these other indicators did not lend themselves to a deeper investigation in relation to the deployment of ME resources during the development process. Not all engineering changes recorded in this system were planned during the development process. Further, many of the five deployment decisions open to ME managers were not associated with reduced incidence of engineering change in a manner consistent with the earlier findings on manufacturability and deployment. In fact, only the experience level of the ME staff deployed seemed to matter consistently. Other deployment decisions were at variance with expectations, but consistent with the outcome of a design freeze early in the development process based upon incomplete information. As such, deployment decisions which enhanced manufacturability, as assessed at the start of routine volume production, may have been associated with unexpected engineering changes later in the first year of routine production.

Finally, the incidence of engineering change seemed to run counter to the company objective of design 'right-first-time'. However, on deeper consideration, this objective may have been attainable only in the case of certain types of engineering change, those which were apparent to the customer. For those changes apparent to manufacturing, a more appropriate objective may have been to design 'right-next-time'.

In this chapter, I look at the engineering changes made on the new prooducts in the divisions. The second section will investigate the relationship between manufacturability-related engineering changes and ME deployment. The final section will consider the the desirability of engineering change, and will propose a framework for the management of engineering change, based upon a distinction between change which is apparent to the customer or to manufacturing and change which is not.

CHARACTERISTICS OF ENGINEERING CHANGE

Engineering change may be thought of in terms of four elements: description of the change area; motivation for the change; the interval within which the change occurs; and, the extent to which the change was anticipated during the new product development process.

Change Area: A product development project involves more than design and development of a product specification; process development is also carried out. The extent of the process development may be as narrow as change to existing methods, or as wide as development of new process equipment, tooling and methods. As such, during, or after, a new product development project, engineering change may occur in four basic areas:

product specification;
process equipment;
tooling;
and, methods.

In each area, but most especially in the area of the product specification, engineering change has the potential to change the design intent of the product, that is, how the product is meant to perform for the ultimate user, the customer. However, many engineering changes which change the design intent are transparent to manufacturing. Conversely, many changes do not change the design intent, and, so, are transparent to the customer. Yet, these changes are not transparent to manufacturing, the intermediate user of the product specification.

Motivation for Change: Identification of the change area represents only one dimension of engineering change. Another dimension is the motivation for the change. Divisions in the company issued engineering change notices for authorized changes. They classified these changes generally in accordance with the following standard classification scheme, summarized in Table 8.1:

Table 8.1

Company Standard Classification Scheme for Engineering Change

Class	Definition
1	An inoperative or potentially hazardous condition
1A	An inoperative or potentially hazardous condition in certain applications only
1B	An unsatisfactory condition which may be allowed to exist on a temporary basis
2	An improvement in design, but, in so doing, the design intent is affected
3	To introduce new features or to change the product rating
4A	Changes which do not affect design intent such as component substitutions, artwork recycles or cost reductions
4B	Changes which do not affect design intent that must be applied as soon as possible
4C	Changes which do not affect design intent but improve marginal design conditions

Division B, added another dimension to this classification scheme by identifying motivation for each change, as summarized in Table 8.2.

Table 8.2
Motivation for Change

Class	Description
CR	Cost Reduction
DC	Design Correction
DI	Design Improvement
DO	Documentation Change
NF	New Feature

Although not as formalized as Division B, Division A also identified two further categories of motivation: yield improvement (YI), and materials substitution (MS).

Change Interval: A third dimension of engineering change is the time during which the change occurs, the change interval. In each of the divisions, change occurred during both the development and the routine production of a new product. For change which occurred during development, the change interval was bounded by the project schedule. For change which occurred during routine production, cutoff points or milestones were established in order to establish intervals within which change trends were investigated. Cumulative production volume is one means of defining these milestones. However, all divisions used time as a proxy for cumulative volume, and Division D assumed design stability if a product was in production for six months without an engineering change notice being issued.

Change Anticipation: A final dimension of engineering change is whether or not change during volume production was anticipated or planned before the start of volume production. As such, a change may be anticipated as part of an ongoing process improvement program, such as the introduction of JIT. Alternatively, process automation may be in progress in parallel with the product development, but not necessarily driven by it. Further, a cost improvement project may be authorized during the the verification stage of the development process, because of the distance from cost targets. Finally, a change may be required because the volume to be produced raised issues of methods, materials quality or design centreing which did not arise during the development phase. There was no evidence to suggest that the changes reported on change notices were planned.

Change Indicators

Class 4 engineering change notices captured manufacturability-related engineering changes, primarily in the area of the product specification. These changes were motivated by requirements for cost reduction, material substitution, design correction, design improvement and documentation change. However, class 4 changes did not capture the full range of change activity ongoing after the start of routine volume production. For example, extensive process automation introduced in Division A for cost reduction purposes, after the start of volume production of product A1, did not register in any change notices.

The automation was carried out as a series of Cost Reduction projects. Cost Reduction project data were available in Divisions A and C.

Finally, in all divisions, interviews with key individuals included discussion on change to product specifications, process equipment, tooling and methods. Some of the changes discussed did not appear in change notices or in cost reduction data. As such, a combination of these three sources provided a more complete picture of the engineering change in each product after the start of volume production, than obtained from class 4 change notices. The change indicators are summarized in Table 8.3.

Table 8.3
Sources of Engineering Change Data

	Change Area			
Data Source	Product Specification	Process Equipment	Tooling	Method
Change notices	x			
Cost reduction project	x	x	x	x
Interview	x	x	x	x

Analysis of change data from each of these sources indicated a wider range of manufacturability-related change in each of the new product development projects than suggested by the change notices alone. Eleven of the 12 new products studied underwent change after the start of routine volume production, that is, after the verification stage. Classification of product B3 at Division B was not possible due to the absence of data. volume production only commenced during the month preceding data gathering. These changes were both planned and unplanned and occurred in four basic areas within one year of the start of volume production. The numbers of products for which unplanned changes were identified are summarized in Table 8.4.

Table 8.4
Products for which Unplanned Manufacturability-related Engineering Changes were made during the First Year of Volume Production

			Motivation for Change					
Unplanned Change Area	No. of Products Changed	CR	MS	DC	DI	DO	NF	YI
Product specification	11	6	8	7	8	2		
Process equipment	2	2						2
Tooling	1	1						
Methods	7	3		2				3

where:

Class	Description
CR	Cost Reduction
DC	Design Correction
DI	Design Improvement
DO	Documentation Change
NF	New Feature
YI	Yield Improvement
MS	Material Substitution

All products underwent unplanned change within the first year after the start of volume production. Unplanned engineering change occurred in many areas, but most commonly in the area of materials substitution, where for cost or supply security reasons, new materials were substituted for those originally utilized. Unplanned methods change occurred for seven products, for three of which methods were changed for cost reduction or yield improvement. Methods change was largely unplanned before the verification stage, although 'product support', provided by ME, was a planned activity which included handling unplanned demands for methods change. As such, while the specific methods changes were unplanned, and ME was reactive in making these changes, the provision of resources for shop support and cost improvement was proactive in anticipation of the need for change.

The numbers of products for which planned changes were identified are summarized in Table 8.5.

Table 8.5
Products for which Planned Manufacturability-related Engineering Changes were made during the First Year of Volume Production

Planned Change Area	No. of Products Changed	CR	Motivation for Change MS	DC	DI	DO	NF	YI
Product specification	2	1	1					
Process equipment	6	6						
Tooling								
Methods	2	1						2

Planned change occurred in at least six products, mainly in the area of ongoing process automation for cost reduction. Process automation was carried out as a series of cost reduction projects. This automation was planned during the product development process, and typically, development had commenced before the start of volume production. However, implementation and startup of the automation was consciously deferred until the manufacture of the product stabilized on the existing line, or on a largely manual line. This deferral was viewed in either one of two ways: good planning, or a response to bad planning.

Simultaneous development of a product and its associated processes was fundamental to the development of manufacturable new products. However, startup of the two developments simultaneously were assessed to have a higher level of risk than the division was willing to bear. The possibility of 'line-stopping' startup problems was felt to increase with the newness of the product and process technologies. Accordingly, it may indeed have been judicious to defer the startup of the new process, where possible, and to get the product 'out the door', albeit at a higher initial cost.

Alternatively, a staggered startup of a new product and its associated new process was also the result of a resource shortfall within the ME organization. Through an inadequate staffing policy, the resources available were mismatched with the scope and scale of the development activities. As a result, the product was designed for both manual and automated assembly, and the initial costs were higher than they would otherwise have been.

It is difficult to be critical of either approach. Each required a judgement by the ME manager during the development process. However, as competitors manage to introduce new products and processes simultaneously, the viability of the outcomes observed may decline.

MANUFACTURABILITY-RELATED CHANGE AND DEPLOYMENT OF ME STAFF

Engineering Change Notices:

Among the other indicators of engineering change, only engineering change notices lent themselves to a deeper examination in relation to the deployment of manufacturing engineering resources during the development process.

Eleven of the 12 new products studied underwent manufacturability-related change during the first year of routine volume production, that is, after the verification stage, based on data available for class 4 change notices. Classification of product B3 in Division B was not possible due to the absence of data: volume production only commenced during the month preceding the field work for this research study. The numbers of products for which changes were recorded are summarized in Table 8.6, in terms of the dimensions of engineering change discussed earlier.

Class 4 change notices were issued for all products during the first year after the start of volume production. Such manufacturability-related change was concentrated in the area of product specification, and motivated by materials substitution, cost reduction, design correction, and design improvement. For at least five of these products (products A1 - A4, and C1), such unplanned change continued after the first year, but this change was not included in the analysis, as it was beyond the planning horizon of their respective development projects.

Table 8.6
Products for which Class 4 Engineering Change Notices were issued during the First Year of Volume Production

Change Area	No. of Products Changed	CR	MS	DC	DI	DO	NF	YI
			Motivation for Change					
Product specification	11	6	7		3	2		
Process equipment								
Tooling								
Methods		1						

where:

Class	Description
CR	Cost Reduction
DC	Design Correction
DI	Design Improvement
DO	Documentation Change
NF	New Feature
YI	Yield Improvement
MS	Material Substitution

Such incidence of engineering change after the start of routine volume production was not without cost to the company. Data were available in Divisions A and C on the cost of change for 1988. In each case, these data related to aggregate costs of change for all engineering changes which occurred during the year, regardless of engineering change class. These costs were not identified by product. They are summarized in Table 8.7.

Table 8.7
Cost of Engineering Change in Divisions A and C
during 1988

	Division A			Division C		
Month	No. of Changes	Total Cost	Average Cost per Change	No. of Changes	Total Cost	Average Cost per Change
January	11	$ 64k	$ 5818	58	$236k	$4069
February	12	$104k	$ 8667	69	$276k	$4000
March	4	$ 71k	$17750	41	$144k	$3512
April	14	$ 88k	$ 6286	29	$264k	$9103
May	4	$ 76k	$19000	35	$200k	$5714
June	12	$ 82k	$ 6833	92	$296k	$3217
July	7	$ 71k	$10143	35	$172k	$4914
August				43	$ 72k	$1674
September				89	$164k	$1843
October				54	$232k	$4296
November				78	$ 44k	$ 564
December				80	$328k	$4100
TOTALS for periods surveyed:	64	$556k	$8688	703	$2428k	$3454

The two sets of cost data should be interpreted with caution. The cost elements included in each set are not necessarily comparable. The cost data for Division C include costs arising from changes and errors, labour inefficiencies, change administration expenses, and sustaining R&D. No breakdown of cost elements included in the cost data for Division A was available. Further, the cost data relate to change activity costs accounted for in relation to changes in process. The change count data relate to the changes initiated on a monthly basis. There was no indication of change completion on a monthly basis. However, given these limitations in the data, the inference is clear, implementation of engineering change is costly in direct financial terms. Further, the cost level may be higher for manufacturing operations characterized by higher unit volumes. Division A was a higher volume operation than Division C, which may account for the difference between their respective average change cost levels.

The cost of engineering change begs the question: what, if anything, can management do during the new product development process to reduce the incidence of change activity after the start of routine volume production. I examined the nature of the associations between engineering change and each of the deployment decisions available to the ME manager, both with and without control for the development context. Kendall tau-B rank correlation coefficients, and corresponding significance levels based upon a one-tailed test were calculated.

Engineering Change and Emphasis on Manufacturability

This section of the chapter is in two parts. In the first part I report on the associations observed between engineering change and the level of emphasis by ME on manufacturability. In the second part I report on the associations observed between engineering change and the phasing of emphasis by ME on manufacturability.

Engineering Change and Level of Emphasis on Manufacturability

The incidence of manufacturability-related engineering change was measured as the number of class 4 engineering changes issued in the first year of volume production, that is, after completion of the new product development process. The general expectation was that the greater the level of emphasis on manufacturability, the lower the incidence of manufacturabiity-related change. More formally:

> H29: the greater the level of emphasis by ME on manufacturability during the new product development process, the lower will be the incidence of manufacturability-related change after the start of routine volume production.

Without controlling for the development context, there was no evidence of association between the incidence of engineering change and emphasis on manufacturability. However, when this basic relationship was examined in different contexts, several different relationships emerged. These results are summarized in Table 8.8.

Table 8.8
Association between Manufacturability-related Change (ECHANGE) and Emphasis on Manufacturability (EOMEMPH)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	.0000	.500	Not as hypothesized	11
Newer products	-.4140	.126	As hypothesized	6
Less new products	.0000	.500	Not as hypothesized	5
Less internal manufacture	-.1429	.326	As hypothesized	7
More internal manufacture	+.4000	.222	Not as hypothesized	4
Staging	-.6000	.045	As hypothesized	6
Pre-Staging	+.5270	.103	Not as hypothesized	5
Short interval	+.6667	.059	Not as hypothesized	5
Long interval	-.2000	.287	As hypothesized	6

For less new products, although manufacturability - related engineering change occurred within the first year of volume production, not all change was related to manufacturability issues which could have been resolved during the new product development process. Product-level data are summarized in Table 8.9.

Table 8.9
Classification of Manufacturability-related Change for Less-New Products

			Of Which:			
Division	Product	Total No. of Changes	Cost Red'n	Design Correction	Mat'l Subst'n	Document'n
A	A3	7	1		6	
B	B2	14	5	1		8
D	D1	2		No		
	D2	5		Data		
	D3	3		Available		

Among these products detailed change information was available only for change in product A3. Of the seven changes listed, only one related to cost reduction. This change was made to the printed circuit board and to the board assembly process to 'improve manufacturability', and was implemented within two months of the start of volume production. In sum, apart from this single change in product A3, there was no evidence to suggest that the class 4 change to less-new products could have been avoided prior to the start of volume production.

Both material substitution and documentation change may not have been avoidable prior to volume production. As discussed earlier, in Chapter Seven, in relation to manufacturability assessments, sample size for evaluation of development models was an issue which management felt influenced the validity of assessments made. Part of the validity concern arose from the batch size of components or materials provided to ME and manufacturing for assembly of these models. The batch sizes may not have been large enough to capture the range of variations in specification with impact on manufacturability. Only in volume production did such variations emerge, and with them the requirement to institute materials substitution engineering change.

Correspondingly, for less new products, there was no evidence of association between the incidence of engineering change and ME emphasis on manufacturabiity. In contrast, for newer products, the incidence of engineering change was lower for greater emphasis on manufacturabiity. The implication is that the performance of newer products was more amenable to the emphasis placed by ME on manufacturability.

All 'internal' products were drawn from Division A. In the set of four internal products, the least-new product, A3, received the highest emphasis on manufacturability and registered the second highest incidence of engineering change. The second newest product, A4, received the lowest emphasis on manufacturability and had the lowest incidence of engineering change. However, product A4 was not a successful development, acknowledged by the ME manager in Division A to be related, in part, to a lower than necessary emphasis on manufacture. After the start of volume production, a major cost-reduction program was initiated to achieve cost targets. However, this program was not reflected in the incidence of engineering change. Correspondingly, for products characterized by a greater degree of internal manufacture of components, greater emphasis on manufacturability was associated with greater incidence of engineering change.

Engineering change seemed amenable to reduction through emphasis by ME on manufacturability in the case of products developed over longer intervals. For such products, time was available and the need to trade development interval off against manufacturability was reduced. Simply stated, given enough time, the product could be designed 'right first time'. Correspondingly, for products developed over longer intervals, the incidence of engineering change was lower for higher emphasis on manufacturability.

In contrast, for products developed over shorter intervals, the time pressures required a greater involvement of ME in the development in order to respond to the problems which arose, and which eventually had to be addressed as engineering changes. In effect, both the incidence of engineering change and the level of emphasis on manufacturability by ME were outcomes of the shorter development intervals. In support, the incidence of engineering change for products developed in shorter intervals was higher for greater emphasis on manufacturability. As such, when time pressures dominated, greater deployment of ME did not prevent design compromises being made which had to be addressed in volume production.

Finally, for products not managed through the Stage Procedure, greater emphasis on manufacturability was associated with greater incidence of engineering change. No explanation is offered for this unexpected finding.

Manufacturability-related Change and Phasing of Emphasis

The notion of design freeze, that is, where change to the design is not permitted after a certain stage in the development process, arose in discussion with the managers. They supported this notion, but the issue of when to 'freeze' the design remained. If parts of a product design were frozen early, the freeze could be on the basis of incomplete design information. As the design evolved further, the necessity for engineering change would have arisen but not have been identified, or may have been delayed until the start of volume manufacturing. This notion ran counter the the expected association between engineering change and the deployment of ME resources, stated formally as:

> H30: the earlier the phasing of emphasis by ME on manufacturability during the new product development process, the lower will be the incidence of manufacturability-related engineering change after the start of routine volume production.

To explore this issue, I examined a number of types of design information, utilized by ME to carry out its product development responsibilities, and also the association between the incidence of engineering change and the the deployment of ME resources.

The completeness of the design information, utilized by ME to carry out its product development responsibilities, evolved from 'general' to 'detailed' over the course of the new product development process. Figure 8.1 summarizes the range of stages over which this information was 'general', and became 'detailed' for products A1, B1 and C1, the first products in their respective families.

Figure 8.1
Nature and Completeness of Information Available to ME
for Products developed First in their Families

```
                                  New Product Development Stage

Design Information         Definition             Verification
Categories                            Development
----------                |----------|-----------|------------|
Constituent Materials:
 General Information                 G------G
 Detailed Information                D-------------------D

Materials treatment:
 General Information                 G
 Detailed Information                D-------------------D

Manufacturing Processes:
 General Information            G----G
 Detailed Information                       D------------------D

Test & Rejection Procedures:
 General Information                        G------------G
 Detailed Information                            D-------------D

Tolerance Level:
 Genaral Information                 G----G
 Detailed Information                                     D---D

References to Standards:
 General Information                 G
 Detailed Information                       D---------------D

Maintenance Requirements:
 General Information                 G-------------------------G
 Detailed Information                            D-------------D

Requirements for Integration
 with Pre-existing processes:
 General Information                 G
 Detailed Information                       D------------------D

Capacity:
 General Information                 G
 Detailed Information                D------------D
```

Figure 8.1 indicates that for products first in their families, some detailed design information was available in all areas except tolerance levels, as early as the development stage, and for some areas as early as the definition stage. However, detailed information was not available in all categories until the verification stage. For subsequent products in the various product families, some detailed design information was available earlier than for products, first in their families, especially where these products incorporated components and sub-assemblies from the earlier products.

In particular, details of the plastic cover and base of a terminal were often finalized before the circuit designs were completed. Mold design and proving required long lead times. As such, circuit designers faced fixed spatial dimensions within which to place circuit boards which satisfied the functional specification. However, these spatial constraints and the costs of changing the molds forced compromises on component density, and, so, board manufacturability. In effect, where early ME emphasis on manufacturability of plastics and the resulting design decisions, were based on incomplete circuit design information, the implications for board manufacturability may have become apparent only with volume production, and precipitated engineering change.

This interpretation was supported through investigation of the association between engineering change and the phasing of ME emphasis on manufacturability, as summarized in Table 8.10.

Table 8.10
Association between Manufacturability-related Change (ECHANGE) and Phasing of Emphasis on Manufacturability (EOMPHAS)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	-.2243	.173	Not as hypothesized	11
Newer products	0.0000	.500	Not as hypothesized	6
Less new products	-.2000	.312	Not as hypothesized	5
Less internal manufacture	-.1429	.326	Not as hypothesized	7
More internal manufacture	-.1826	.359	Not as hypothesized	4
Staging	+.2760	.222	As hypothesized	6
Pre-Staging	-.4000	.164	Not as hypothesized	5
Short interval	-.5270	.103	Not as hypothesized	5
Long interval	-.0667	.425	Not as hypothesized	6

Without control for the development context, the association was not as expected originally: the earlier the emphasis, the greater was the incidence of change. When the basic relationship between emphasis and change was controlled for product newness, process position and design - ME coordination, the relationship was not as expected. Only in the case of products managed through the Stage Procedure was the expectation of fewer changes upheld.

This correspondence between phasing of ME emphasis on manufacturability and the incidence of engineering change is consistent with the alternative paradigm for product development described, but not tested, by Hayes et al. (1988). Under this paradigm, product development is characterized by extensive overlap of phases, with continual two-way interchange of information at low levels (Hayes et al., 1988). These characteristics contrast with those of the 'conventional' paradigm, where new product development takes place as a sequence of activities undertaken by separate organizational units with diffused responsibility for the overall success of the project. The two paradigms are compared in Table 8.11.

Table 8.11
Contrasting Early Manufacturing Involvement in the Development Process under the Conventional and New Paradigms for New Product Development

	Paradigms	
Dimension	Conventional	New
Time available to manufacturing to complete its part of the project:	Longer	Shorter
Completeness of Information to Manufacturing	More complete	Less complete
Subsequent (post-launch) Engineering Changes	Fewer	More??

Under the new paradigm, early manufacturing involvement in design for manufacturability is characterized by less complete information. Where Hayes et al. are unclear is in relation to the incidence of engineering change in their alternative paradigm. The evidence of this study provides support for increased engineering change under this alternative paradigm. Accordingly, achievement of an objective of design 'right-first-time' may not be possible through earlier ME involvement in the new product development process.

Engineering Change and Level of ME Deployment

This section of the chapter is in two parts. In the first part I report on the relationships observed between engineering change and the level of ME deployment in the definition stage of the new product development process. In the second part I report on the relationships observed between engineering change and the level of ME deployment in the verification stage.

Engineering Change and ME Deployment in the Definition Stage

The timing of ME deployment on a new product development project was one of the decisions open to the ME manager. Consistent with the relationships between manufcturability and ME deployment in the definition stage, reported in Chapter Seven, the general expectation was that:

> H31: the greater the level of ME deployment in the definition stage of the new product development process, the lower will be

> the incidence of manufacturability-related engineering change after the start of routine volume production.

However, this expectation was not borne out, under any circumstance. For newer products, there was no evidence of any relationship. Where there was evidence of association, this association was positive, suggesting that greater deployment of ME resources in the definition stage was associated with greater levels of engineering change. These results are summarized in Table 8.12.

Table 8.12
Association between Manufacturability-related Change (ECHANGE) and ME Deployment in the Definition Stage (HRSINS1)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	+.2963	.157	Not as hypothesized	8
Newer products	0.0000	.500	Not as hypothesized	4
Less new products	+.6667	.087	Not as hypothesized	4
Less internal manufacture	+.9129	.035	Not as hypothesized	4
More internal manufacture	+.1826	.359	Not as hypothesized	4
Staging	+.1826	.359	Not as hypothesized	4
Pre-Staging	+.6667	.087	Not as hypothesized	4
Short interval	+.3162	.224	Not as hypothesized	5
Long interval	+.8165	.110	Not as hypothesized	3

As discussed in Chapter Seven, ME activities in the definition stage seemed to have been important in relation to the development of manufacturable products. Greater expenditure of ME manhours at this stage may have been on the start of activities which could have been delayed to later stages of the development process. However, by becoming involved earlier, ME seemed to have enhanced the manufacturability of the product. However, that earlier presence may have resulted in early freezing of aspects of the design.

As noted earlier, there was no evidence to suggest that the engineering changes reported on change notices were planned. Accordingly, the possibility exists of early design freeze arising from early and high emphasis on manufacturability contributing to the need to implement a greater number of engineering changes after the start of routine volume production.

Manufacturability-related Change and ME Deployment in the Verification Stage

The timing of ME withdrawl from a new product development project was one of the decisions open to the ME manager. Consistent with the relationships between manufcturability and ME deployment in the verification stage, the general expectation was that:

> H32: the greater the level of ME deployment in the verification stage of the new product development process, the higher will be the incidence of manufacturability-related engineering change after the start of routine volume production.

However, this expectation was not borne out in any context. Where relationships were strong, the data suggested that a lower incidence of change was associated with a higher level of ME deployment in the verification stage. The strength and significance of this basic relationship was moderated to some extent by process position and design-ME coordination. However, the direction of the association was unchanged. These results are summarized in Table 8.13.

ME activities in the verification stage seemed to have been important in relation to avoidance of engineering change. Greater expenditure of ME manhours may not have been derived from completing activities which had been delayed from the earlier stages of the development process. Rather, they may have been expended on completing the scheduled activities well. Accordingly, for ME to remain on the project longer may not necessarily have enhanced the manufacturability of the product, as reported earlier, in Chapter Seven. Instead, that extended presence may have resulted in more complete process documentation (detailing standards and methods) available to the shop floor, so avoiding the necessity to issue an engineering change to correct the documentation later.

Table 8.13
Association between Manufacturability-related Change (ECHANGE) and Level of ME Deployment in the Verification Stage (HR3INS3)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	-.4444	.066	Not as hypothesized	8
Newer products	-.6667	.087	Not as hypothesized	4
Less new products	-.6667	.087	Not as hypothesized	4
Less internal manufacture	-.9129	.035	Not as hypothesized	4
More internal manufacture	-.1826	.359	Not as hypothesized	4
Staging	-.1826	.359	Not as hypothesized	4
Pre-Staging	-.3333	.359	Not as hypothesized	4
Short interval	+.1054	.400	As hypothesized	5
Long interval	-.8165	.110	Not as hypothesized	3

To explain this observation in this way highlights again the differing implications for product performance of similar ME deployment strategies. In Chapter Seven, I concluded that while earlier and greater deployment of ME was associated with improved performance, the performance measure which was improved was contingent upon the context. Here again a similar conclusion is appropriate, although without the dependence on context. In sum, management of the ME function during the new product development process was not a simple task. There were no 'golden rules' at the level of detail and closeness to the product and process at which the ME managers operated. Instead, there were tradeoffs and compromises, and context-specific outcomes from similar deployment strategies.

Manufacturability-related Change and ME Staff Experience

As defined, experience was gained by ME staff over a number of related or similar new product development projects. This experience translated not just into the the ability to make competent choices when acquiring equipment, and modifications as it was used, but also into an understanding of existing processes. On the basis of this understanding, the ME staff provided positive guidance in developing manufacturable product designs in the context of existing manufacturing processes. However, this understanding of the inter-relationships between product and process technologies, while difficult to accumulate, was easily lost, as it was held in the ME staff themselves, who could leave the organization 'without trace of their being'.

Correspondingly, the general expectation was that the incidence of engineering change would be lower when the product development teams included ME staff with a higher level of experience. More formally:

> H33: the greater the level of ME staff experience, the lower will be the incidence of manufacturability-related engineering change after the start of routine volume production.

This expectation was borne out in general, and, in particular, in the various development contexts. The strength and consistency of the relationship suggests that the level of experience of the ME Staff was associated with the avoidance of engineering change. This experience was carried forward from earlier and related products, and had a stronger association for less new products than for newer products or, indeed, for any other sub-category. This distinction is not surprising, given the definition of product newness is relation to earlier products. As such, the avoidance of engineering change was associated with the capturing experience, not just in the product components and subassemblies, but also in the ME staff. These results are summarized in Table 8.14.

The importance of ME staff experience in relation to the avoidance of engineering change has strong implications for the staffing of the ME function. The vulnerability of ME staff experience was illustrated in Chapter Five earlier, in relation to the staffing of the ME function in each division, and, in particular, in Divisions A, B and D. Briefly, I expected that the number of ME staff, and the ratio of ME engineers to technicians would be dependent on manufacturing strategy, being an outcome of policy decisions on engineering support levels. While there was no explicit statement of manufacturing strategy, each division had de-facto policies which reflected the particular product - markets served and their competitive realities. However, in Divisions A and B, operational pressures strongly influenced the implementation of one such policy, in terms of ME staff size and composition. As such, this short-term response to operational pressures led to 'swings' affecting the ME establishment, both in size and mix of engineers and technicians, sometimes resulting in inconsistency between the size and composition of the ME staff, and the Division's long-run objectives.

Table 8.14
Association between Manufacturability-related Change (ECHANGE) and ME Staff Experience (MESTFEXP)

Control Variable	tau	p<	Direction of Association	No. Cases
No control	-.5511	.015	As hypothesized	11
Newer products	-.3581	.165	As hypothesized	6
Less new products	-.8367	.026	As hypothesized	5
Less internal manufacture	-.6901	.026	As hypothesized	7
More internal manufacture	-.1826	.359	As hypothesized	4
Staging	-.5013	.086	As hypothesized	6
Pre-Staging	-.5976	.083	As hypothesized	5
Short interval	-.5270	.103	As hypothesized	5
Long interval	-.7303	.032	As hypothesized	6

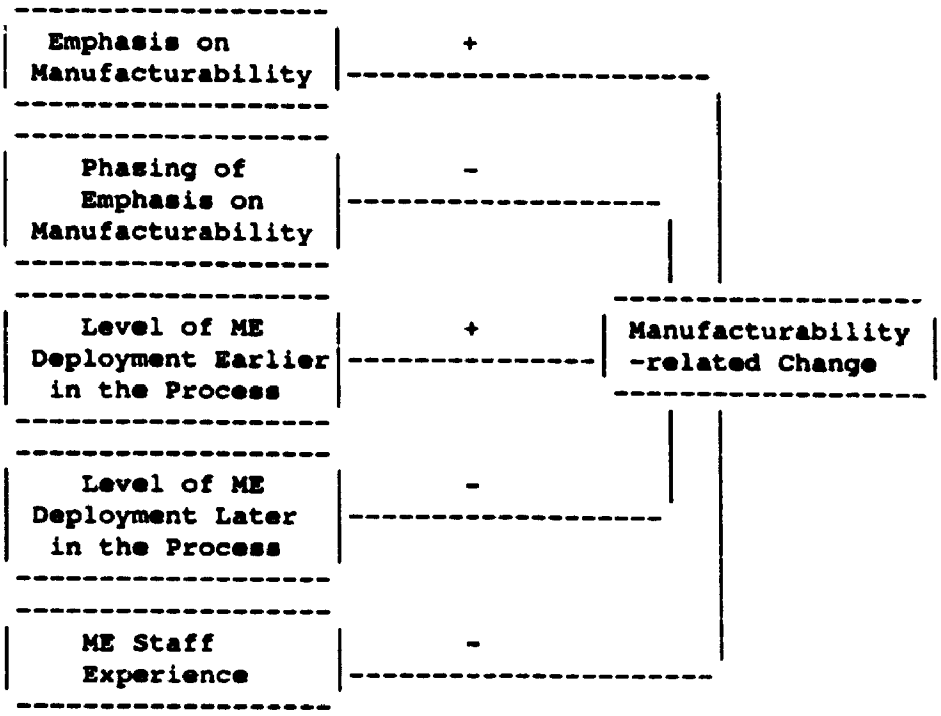
When viewed in the context of the association between the incidence of manufacturability-related engineering change in newly developed products, and ME staff experience, these 'swings' in the ME profile had potentially more damaging consequences. Rather than just reducing numbers of ME staff and limiting the scope or sequencing of projects undertaken, these swings may have diluted the very experience required to avoid costly engineering change. As such, ME staffing decisions seem to have long-term and quantifiable implications for the performance of new product developments.

SUMMARY: MANUFACTURABILITY-RELATED CHANGE & ME DEPLOYMENT

Figure 8.2 outlines the basic set of relationships which emerged in relation to the incidence of manufacturability-related engineering change after the start of routine volume production, and ME deployment during the development process. These relationships were contingent upon the development context.

Figure 8.2

Association between Manufacturability-related Change and ME Deployment



Notes: positive association denoted by '+'
negative association denoted by '-'

MANAGEMENT OF ENGINEERING CHANGE

Design it right-first-time or next-time?

Engineering change continued to occur after the start of volume production in the new products studied in spite of management exhortations to design right-first-time, new management procedures, and earlier manufacturability assessments. Yet, the new product development projects were, and continued to be, characterized by conflicting objectives: delivery of a functioning product to the customers on time; and, delivery of a manufacturable design to manufacturing. Each set of objectives had differing implications for engineering change. The question remains, then, is an objective of to design right-first-time attainable or is a more practical objective to design right-next-time?

The framework developed earlier for the analysis of engineering change assisted in the classification of change, by change area, motivation, interval and anticipation. However, in order to address the desirability of engineering change after the start of volume production, this framework needs to be expanded. The expansion involves dividing engineering change into two macro categories: design-intent affecting change, and non-design intent affecting change. Within each of these categories, the previous framework remains intact: engineering change may occur in the areas of product specification, process equipment, tooling or methods; change may be planned or unplanned; and, change may occur both before and after the start of volume production.

Design Intent and Transparency of Change: The design intent of a product is its range of operating features and compatibilities that make the product attractive to buy, and easy to install, use, service and upgrade. Change which affects these features and compatibilities is design intent affecting change. Such change is apparent to both the ultimate product user, the customer, and also to the intermediate user of the product specification, manufacturing. As was clearly indicated in the the company standard design change classification scheme, a class 1 change, made in repsonse to an inoperative or potentially hazardous condition, is design-intent affecting. If the product feature does not work, the design intent is not being fulfilled. If this change is required after the product has been released to the market, the costs are measured in such currency as image and reputation, in addition to more quantifiable items as redesign costs and lost revenues. These changes may be initiated by design or by marketing.

Design intent affecting change may not be transparent to manufacturing, especially if the change requires change to materials, process equipment, tooling or methods. Implementation of such change results in manufacturing costs which are measured in terms of waste, rework, and downtime arising from stopping and scrapping work in process, both unlearning and relearning of methods, and qualification of new parts or suppliers. In sum, change which affects design intent is costly when it occurs after the start of volume production. The company estimated that the relative impact of a 'design flaw' detected after the verification stage, was 100 times greater than one detected during the development stage.

Change which does not affect the design intent of a product is transparent to the customer, but not necessarily to manufacturing. This type of change may involve re-layout of printed circuit boards to reduce component density, substitution of components, automation of process stages, or even, reversion to manual methods. When carried out reactively, the objective o this type of change is to meet cost or yield targets originally set as part of the original new product development objectives. When carried out proactively, these changes are expected to improve cost or yield performance relative to targets already attained. These changes may be initiated by manufacturing, ME, or by design.

Timing of Change: Design intent and non-design intent affecting change may occur at any time before or after the start of volume production. Before the start of volume production, each type of change is an expected intermediate outcome of the new product development process, as the imprecision - and consequently, the risk and uncertainty - is extracted from the design specification by the project team through design reviews, manufacturability assessments and interfunctional cooperation. Ideally, the incidence of each type of change should have reduced to zero by the start of volume production. However, the experience of the four divisions in this study was that, while some design intent affecting change occurred after the start of volume production, the majority of the change which occurred was non design intent affecting.

The development of these products was managed by more or less experienced project teams who applied coordination mechanisms such as the Stage Procedure to discipline the interactions among the design, marketing and ME functions. As such, when considered in terms of the objective of 'design right-first-time', the implication from these products is that design intent affecting change was largely avoided, and indeed, from a design intent perspective, the products were designed 'right first time'.

Further, the inference from the experience of these products is that the incidence of non design intent affecting change, introduced after the start of volume production, is unavoidable, and, from this perspective, products cannot be designed 'right first time'. However, the time and volume-based limitations on the screening of designs to eliminate these change during the development process suggests an inevitability of this type of change after the start of volume production. Non design intent affecting change seems almost a natural outcome of volume production.

Management for Reduction of Non-Design Intent Affecting Change: However, non-design intent affecting change is manageable and may be reduced in part, if not to zero. It is certainly an objective worth striving for. Underlying the selection of the twelve products in this study were four families of products. The newer products were less manufacturable and experienced more manufacturability-related change than the less-new products. Further, the areas where less new products experienced problems were not included as elements of earlier products in the same family. As such, through addressing the non-design intent affecting change in the earlier members of these product families, the recurrence of that type of change in later, less-new products disappeared. In effect, the divisions learned from their previous change experiences, and carried that learning in modular form to later products.

The learning from product to product was captured in formal revisions to parts drawings, component specifications, or manufacturability guidelines, use of common parts modules, in revisions to the Stage procedure, where manufacturability assessments were scheduled earlier in the development process. This learning was also held in the project team members. While there was continuity of membership of the various project teams over the projects, the organizational levels, from which project engineers were drawn, were lower for less-new products. As such, the divisions discarded some of the learning held and remained at risk from the potential inabilities of individual staff to apply their experience, gained on one project, on a subsequent project.

CHAPTER NINE: CONCLUSIONS AND IMPLICATIONS

Manufacturability is both a problem and an opportunity for manufacturing firms, and the roots of each are common: an environment where, increasingly, competition is on the basis of rapid production ramps and high manufacturing yields at competitive costs. Developing a product which is easy to manufacture, which matches the process capabilities, and which does not require disruptive engineering change, is key to competing on this basis. Yet, there are wide gaps in our understanding of how to manage this problem and to realize the opportunity. Design and engineering techniques have been tried, with only limited success; they address pieces of the problem but are incomplete because they assume the existence of a manager who can manage the tradeoffs which inevitably arise during the new product development process. Simple solutions and packaged programs are no substitute for a deeper understanding of the management task involved in developing a manufacturable product. Only when they gain this understanding, will firms be able to move decisively and compete on the basis of manufacturability.

The new product development process requires the integration and interaction of a number of distinct groups of resources, including marketing, design, manufacturing, procurement and quality. Each group has development objectives for which it is more or less dependent upon the output of the other groups. The development of manufacturable new products is one such objective, and is shared, primarily, among the design, manufacturing and vendor engineering groups.

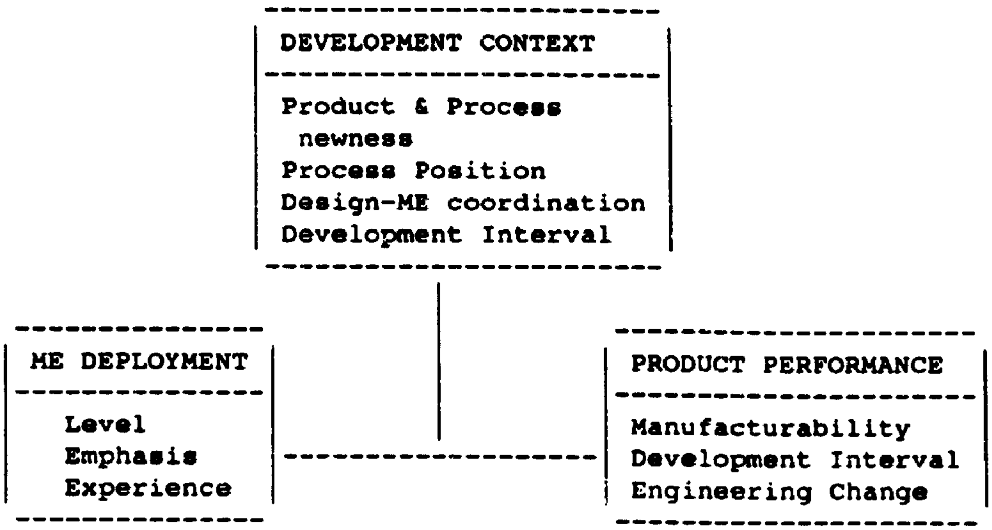
In this study, I focused on the manufacturing engineering (ME) group. I investigated the development of twelve new products, from a management perspective, in four divisions of one company. I asked four specific questions:

> What specialist engineering resources are deployed in the development of manufacturable new products?
>
> When, during the new product development process, are these engineering resources deployed?
>
> Is the successful achievement of manufacturable new products associated with the way these engineering resources are deployed?
>
> Is an association between the achievement of manufacturable new products and the way these engineering resources are deployed contingent upon the development context?

To address these questions, I developed a framework around the theme that the manufacturability-related performance of new products was associated with the deployment of manufacturing engineering (ME) resources during the new product development process. The context within which this new product development activity took place was defined by the manufacturing strategy of the firm. As such, manufacturability-related performance, similar to other dimensions of product performance, was associated with two sets of factors, one of which was controllable by manufacturing engineering management, while the second set was defined the development context. The framework is shown in Figure 9.1.

Figure 9.1

Relating Product Performance to Manufacturing Engineering Deployment



I found that manufacturability, the incidence of engineering change, and the length of the development interval each reflected the way in which ME resources were deployed by the ME manager during the process. The relationship between product performance and ME deployment was contingent upon the development context, which was more or less fixed for an individual new product development project.

Management of Manufacturing Engineering

Manufacturing Engineering Activities: The fundamental task of manufacturing engineering was to integrate the product and process technologies, and, in doing so, ME was a major player in the development of manufacturable new products. ME focused, not only on process, but also on product development, support and improvement, consistent with the widening role of ME as an operations integrator. ME activities, during the product development process, included manufacturability assessment, process specification and qualification, standards setting and product costing. Product-focused activities, after completion of the product development, included initiation, review and implementation of cost reduction projects, manufacturability-related engineering changes, and employee suggestions. These later product-focused activities were carried out by sections of the ME groups, whose involvement in product development was less than other sections, such as the assembly engineering rather than new product development section.

Grouping of ME Resources: The ME function incorporated manufacturing, test and industrial engineering specialties. Although many areas of responsibility were common to the function, I observed two organizational approaches to coordination of these responsibilities. The first, a functional approach, was characterized by a single ME department which incorporated all of the sub-areas of ME represented in the division. The functional approach reflected a concern for minimising communications problems and preserving a 'critical mass' of ME expertise in the development, support and improvement of products and processes characterized by relatively high volumes and low variety.

The second organizational approach to coordination of ME responsibilities featured a split along two dimensions: timing and product group. The time-based split divided the ME staff into two basic groups relative to the start of routine volume production of products. Product support and improvement were grouped by product type, reflecting differences in manufacturing processes and standards among the products. With high rates of new product introduction, relatively low volumes and high variety, the functional organization would have experienced coordination problems.

The differing approaches to grouping of ME resources in the divisions each had vulnerabilities. The apparent size of the functional group masked resource shortfalls, particularly when new products and processes were under development at the same time that existing products were in volume production. For the time and product-based groups, integration of development, support and improvement of products and processes was facilitated by previously established procedures for formal transfer of responsibility. However, the ease of integration was dependent also upon personal interactions which were based upon previous working relationships.

ME Activitities in the New Product Development Process: ME first became involved in the new product development process once the product concept was approved, when the focus was on development of technical specifications. ME remained involved in the process through the development of prototype units, and until the design conformed to product specifications, and product cost targets were achieved in a pilot run.

The development focus of ME changed over the course of the development process, from process planning and manufacturability assessment in the earliest stage to supervision of the pilot run in the final stage. During the various stages of the process, ME worked on an evolving set of technical deliverables, which required the expenditure of manhours on differing sets of product and process related activities. The spread of activities over the stages of the development process was roughly even, although some categories of activities were concentrated in the earlier or later stages. Many activities spanned one or more stages of the development process, substantiating the notion of early involvement of engineering resources in overlapping stages of the development process.

Product Performance and Deployment of ME Staff:

Manufacturability-related performance of a new product had three dimensions: development interval, manufacturability, and manufacturability-related engineering change. Accordingly, 'better' performance was described in terms of a short development interval, ease of manufacture, low severity of manufacturability-related problems, and few manufacturability-related engineering changes.

The deployment of ME staff on a new product development project was the outcome of a set of management decisions. These decisions included assignment of specific staff members to the project, when to assign to, and when to withdraw from the project, and the degree of their emphasis on manufacturability while on the project. My interest was not in the process by which these decisions were made, but rather in the outcome of these decisions when made.

Through greater and earlier deployment in the development process, ME resolved manufacturability issues earlier and, so, avoided having to spend time addressing problems later. It seemed that, through such earlier involvement in the process, ME was carrying out 'preventive maintenance' of the development process, with greater 'up-time' of the process and consequently shorter development intervals. Yet, there were conflicting signals as to what constituted this preventive maintenance. The ease of manufacture of products and the incidence of manufacturability-related change seemed to bear no relation to the emphasis placed by ME on manufacturability. In contrast, the greater and earlier the emphasis on manufacturability, the less severe were the manufacturability-related problems, and the shorter was the development interval. Further, the use of more experienced ME staff seemed not to matter in terms of the length of the development interval, while experience was associated with greater manufacturability and fewer manufacturability-related engineering changes.

In sum, the relationship between manufacturability-related performance and the deployment of ME resources during the development process was complex. Other forces were at work, some of which were situational and altered the management challenge. Intuitively, a product comprised of many new components and subassemblies posed a development challenge different from a product which was largely a repackaging of existing modules. A product developed under severe pressure of time forced tradeoffs between market availability and component standardization to the top of the development agenda. The manufacturability of a product comprised of manufactured rather than sourced components differed in its amenability to the development efforts of ME.

Development Context: The context within which new product development activity took place was defined by the manufacturing strategy of the firm. The extent to which a product incorporated more or fewer new components and subassemblies, whether or not these components and subassemblies were manufactured inhouse or sourced externally, the time pressure surrounding a project, and the management approach to the coordination of design and manufacturing engineering resources, each in its own way defined a different context within which new products were developed.

Product Newness: Newness implied diminished use or availability of existing staff experience or previously developed product components. Accordingly, for 'new' products the ME staff placed more emphasis on manufacturability earlier, because they included more new components and assemblies which had not been assessed for manufacturability. Further, in contrast to less-new products, these new components and assemblies had not been tried in volume production. As such, newer products proved less manufacturable and subsequently required engineering change to achieve specified goals, after the start of volume production.

Process Position: Products utilizing more internally manufactured components had longer development intervals, proved less manufacturable after launch, and had more manufacturability-related engineering changes than products utilizing more externally sourced components. During the development of these 'internal' products, ME expended more manhours in the definition stage, and placed greater emphasis on manufacturability earlier. The span of responsibility of the ME staff in the development of 'internal' products was greater than for 'external' product, and included the matching of individual component designs, rather than higher level sub-assemblies, with existing and new manufacturing processes. Accordingly, ME could not afford to assume that component designs were manufacturable - they had to ensure their manufacturability, but did not get it 'right first time'.

Design-ME Coordination: The Stage Procedure was introduced by the company as a disciplined management approach to enable the development of manufacturable new products in shorter development intervals. Staging succeeded in structuring the development context. Formal review of project progress, carried out by management from within and outside the project team, facilitated identification and agreement on tradeoffs among priorities. The review process was event-driven and involved the formal transfer of responsibility for achievement of remaining targets. The early involvement of ME was legitimized, and manufacturability assessments were specifically required early in the development process.

In its own way, Staging was not unlike a newly developed product, based upon new components and subassemblies. The corporate designers of the procedure did not get it 'right first time', and the individual divisions amended the procedure or broke the 'rules' on an ongoing basis. This experience building was still in process during my study. As such, the performance of products managed through Staging did not differ significantly from those managed through the less formal set of procedures which pre-dated Staging. However, I would expect that as divisions, and product development teams within divisions, became more familiar with this management approach, the performance of products would become more predictable.

Length of Development Interval: An additional element of context was found to be the time taken to develop the product. Of itself, this inclusion was not surprising. However, in the original framework for this study, the length of development interval was proposed as associated with the deployment of ME resources during the new product development process. In the event, the time taken to develop the product both set the context for the development, and emerged as an outcome of ME deployment. Marketing set the date for launch of the product with reference to the competitive requirements of the market. In the market in which each of the divisions competed, the resulting interval available to develop functioning, manufacturable and cost effective products was short. Correspondingly, from the perspective of ME, the interval within which they had to complete their responsibilities was more a given feature of the project than a variable which they could influence.

The performance of products developed in longer development intervals was better than for short-interval products. Further, the ME staff placed greater emphasis on manufacturability earlier for short-interval products. Just as the performance of newer products reflected the absence of information, the performance of short interval products reflected an inability to use available information. Each context was uncertain, although the origins of the uncertainty differed. For newer products, the operating characteristics and manufacturing requirements of components and subassemblies were unknown initially, and often remained unknown until the start of volume production. For short-interval products, while the operating characteristics and manufacturing requirements were known, ME was not capable of integrating them in the time allowed.

Summary: In sum, context mattered in the development of these products. Further, except through decisions, such as whether to make or buy a subassembly, the dimensions of the development context were not directly influenced by the new product development teams. Instead, the potential for change existed within the formal planning process. The ME managers had some input into this process, through identification of the number and mix of staff required in their departments, or the level of component manufacture to be carried out internally. These decisions, taken in relation to the business strategy, sustained, improved or otherwise altered the context of each new product development project, and so, potentially, both the deployment of ME during the project and the ultimate product performance.

Product Performance a. ME Deployment: Based upon the differences in product performance and in ME deployment among development contexts, I was not surprised to find that the relationship between product performance and ME deployment was dependent also on the context within which the product was developed. However, these findings add to the understanding of the development of manufacturable new products from a management perspective. Three major conclusions emerge from these findings, which give some indication of the scope of the management task in the development of manufacturable new products, while, at the same time, providing guidance for management action.

Context-Dependent Relationships: First, the relationships between individual dimensions of product performance and individual ME deployment decisions were largely dependent on the context within which the products were developed. The end of the development interval was often set by Marketing in relation to a product launch date on the market. However, the length of the development interval was also the outcome of the completion of development activities by many functional groups interacting during the new product development process.

One of these groups was manufacturing engineering, for whom a major concern was manufacturability. However, the direction, and, in some cases, the existence of a relationship between the length of the development interval and many individual deployment decisions depended upon the newness of the product. Similarly, though to a lesser extent, the relationship between the length of the development interval and ME deployment varied with the degree of internal manufacture of components and subassemblies, and with the approach to coordination of design and ME.

The pattern of relationships between manufacturability and individual deployment decisions was similar for newer products, for products characterized by more internal manufacture of components and subassemblies, for products managed through the Stage procedure, and for products developed within shorter intervals. The manufacturability of products developed in these contexts was higher for greater and earlier deployment of ME resources. For products developed in other contexts, the relationships were less consistent.

Whereas the experience of the ME staff led to better manufacturability and shorter development intervals in specific contexts, the relationship with lower engineering change, with one possible exception, was unconditional. More experienced ME staff brought a depth of understanding of the relationships between product

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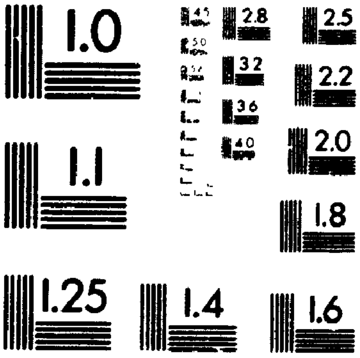


and process technologies to bear on technologically uncertain situations, with positive results. Other deployment decisions were consistent with the outcome of a design freeze early in the development process based upon incomplete information. As such, deployment decisions which enhanced manufacturability, as assessed at the start of routine volume production, were associated with unplanned engineering changes during the first year of routine production.

<u>Emergence of Deployment Strategies:</u> Second, management to achieve manufacturable new products through the deployment of ME resources was not a simple task, but required a deployment strategy, comprising a series of individual deployment decisions. Regardless of context, product performance was not associated solely with getting ME involved early in the development process; a decision to get involved was always accompanied by other deployment decisions. The conventional wisdom, based upon earlier studies, was that better performance resulted from getting manufacturing involved early in the process. I confirmed this wisdom: in eighteen out of thirty different contexts, better performance, on some dimension, was indeed associated with earlier involvement of manufacturing, and, in particular, manufacturing engineering. In the remaining twelve contexts, the relationships were variable, though some were consistent with freezing the design early in the development process based upon incomplete information.

However, the decision on when to get ME involved was only one of five main decisions which the ME and project managers had to take when deploying ME resources in the new product development process. The other decisions concerned who to involve, when and what emphasis to place on manufacturability, and when to withdraw from the project. The decision on when to get involved, and at least one other decision, such as the experience level of the ME staff deployed, were important in most cases. I concluded that the management task in achieving manufacturable new products through the deployment of ME resources required a deployment strategy, comprising differing combinations of decisions on timing and scope of ME involvement, and on staffing and staff development.

Contingency of Deployment Strategies: Finally, the association between manufacturability and ME deployment was contingent upon the development context. For products which were newer, utilized many internally manufactured components and subassemblies, or were developed over shorter intervals, four and often all five of the deployment decisions was important to performance. These products had both unstable product and process design information.

For newer products, the product and process concepts were still in formation and not yet integrated with each other. In products developed in short intervals, although individual concepts may have been stable, time pressure compromised the quality of the information exchanged by design and manufacturing engineers. For internal products, the development detail required from the ME group complicated the integration of product and process technologies. At that level of detail, ME continually faced new manufacturing situations and information. Greater design instability increased the development challenge and demanded more complex management responses.

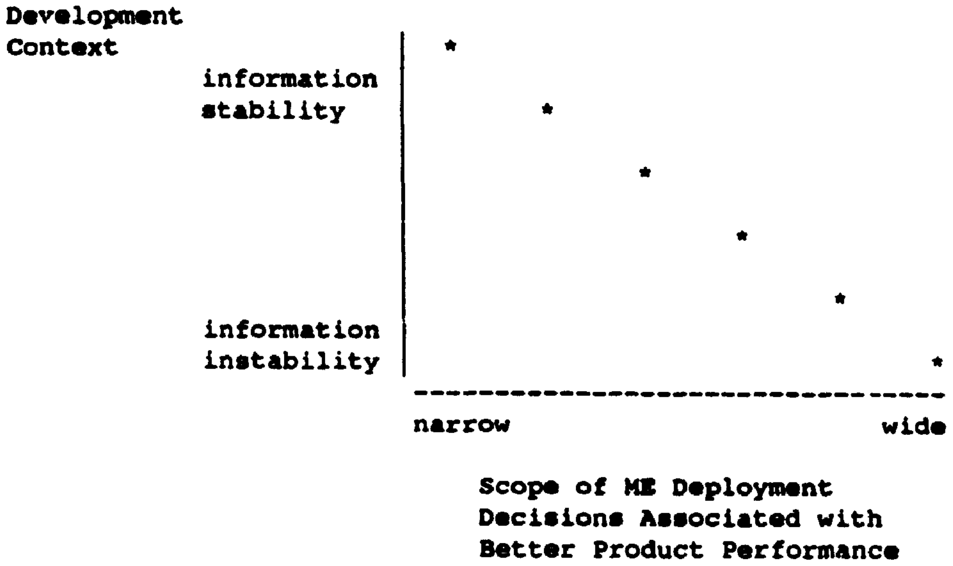
In contrast, for products which were less-new, utilized many externally sourced components and subassemblies, or were developed over longer intervals, only two or three ME deployment decisions mattered. The greater stability in the product and process design information available to ME in these contexts limited the development challenge and the scope of the corresponding management response.

However, the association between the achievement of better performing new products and the deployment of ME resources was contingent also upon the particular dimension of product performance in question. Not all performance dimensions lent equal opportunity to ME to make changes associated with enhanced performance. For example, ME had greater potential to improve the manufacturability of products than to shorten the development interval. In many respects, manufacturability was a key focus of ME, for which it acted in a position of prime responsibility. ME could develop guidelines and criteria for manufacturable designs, cooperate with designers on working within those guidelines, and later carry out an assessment of the resulting manufacturability.

In contrast, ME was only one of a number of functions which contributed to the development schedule, and so to the length of the development interval. As I saw in a number of cases, while ME completed its 'deliverables', the project schedule slipped or was shortened due to technological or market forces outside its range of influence. In sum, product performance had three dimensions, and differing combinations of deployment decisions were associated with better performance along these dimensions. However, for any given deployment strategy, performance on any particular dimension depended upon its amenability to change.

ME Deployment and Development Context: I summarize the above conclusions in Figure 9.2. This figure reflects the scope of management's response to the stability of the development context, for better performing products. Because of the exploratory nature of the study, this graph can only be treated as suggestive. However, it gathers many of the threads of our understanding into a single simple picture.

Figure 9.2
ME Deployment and Development Context



The graph suggests a way to represent the interaction of ME deployment strategy and the development context. The horizontal axis represents the scope of the deployment decisions emphasized by the ME manager in differing development contexts. A narrow scope involves only two of the five major deployment decisions: when to get ME resources involved in the project, and when to withdraw them from the project. A wider scope involves at least one of the remaining two deployment decisions: what experienced staff to assign to the project, and what emphasis to place on manufacturability. In this scheme, when to get involved and at least one other decision is associated with better product performance.

The vertical axis represents the range in the stability of product and process design information available to ME during the development process. For newer products, products developed in short intervals, or products characterized by internal manufacture of components and subassemblies, this information is more unstable.

A new product development project occupies a particular region of the graph, depending upon the stability of its development context and the ME deployment decisions made by management. Typical of a project positioned in the bottom right-hand corner is a product using largely new components and subassemblies. In such a project, the product and process design concepts are not yet fixed in relation to each other, and require early involvement of experienced ME staff to place great emphasis on manufacturability and stay with the project until volume production starts.

In the upper left-hand corner, one would find less-new products, where the product design and process concepts are largely fixed in relation to each other, having been carried forward from earlier products in the family. Accordingly, while these projects also require the early involvement of ME staff, the need for emphasis on manufacturability is not so great. Further, provided the experience of earlier products has been built into the product and process design, and is reflected in revisions to the management approach, the need for highly experienced ME staff is not as important to the performance of the product.

Our discussion of the graph, up to this point, has been in terms of the more easily placed 'diagonal' cases. However, new product development projects may be placed off the diagonal, either to the right or to the left. For example, achievement of manufacturability was associated with more complex deployment strategies than achievement of shorter development intervals, even in more stable development contexts. ME seemed to have a greater influence on manufacturability than on the length of the development interval. As such, when a dimension of product performance is more amenable to the efforts of ME during the development process, ME makes sure that the product performs well on that dimension, through a more complex deployment strategy.

In sum, the deployment-context graph incorporates three major conclusions emerging from this study. First, the relationships between individual dimensions of product performance and individual ME deployment decisions were largely dependent on the context within which the products were developed. Second, management to achieve manufacturable new products through the deployment of ME resources required a deployment strategy, comprising a series of individual deployment decisions. Finally, the association between achieving manufacturable new products and deploying ME resources was contingent upon the development context.

IMPLICATIONS FOR MANAGEMENT

If the findings of this study are confirmed to be generalizable to products developed beyond the company studied, they carry several implications for senior manufacturing managers, and for the manufacturing engineering manager. For each manager, these implications involve manufacturing strategy, organization structure, and product performance.

Implications for the Senior Manufacturing Manager

Policy Formulation: As a policy maker for the manufacturing organization, the senior manufacturing manager plays a key role in the manufacturing planning process and oversees its implementation in his organization. The process aims to support a variety of strategic targets, such as market expansion, increasing market share, improving margins, building the team and improving its skills. The context within which new products are developed is another strategic issue. The newness of the technology, the location of component manufacture, the management approach to functional integration during the development process, and the required standards of product development interval and manufacturability are dimensions of this context which shape the management task and the performance outcome. For the senior manufacturing manager these dimensions of context are important to the planning agenda, and depend substantively on the quality of ME input to their debate.

ME managers are aware of the problems in developing manufacturable new products. They understand them, they are exposed to them every day, and they have to live with their consequences. Without close interaction with the ME manager during the planning process, the senior manufacturing manager will risk losing the benefit of accumulated ME experience, and may reach decisions about the development context incompatible with the selected business targets. He should ask such questions as does it matter if the new product manufacturing location is still undecided? What are the organizational implications of greater external sourcing of parts and subassemblies? How will new products affect the demands on ME skills?

Organization Structure: This study has illustrated the key 'line' rather than 'staff' function performed by ME in the new product development process. For the senior manufacturing manager, these insights raise questions of where ME 'fits' in the manufacturing organization, and what staffing policy is appropriate for building, maintaining and using ME's accumulated experience. Such a reeveluation may lead, in the extreme, to an organizational change such as occurred at Yamazaki Mazak of Japan (1986). There, production and engineering activities were integrated to give engineering management line responsibilities, with production management providing staff support.

Yet while the importance of manufacturing engineering to product development is increasing, ME's organizational identity is becoming harder to define. Earlier involvement of ME in the new product development process blurrs the distinctions between functional or discipline-based design and manufacturing engineers. Effective new product development needs ME and design engineers who are familiar with the specific requirements of and constraints on each other's responsibilities. Building this familiarity requires ME to develop criteria for manufacturability that reflect the manufacturing processes which will be used. However, ME needs familiarity with the constraints on product design, so that their manufacturability criteria do not place unnecessary limitations on the product designers. Accordingly, senior management should routinely assess formal training needs for manufacturing and design engineers to gain awareness of each other's competence and limitations. A series of structured visits by design engineers to the facilities where their products will be manufactured, is one way to aid the process.

Traditionally, senior management have viewed ME as an element of manufacturing overhead, whose size is determined through financial cost measures rather than product and process responsibilities and activities. However, the tendency towards short-term reductions in ME staff in response to current sales results, leads to inconsistency between the size of the ME staff and the firm's long-run objectives. Ensuring that both ME staff level and mix is consistent with the development program of the firm is important to the senior manufacturing manager. Without the appropriate numbers, mix of expertise and experience, ME will be forced to 'cut corners' in trying to develop products to specification in the increasingly shorter times which are available. Adverse consequences are measured in terms of costly manufacturing problems, engineering changes, and loss of intellectual assets. ME experience that is held only by ME staff members and not captured in documentation and training programs, is vulnerable. Maintaining the continuity of ME membership of successive product development teams, is one way to capitalize on past experience and learning.

Even if senior manufacturing management recognizes the need to increase the ME establishment, where are these MEs going to come from? How long will it take to find them, recruit them, and develop them into contributing members of the ME establishment? Most manufacturing engineers need special training and exposure to achieve a proper balance of technical and managerial skills necessary for success in future decades. Traditional university engineering programs tend to overlook the development and preparation of graduates ready for the management challenge inherent in the new product development process. Accordingly, establishing a supply of management-oriented manufacturing engineers is a important priority for both manufacturing industry and manufacturing engineering programs.

Performance: The final major implication of this study for the senior manufacturing manager concerns management performance and the assessment of new product performance, in particular, in relation to the evocative, but commonly misunderstood, objective of design 'right-first-time'. The senior manager should assess the time frame over which manufacturability-related product performance is evaluated, while ensuring that performance is indeed reviewed.

As a motivator, the objective of design right-first-time is clear. However, its achievement is difficult. Provision for active involvement by the senior manager in the performance review process is often made in development procedures. This involvement is possible both during and after the completion of the product development. However, senior managers do not always attend the formal progress reviews during the product development process, resorting instead to report reading. These managers lose a unique opportunity to provide needed guidance and support for their product development teams, or, in a word, to coach their teams towards their objectives.

Yet, corporate procedures governing the development of new products are no substitute for managing a project. Rather, in addition to performance review, they provide an opportunity for management to manage the tradeoffs that always arise over the course of a project. However, they may also inhibit progress unnecessarily, and development teams break these rules in the best interests of the project. So, just as the trick in rule breaking is to know what rules to break and when, senior managers need also to know when to 'turn a blind eye' on the activities of the development team, and to evaluate the results rather than the processes by which they were achieved. As always, of course, the senior manager must investigate the procedure to capture and legitimize the actual process followed by the development team for the next project.

The length of the time frame over which manufacturability-related product performance is evaluated, is worthy of senior management attention. Newer products are typically less manufacturable and experience more manufacturability-related change than less-new products. Ideally, the incidence of this type of change should have been eliminated by the start of volume production. In practice, however, this type of engineering change is common after production starts and is often related to time and volume-based limitations on the screening of designs during the development process. By addressing those manufacturability issues, which emerge after volume production starts, the recurrence of that type of change in later, less-new products might be avoidable. As such, a product exists in relation to its family, and is a function of all other related products up to its time. Accordingly, evaluation of the manufacturability-related performance of a given product in relation to its family, and over a longer period, might provide a more useful assessment with guidance for future action.

Finally, while progress against technical and commercial objectives is reviewed during the development process, the senior manufacturing manager needs to ensure that the management of the development process as a whole is reviewed on completion of the process. There is great potential in getting team members to structure their management experience of the project, and to discuss it with members of the ME group and with the other functional groups represented on the development team. The end results could include the improvement of procedures, the highlighting of false operating assumptions, and building trust for the next project.

Implications for the Manufacturing Engineering Manager

Policy Implementation: The manufacturing engineering manager plays a key role in the implementation of manufacturing policies in his (or her) organization. The management of the new product development process to achieve product manufacturability is not a simple task. I have discussed the importance of development context to the performance of new products and to the deployment of ME resources during the new product development process. The implication is clear: assessment of the development context of a project is important before committing any ME resources to the project.

In particular, the ME manager should consider carrying out an evaluation of product newness at the start of the definition stage of the development process. As such, each product development would be considered in relation to its family. This evaluation would parallel the manufacturability assessment and value analysis sessions, and establish the relative newness of product and processes in terms of major product components and subassemblies. The focus would be on the management implications of the newness of this product, in terms of ME deployment. This family, rather than product focus, would also put the ultimate product performance in perspective: that is, in relation to its family.

Organization of ME: Earlier involvement of ME in the new product development process requires that both ME and design engineering become familiar with the specific requirements of and constraints on each other's responsibilities. A disciplined management approach to the coordination of design and ME resources during the new product development process contributes to achieving this familiarity. However, such an approach does not, of itself, replace the need for individual ME staff members to be able to relate to other functionaries without guidance from procedures.

Accordingly, a key objective of the ME manager is the development and assignment of competent staff to new product development projects. In this context, ME staff competence is defined, not merely in a technical engineering sense, but also in relation to an ability to interact and to integrate their activities with product designers and marketeers. Development of these ME staff will be helped by use of explicit criteria for manufacturability, and care in the timing of that use during the development process.

The need for this type of integration and reflection defines a 'new breed' of manufacturing engineer. No longer just the technical specialist in specific process areas, the ME should have strong communication skills, work effectively in multi-disciplinary teams, be able to communicate his (or her) management experience, and feel challenged to update the breadth and depth of his technical skills on a regular basis.

Performance: Structured ME experience of the product development process is captured in formal revisions to parts drawings, component specifications, manufacturability guidelines, and use of common parts modules. The experience is also reflected in revisions to the coordination of design and ME resources during the development process. The timing of manufacturability assessments is an example of such a revision. Most vulnerably, ME experience is held by ME staff members. The vulnerability arises from the difficulty in achieving continuity of ME staff membership of successive product development teams, due either to competing projects or to 'swings' affecting the ME establishment, both in number and mix of engineers and technicians, resulting from short-term changes in sales levels. Providing a forum for ME staff members to structure and disseminate their experience following each new product development project, is an important consideration for the ME manager.

Part of the structuring of experience could come from analysis of the records of ME manhours expended during the development process, and from engineering change notices. ME managers have details of manhour expenditure available to them, gathered as part of the cost control function, and based upon timesheets. Engineering changes are recorded for change control purposes. This study demonstrated some uses, beyond change or cost control, to which these data can be put, such as project evaluation. While managers may say, with some truth, that these data do not reflect actual occurrences, because they are used to smooth budgets or to control the extent to which change is publicized, they are only fooling themselves. Inattention to the quality of manhour expenditure and change records results in a poor basis from which to improve performance on the future projects.

IMPLICATIONS FOR RESEARCH

Research on management for manufacturability is just emerging. This study suggests a number of directions for future research. First, the sample of products investigated in this study was drawn from one product category, developed within one company. This company was, in many respects, recognized as a well-managed company in a highly competitive and rapidly changing industry. However, as in any study based upon such a small sample, the findings serve more to spotlight future research directions than to reach precise conclusions. Replication for other products, in other firms and industries is an important next step. Inclusion of more product development projects and firms would strengthen the potential of the statistical analysis. Inclusion of other industries, with similar or different rates of new product introduction, may or may not produce similar results, as the new product development process and the embodiment of the manufacturing engineering expertise may differ. However, the end result would be to enhance the conceptual framework underlying this study.

Through this study, the concept of engineering change expanded to distinguish between that apparent to the customer, and to manufacturing. In applying this concept, the objective of designing 'right-first-time' became more meaningful. However, the original operationalization of the incidence of engineering change was limited in the scope of its coverage. While I identified additional indicators of engineering change, I was not able to utilize the data in any statistical analysis. Further study of engineering change is necessary, based upon this wider set of indicators.

Beyond simply extending the study, a number of specific and tantalizing research opportunities with management implications have emerged also. The study investigated a set of relationships among variables, some of which were situational and others of which were managerially influenced. For the individual new product development projects, the deployment of manufacturing engineering resources was largely determined by the ME managers. However, the context within which the product was developed also influenced both the nature and availability of those resources, and also the ultimate product performance. What is the relative strength of these influences? To what extent is the performance of newly developed products influenced more by context than by direct management action on the project? If context is important, what avenues are open to ME managers to influence this context as part of the policy formulation process?

This study focused on the deployment of manufacturing engineering resources during the development process. The context within which these resources were deployed was defined, in part, by the extent of inhouse manufacture of components and subassemblies. The role of a manufacturing engineering group with an external focus on vendor management was identified but not investigated. The parallels between the management of this externally focused group and the ME group investigated in this study should be investigated. What are the similarities and differences in the management task of integrating design with manufacturing, when the manufacturer is geographically and organizationally separate? Are the same engineering resources of use, and are the deployment strategies similar? As companies change the degree to which they depend upon outside sources for the supply of components and subassemblies, these questions become key in making the best choices among alternative types of engineering resources.

The length of the development interval emerged as a dimension of the context within which new products were developed, in addition to being an outcome of the development process. This outcome raises the issue of inter-relationships among the elements of product performance. Manufacturability, engineering change, and development interval were shown to be individual dimensions of product performance. However, the possibility of mediation of the basic performance-deployment relationship, by, for example, the length of the development interval or the ease of manufacture, remains unanswered. In other words, are there intermediate and final performance indicators which are related and have explanatory and even, predictive power? A similar study, based upon a larger sample size, would permit such a framework to be analysed, and provide more specific guidance for managers in managing among conflicting development objectives.

In like fashion, there may well be inter-relationships among the various dimensions of manufacturing engineering deployment. For example, is a particular profile or distribution of manhour expenditure associated with carrying out differing sets of activities in differing product development contexts? If so, are there particular combinations of activities and manhour expenditure which lead to better product performance?

Manufacturing engineering is a strategically important function in the fight by companies to develop a sustainable, manufacturing-based competitive advantage. The focus of this study was on the product development activities of ME. There are other dimensions to this function, including process development, support and improvement, and product support and improvement. Exploration of these dimensions of ME management is a necessary further step towards understanding a major infrastructural element of manufacturing. This study is a positive step towards such an understanding.

Finally, increased manufacturability over a family of new products is a sign of a learning organization, and may lead to simple survival on a cost basis. Design and engineering techniques for the development of manufacturable products are available, and this study has pointed the way in terms of ME deployment strategies. However, simple survival is not the same as long-term success which requires, not only manufacturable new products, but also the availability of functionally better and manufacturable products in less time than one's competitors. Constantly improving the outcome along all three dimensions of product performance requires the management of tradeoffs during the development process.

Yet, are such tradeoffs and long term success becoming increasingly incompatible? This area warrants further research. Management of tradeoffs among the various dimensions of product performance must be better understood. Which of the dimensions are primarily a reflection of marketing or manufacturing skills, and which reflect design, manufacturing engineering or vendor engineering expertise? In what ways might these various engineering functions be managed such that the three objectives of functionality, manufacturability and rapid availability can be met? Is manufacturing becoming in some ways less important and subsidiary to engineering, as the intolerance for tradeoffs drives engineering towards being right first time?

These questions highlight the increasing complexity and challenge facing manufacturing firms. A host of tools is available, and under development, designed to improve the responsiveness, flexibility and effectiveness of manufacturing in relation to new product development.

Many of these tools are computer-based and integrated with systems in other functional areas. However, without a fundamental understanding of the management of manufacturing engineering resources, firms may never realize the potential of these tools for improvement. The challenge facing researchers is to facilitate such understanding.

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APPENDIX I - PRODUCT SUCCESS STUDIES

Study	Definition of Success	Key Determinants of Success
Myers & Marquis (1969)	Commercial success: return on sales; savings in production costs.	Internal & external communication; Innovation as a Corporate-wide task; Need-pull; Cumulation of small incremental innovations.
Globe, Levy & Schwartz (1973)		Technical entrepreneur; Early recognition of market need; Funding availability; Confluence of technologies.
Rubenstein, Chakrabarti, O'Keeffe, Souder & Young (1976)	Technical and Economic success	Recognition of needs; Clarity of performance requirements; Frequency of contact with customers/users; Level of interdepart--mental & project team communication; Success in meeting time schedules.

Study	Definition of Success	Key Determinants of Success
DeCotiis & Dyer (1977; 1979)	Manufacturability & business performance; technical performance; cost efficiency; personal growth; technological innovativeness.	External environment relations; Functional organization relations; Internal operations
Yoon & Lilien (1985)	First year market share.	Market growth; life cycle stage; Marketing efficiency.
Ettlie & Rubenstein (1987)	Technical success: performance relative to project specification, at budgeted cost, during a required time period. Commercial success: market share & ROI.	Firm size; Product radicalness.
Cooper & Kleinschmidt (1987 a)	Financial performance; opportunity window; market share.	Product advantage; Agreement on product and project prior to development; Synergies: technological production, marketing & managerial.
Langowitz (1988)	Initial commercial manufacture outcome: output, quality, delivery problems; smoothness of the initial manufacture.	Priority of manufacturability in the product's design; Emphasis on manufacturability; Development process coordination.
Hise, O'Neal, McNeal, Parasuraman (1989)	Commercial success	Performance of specific product design activities.

APPENDIX II - STUDIES COMPARING PRODUCT SUCCESS & FAILURE

Study	Definition of Success	Key Determinants of Success
Rothwell, Freeman, Horlsey, Jervis, Robertson, & Townsend (1974)	Commercial performance: market share & profit	Strength and characteristics of management; Marketing performance Understanding of customer needs; R&D efficiency in development; Communications.
Gerstenfeld (1976)	Technical performance	Tight project control; Early warning systems.
Cooper (1979)	Commercial performance: profitability	Product uniqueness & superiority; Market knowledge; Marketing, technical & production synergy & proficiency.

Study	Definition of Success	Key Determinants of Success
Hopkins (1980; 1981)	Performance against management's original expectations.	Market research; Technical problems in design or production; Timing of market introduction; Allocation of responsibility for project initiation & coordination; Formalization of arrangements for ensuring closer cooperation between marketing, R&D and 'other functions'.
Maidique & Zirger (1984)	Achievement of financial breakeven	Match with user need; Planning effectiveness; Development efficiency; Closeness to firm's areas of expertise; Timing of market introduction.
Baker, Green & Bean (1984)	Technical & commercial success	Project uncertainty; Production/Marketing experience; Top management involvement; Business & technical goal definition.

Study	Definition of Success	Key Determinants of Success
Cooper & Kleinschmidt (1987 b)	Commercial success: profitability, payback period, market share, relative sales, opportunity window.	Product advantage; Proficiency of pre-development, technological & market-related activities; Protocol; Market potential; Marketing synergy.

APPENDIX III - KEY INDIVIDUAL INTERVIEW QUESTIONS

New Product Performance and the Deployment of Manufacturing Engineering Resources during the Product Development Process

KEY INDIVIDUAL INTERVIEW

Division:
Interviewee:
Project:
Date:

WHAT THIS INTERVIEW IS ABOUT

This interview is being conducted by Paul Coughlan, School of Business Administration, University of Western Ontario, London. It is one of a number being conducted in your Division. The purpose of the interview is to develop a description of the Manufacturing Engineering task and staff allocations to a new product introduction project. The interview will focus on one particular project in which you have been involved. Specifically, I am trying to determine some of the factors associated, both positively and negatively, with the manufacturability-related performance of newly-developed products , and, in particular, the relationship between the deployment of the Manufacturing Engineering function and this performance.

WHAT YOU SHOULD DO

Please provide frank, honest responses to the questions asked. You will not be required to answer all of the questions on the attached questionnaire. For those questions asked, if you require time to access or verify data in order to respond, please take the time. During the interview, I will record your answers directly on the questionnaire. After the interview, please give me your reaction to the interview process, and feel free to make constructive suggestions to improve the interview content or process.

Thank you for your cooperation.

Paul Coughlan

Project Targets and Achievements

PLEASE ANSWER THE FOLLOWING QUESTIONS ON THE TARGETS AND ACHIVEMENTS OF THE PROJECT.

** Description of the product:

Name:

Market:

		Basic	Featured
Consumer	- lease		
	- retail		
Industrial	- lease		
	- retail		

Key Features:

Product Family:

Place in
Product Family: First:

cond:

Third:

Other
(please specify):

Key Dates:

design start ----------------------

basic shape selection ----------------------

funding submision ----------------------

order tooling ----------------------

order machinery ----------------------

design & develop test equipment ----------------------

finalise design ----------------------

preproduction ----------------------

1st production shipments ----------------------

** Which of the following documents are available for this project?

1. Commercial Specification
2. Capital Funds Appropriation
3. R&D Spending Summary
4. Manufacturing Plan
5. Quality Plan
6. Test Plan
7. Stage review minutes for Stages 1, 2, & 3
8. Project Schedule
9. Post-Audit
10. Engineering Manhour Returns by individual, by engineering case, by month, over the duration of the project.
11. Engineering Manhour Returns by individual, by cost improvement case, by month, since commencement of volume production.
12. Manufacturing Engineering organisation charts
13. Project organisation charts over the duration of the project
14. Engineering Change Notices for up to one year after product launch
15. Project Labour Profile

Product and Process Newness

PLEASE ANSWER THE FOLLOWING QUESTIONS ON THE GENERAL CHARACTERISTICS OF THE PROJECT. THESE QUESTIONS WILL COMPARE THE PRODUCT AND PROCESS WITH PREVIOUS PRODUCTS AND PROCESSES.

** Describe the Product Structure of the product:

	Number of Parts	
Product Elements:	Plastic / Mechanical	Electronic
1. Main PCB Assembly		
2. Keypad Assembly		
3. Base Assembly		
4. Communications Module		
5. Cords		
6. Jacks		
7. Other (please specify): -----------------		

** Quantify the following product characteristics:

1. Levels of Assembly -----
2. Number of Screws -----
3. Number of Rivets -----
4. Number of Free Leads -----
5. Number of Types of Material -----
6. Other (please specify)

   --------------- -----

** Describe the manufacturing processes used when the product was launched.
Is a process flow chart available?

** For which, if any, of the following product elements, was manufacture subcontracted, or manufactured on a dedicated production line?
If not manufactured on a dedicated production line, approximately how many other products shared the same production line?

Product Elements:	Subcontracted	Manufactured on a dedicated line	Other products on the line
1. Main PCB Assembly			
2. Keypad Assembly			
3. Base Assembly			
4. Communications Module			
5. Terminal Packing			
6. Cord Extrusions/Jacks			
Plastic Moldings:			
7. Communications module			
8. Keypad			
9. Housing			
10. Other (please spec)			

** Did the Plastics/Mechanical parts in the following product elements have to be altered or redesigned to be used in the new product?

Product Elements:	No alteration	Minor	Considerable	Major	Largely New Product
1. Main PCB Assembly	5	4	3	2	1
2. Keypad Assembly	5	4	3	2	1
3. Base Assembly	5	4	3	2	1
4. Communications Module	5	4	3	2	1
5. Cords	5	4	3	2	1
6. Jacks	5	4	3	2	1
7. Other (please specify): ----------------	5	4	3	2	1

** Did the Electronics parts in the following product elements have to be altered or redesigned to be used in the new product?

Product Elements:	No alteration	Minor	Considerable	Major	Largely New Product
1. Main PCB Assembly	5	4	3	2	1
2. Keypad Assembly	5	4	3	2	1
3. Communications Module	5	4	3	2	1
4. Other (please specify): ----------------	5	4	3	2	1

** Did the Manufacturing Process Equipment for the following product elements have to be altered or redesigned to be used for the new product?

Product Elements:	No alteration	Minor	Considerable	Major	Largely New Process
1. Main PCB Assembly	5	4	3	2	1
2. Keypad Assembly	5	4	3	2	1
3. Base Assembly	5	4	3	2	1
4. Communications Module	5	4	3	2	1
5. Terminal Packing	5	4	3	2	1
6. Cord Extrusions/Jacks	5	4	3	2	1
7. Plastic Moldings:	5	4	3	2	1
8. Other (please specify)	5	4	3	2	1

** Did the Tooling for the following product elements have to be altered or redesigned to be used for the new product?

Product Elements:	No alteration	Minor	Considerable	Major	Largely New Tooling
1. Main PCB Assembly	5	4	3	2	1
2. Keypad Assembly	5	4	3	2	1
3. Base Assembly	5	4	3	2	1
4. Communications Module	5	4	3	2	1
5. Terminal Packing	5	4	3	2	1
6. Cord Extrusions/Jacks	5	4	3	2	1
Plastic Moldings:					
7. Communications module	5	4	3	2	1
8. Keypad	5	4	3	2	1
9. Housing	5	4	3	2	1
10. Other (please specify)	5	4	3	2	1

** Did the Manufacturing Methods for the following product elements have to be altered or redesigned to be used for the new product?

Product Elements:	No alteration	Minor	Considerable	Major	Largely New Methods
1. Main PCB Assembly	5	4	3	2	1
2. Keypad Assembly	5	4	3	2	1
3. Base Assembly	5	4	3	2	1
4. Communications Module	5	4	3	2	1
5. Terminal Packing	5	4	3	2	1
6. Cord Extrusions/Jacks	5	4	3	2	1
Plastic Moldings:					
Plastic Moldings:					
7. Communications module	5	4	3	2	1
8. Keypad	5	4	3	2	1
9. Housing	5	4	3	2	1
10. Other (please specify)	5	4	3	2	1

** Identify changes in the stages used in the manufacturing process after the product was launched.
When did these changes take place?

Stage	Manual to Automated	Capacity Increase	Capacity Decrease	Equipt	Methods
1. Main PCB Assembly					
2. Keypad Assembly					
3. Base Assembly					
4. Communications Module					
5. Terminal Packing					
6. Cord Extrusions/Jacks					
7. Plastic Molding					
8. Other (please specify)					

** Identify the reasons for these changes:
By whom were they initiated?

Assembly Stage	Product Design	Process Design	Market Demand	Product Cost	Product Yield	Experi--ment	Other
1. Main PCB							
2. Keypad							
3. Base							
4. Communications Module							
5. Terminal Packing							
6. Cord Extrusions/Jacks							
7. Plastic Moldings							
8. Other (please specify)							

ME Involvement

PLEASE ANSWER THE FOLLOWING QUESTIONS ON THE INVOLVEMENT OF ME IN THE THE PROJECT.

** What Departments were involved in the management of the Project? At what stages of the project were they involved? What roles did these Departments play in the management of this project: prime or support?

	Project Phases				
Departments:	Initiation	Defn.	Devlmpt	Verificn	Mfng & Deploymt
1. Technology					
2. Marketing					
3. Manufacturing					
4. Manufacturing Eng.					
5. Quality					
6. Other (please specify): ___________________					

** For each of the major Project phases in which the ME Dept. was involved, what 'deliverables' were due at the end of each phase?

	Deliverables	
	Major	Minor
1. Initiation		
2. Definition		
3. Development		
4. Verification		
5. Manufacturing And Deployment		

** What number of staff in the ME Dept. WERE on the project team?
At what stages of the project were they involved?

Staff Categories:	Project Phases Initiation	Defn.	Devlmpt	Verificn	Mfng & Deploymt
1. Managers					
2. Engineers					
3. Engineering Technicians					
4. Clerical Staff					
5. Other (please specify): ____________________					

** What experience of previous projects did these ME staff have?
What was the date of the most recent such project?

	Related Projects	Similar Projects	Dis-similar Projects
1. With this Division			
2. With other Division(s)			
3. With other companies in the industry			
4. With other companies outside the industry			
5. Other (please specify): __________________			

** What number of staff in the ME Dept. who were NOT on the project team were involved in the support of this project?
At what stages of the project were they involved?

	Project Phases				
Staff Categories:	Initiation	Defn.	Devlmpt	Verificn	Mfng & Deploymt
1. Managers					
2. Engineers					
3. Engineering Technicians					
4. Clerical Staff					
5. Other (please specify): ___________					

** What experience of previous projects did these ME staff have?
What was the date of the most recent such project?

	Related Projects	Similar Projects	Dis-similar Projects
1. With this Division			
1. With this Division			
2. With other Division(s)			
3. With other companies in the industry			
4. With other companies outside the industry			
5. Other (please specify): ___________			

Design - Manufacturing Coordination

PLEASE ANSWER THE FOLLOWING QUESTIONS ON THE PROJECT MANAGEMENT PROCEDURES USED.

** Outline the Project Organization Structure, noting, in particular, 'prime' responsibilities for achievement of project phases, and the Manufacturing Engineering organization for the project:

** Describe the Design-Manufacturing Coordination Procedures used:

1. Stage Procedure
2. Other (please specify): ------------------

** In what form did the ME Dept. first learn of the requirements of this project?

1. Documented description of requirements
2. Conceptual discussion of requirements
3. Other (please specify): ---------------

** What form of requirements description was used?

1. Blueprints
2. Specifications
3. Standards
4. Other (please specify): -------------

** Did blueprints contain the following information?

	Detailed	General	None
1. Product Shape			
2. Product Dimensions			
3. Constituent Elements			
4. Other (please specify): ------------------			

** Did specifications contain the following information?

	Detailed	General	None
1. Constituent Materials			
2. Materials Treatment & Finish			
3. Manufacturing Processes			
4. Test and Rejection Procedures			
5. Tolerance Level			
6. References to Standards			
7. Maintenance Requirements			
8. Requirements for Integration with pre-existing equipt.			
9. Capacity			
13. Delivery Schedule			
14. Other (please specify):			

** Describe the origins of the Standards used.

	Detailed	General	None
1. Company-Specific			
2. Division-Specific			
3. Industry-Specific			
4. National			
5. International			
6. Other (please specify):			

Manufacturability

PLEASE ANSWER THE FOLLOWING QUESTIONS ON THE MANUFACTURABILITY OF THE PRODUCT.

** In which of the phases of the project did the following concerns arise for ME, if at all?

	Project Phases				
Concerns:	Initiation	Defn.	Devlmpt	Verificn	Mfng & Deploymt
1. Tolerances					
2. Number of Parts					
3. PCB Component Density					
4. Number of Free Leads					
5. Standardisation of Fasteners, Components, Materials, Finishes					
6. Presentation of Parts					
7. Orientation of Parts					
8. Insertion of Parts					
9. Joining of Parts					
10. Need for Final Assembly Adjustments					
11. Self-Locating Features of Parts					
12. Other (please specify):					

** In your opinion, what emphasis was placed by ME on the attributes of piece parts and assemblies for the product as a whole?

	Low Emphasis				High Emphasis
1. Tolerances	1	2	3	4	5
2. Number of Parts	1	2	3	4	5
3. PCB Component Density	1	2	3	4	5
4. Number of Free Leads	1	2	3	4	5
5. Standardisation of Parts	1	2	3	4	5
6. Presentation of Parts	1	2	3	4	5
7. Orientation of Parts	1	2	3	4	5
8. Insertion of Parts	1	2	3	4	5
9. Joining of Parts	1	2	3	4	5
10. Need for Final Assembly Adjustments	1	2	3	4	5
11. Self-locating Features	1	2	3	4	5
12. Other (please specify):	1	2	3	4	5

** How would you rate the ease of manufacture of the product at the commencement of volume production?

	Poor				Outstanding
1. Tolerances	1	2	3	4	5
2. Number of Parts	1	2	3	4	5
3. PCB Component Density	1	2	3	4	5
4. Number of Free Leads	1	2	3	4	5
5. Standardisation of Parts	1	2	3	4	5
6. Presentation of Parts	1	2	3	4	5
7. Orientation of Parts	1	2	3	4	5
8. Insertion of Parts	1	2	3	4	5
9. Joining of Parts	1	2	3	4	5
10. Need for Final Assembly Adjustments	1	2	3	4	5
11. Self-locating Features	1	2	3	4	5
12. Other (please specify):	1	2	3	4	5

** In what areas did the project in general experience problems? What influence did these problems have on achievement of technical, cost and introduction goals?

	Problems				
	None	Minor	Minor & Major	Major & Minor	Major
1. Fabrication & handling of individual piece parts					
2. Inspection & test of individual parts & assemblies					
3. Assembly, kitting, & handling of individual parts					
4. Process Start-up					
5. Other (please specify): ________________					

ME Staff Management

PLEASE ANSWER THE FOLLOWING QUESTIONS ON THE MANAGEMENT OF THE MANUFACTURING ENGINEERING FUNCTION IN RELATION TO THE DEVELOPMENT AND INTRODUCTION OF THE PRODUCT AND ITS ASSOCIATED MANUFACTURING PROCESSES. THE INITIAL FOCUS WILL BE ON YOUR POSITION ON THE PROJECT TEAM.

** What position did you hold on the project?

1. Department Manager
2. Project Manager
3. Section Manager
4. Other (please specify) ____________________

** When were you appointed to this position?

Date: ______________

** To whom did you report?

	Direct Line	Dotted Line
1. General Manager		
2. Director		
3. Department Manager		
4. Project Manager		
5. Section Manager		
6. Other (please specify): ____________________		

** On what basis? With what frequency?

Basis:	twice a year	monthly	weekly	twice weekly	daily
1. Written report					
2. Verbal report					
3. Exception					
4. Other (please specify)					

** Who reported to you?

1. Director
2. Department Manager
3. Project Manager
4. Section Manager
5. Other (please specify)

** With whom did you work?

1. General Manager
2. Director
3. Department Manager
4. Project Manager
5. Section Manager
6. Other (please specify)

** For what manufacturing engineering activities were you directly responsible?

1. Production Planning / Process Engineering
2. Tool Design
3. Tool Room
4. Process Equipment Engineering
5. Test Set Engineering
6. Plant Layout
7. Material Handling
8. Work Standards / Methods
9. Production Analysis
10. Reproduction and Records
11. Manufacturing Standards
12. Other (please specify)

** Did you assign ME staff to the project?

Yes ---

No ---

** How would you rate the ME staff as a group who were involved on the project?

	Poor				Outstanding
1. Experience on Related Project(s)	1	2	3	4	5
2. Experience on Similar Project(s)	1	2	3	4	5
3. Experience of Working with Multi--Disciplinary Colleagues	1	2	3	4	5
4. Technical Expertise	1	2	3	4	5
5. Academic Qualification	1	2	3	4	5
6. Other (please specify):	1	2	3	4	5

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** Please name any ME staff on the Project Team with whom you had worked before (on a different project).

Name	Project	Duration of Earlier Association
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** To what activities did you assign these subordinates?

1. Production Planning / Process Engineering
2. Tool Design
3. Tool Room
4. Process Equipment Engineering
5. Test Set Engineering
6. Plant Layout
7. Material Handling
8. Work Standards / Methods
9. Production Analysis
10. Reproduction and Records
11. Manufacturing Standards
12. Other (please specify) --------------------

** What was the length of a typical activity assignment?

1. less than 6 months ------
2. 6 months to a year ------
3. 1 - 2 years ------
4. Other (please specify): ------------------

** For the project, is a project schedule available?

Yes ---   No ---

** If yes, please describe the development of the product, and the associated manufacturing processes, in terms of activities detailed on the schedule for which you were responsible, and assigned ME staff:

ACTIVITY:

PRODUCTION PLANNING/ PROCESS ENGINEERING	SCHEDULE ACTIVITIES
	------------------
1 Manufacturability assessment	------------------
2 Operations sequencing	------------------
3 Machine selection	------------------
4 Manufacturing spec. preparation	------------------
5 Non productive matl. specification	------------------
6 Machine and tool spec.	------------------
7 Machine and tool cost estimating	------------------
8 Assistance in prodn difficulties	---------------- --
TOOL DESIGN	
9 Design of special machines/equipt/tools	------------------
10 Checking/proving of vendors machine/ tool design work	

11 Tool requirements analysis

TOOL ROOM

12 Tool maintenance

13 Die, fixture, gage construction

14 Tooling modification

EQUIPMENT ENGINEERING

15 Process equipment specificn./selection

16 Equipment cost estimating

17 Process specification preparation

18 Equipt. coordination for shop trials

PLANT LAYOUT

19 Prodn. flow analysis/determination

20 Location of machines, equipment, storage facilities, aisles, shipping/receiving

MATERIAL HANDLING

21 Analysis of product design, process, layout, materials, packaging and supply requirements

22 Matl. handling system development

WORK STANDARDS / METHODS

23 Establish direct labour budget stds. ------------------

24 Prepare direct labour estimates for price studies, projects ------------------

25 Periodic study of production operations ------------------

26 Correction of off--standard conditions ------------------

27 Employee suggestions evaluation ------------------

28 Standards verificn. ------------------

29 Determination of bases for authorisn. of direct labour ------------------

PRODUCTION ANALYSIS

30 Prepare/review project control records ------------------

31 Obtain/distribute advance information on new parts/programs ------------------

32 Analyse/coordinate product change requests ------------------

33 Develop data for make-or-buy determination ------------------

34 Prepare cost analyses presentations, illustrations, reports, artwork ------------------

REPRODUCTION and RECORDS

35 Maintain up to date tool drawings, releases,

and planning records

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36 Quantity reproduction /distribution of drawings, and process sheets

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37 Processing of work orders and procurement requests

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38 Control of office equipment and layout

MANUFACTURING STANDARDS

39 Development of local standards

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40 Development of proposals for company standards

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41 Publishing and distribution of standards
