A MODEL FOR THE USE OF COST INFORMATION IN AMT ENVIRONMENTS

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ABSTRACT

This thesis provides a critical review of the way in which cost information is used as a basis for decision-support across the broad range of manufacturing activity and goes on to propose and develop a model for the more effective use of such information. The research "bridges" the functions of engineering, management and accounting and is innovative in the way that it places recent research in the area of management accounting into the context of engineering and management decision-making.

The review of current practice is based upon published material, a survey of practice in three manufacturing organisations and upon extensive experience gained by the author in industry, "Teaching Company Scheme" (TCS) supervision and supervision of industry based undergraduate projects concerned with cost management. The research reveals widespread belief on the part of engineers, managers and accountants, that current approaches and practices with respect to the use of cost information do not provide a sufficiently accurate and realistic base for decision-support and goes on to identify the underlying reasons for this belief. Analysis and discussion is provided to support the hypothesis that "Traditional approaches and practices with respect to the determination, communication and use of cost information do not provide a satisfactory basis for decision-support in today's highly competitive and technologically advanced markets".

A comprehensive review and analysis of recent and current initiatives and developments in the areas of management accounting, concurrent engineering, structured project management and information technology is provided and forms the basis for the development of a conceptual model. The model integrates concepts, principles and techniques from: activity based costing, "structured" project management and concurrent engineering. Recommendations for further work with respect to industrial implementation and development of the model are provided.

PREFACE

The research described in this thesis is broadly based and multi-disciplinery in its nature, drawing extensively from the considerable industrial and academic experience of the author. The work is innovative in the way in which it applies and integrates "new" approaches to the use of cost information and does not represent an attempt to develop particular approaches at the "detail" level. The primary aim of the research was to enable greater understanding of the "whole" and to provide a "platform" for more "focused" research at the detail level.

One of the major challenges associated with the work was that of "bridging" the functions of engineering, management and accounting i.e. placing recent developments in the areas of management accounting, concurrent engineering and structured project management into the context of engineering and management decision-making. Experience gained by the author in industry, "Teaching Company" supervision and in supervision of industry based undergraduate projects concerned with cost management, was of considerable value in carrying out the work.

Having completed the research the author is reminded of a conference several years ago, at which the late John Burbidge posed a question to one of the speakers. The speaker gave a comprehensive reply and was thanked by Professor Burbidge. Professor Burbidge went on to say that "I remain confused but upon a much higher plane". It is intended that the work described in this thesis will provide the basis for a continued programme of research into this important and complex area of decision-making.

The broad nature of the research was reflected in the supervisory team and I am indebted greatly to:

Dr Kevin Barber (Total Technology Unit - UMIST) for his guidance and support as Director of Studies, his breadth of understanding and his ability to pose very "pointed" questions.

Prof. Colin Drury (Reader in Accountancy - University of Huddersfield) for essential guidance and advice concerning accounting issues and for his enthusiasm and interest with respect to the broader aspects.

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The major industrial input to the research was provided by three companies and it would not be practical to mention all the staff to whom I am indebted. I would however like to thank in particular:

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Thanks are due also to my wife Sandra and to my children Marie, Daniel and Rebecca, for supporting me and accepting my virtual absence from family life for long periods over the last five years.

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1.0
INTRODUCTION

For the majority of manufacturing organisations the overall business objective is the maximisation of long run profitability. If profit is defined as simply the difference between revenues and total cost, then it is clear that the acquisition, analysis and dissemination of accurate cost oriented information is of fundamental importance to effective decision-making. This programme of research aims to establish the degree to which current techniques and practice with respect to the determination, dissemination and use of cost information, supports effective decision-making. A further aim of the research is to critically review recent developments/initiatives in the areas of cost accounting, design management, manufacturing management and IT and to develop an integrated and effective approach to their application. A considerable amount of research has been carried out within the various "disciplines" by other workers but relatively little has been published with respect to its integration and practical application.

1.1 BACKGROUND

The following sections (1.1.1 to 1.1.6) are intended to provide an overview of the areas and issues which will be addressed and hence the scope of the work. The concepts and issues introduced are developed in detail in the main "body" of the report.

1.1.1 Sources of Cost Information

Traditional approaches to the determination of manufacturing cost are effective in the aggregation of costs for financial accounting purposes, but do not provide a suitable basis for determination of the cost associated with particular products/services Kaplan [1] and Drury et al [2]. Kaplan [1] and Bellis-Jones [3] claim that firms are unaware frequently that some products which appear to yield healthy profits are in fact being produced at a loss. It follows that some products which have been discontinued, as a result of their apparent lack of profitability, may in fact have been important contributors to the overall profitability of a firm.

Johnson and Kaplan [4] contend that most of the management accounting practices currently in use, had been developed by 1925 and as such are not relevant to the highly competitive and increasingly technological manufacturing environment of today. While the views of Kaplan and Johnson are not accepted universally they do enjoy considerable support [5], [6], [7], and [8]. The most widely supported approach to radical change in the area of management accounting is that of "activity based costing"(ABC), developed by Kaplan and Cooper [9] and [10]. It is claimed that ABC allows for more accurate allocation of overhead to particular products and that it provides a focus on the activities that "drive" cost. An alternative or complementary approach is that of "throughput accounting"(TA) , as proposed by Galloway and Waldron [11] and by Schmenner [12]. Throughput accounting takes the emphasis away from the identification of accurate/relevant product costs and concentrates on promoting the adoption of manufacturing decisions which will maximise saleable/profitable output over a given period.

The wide ranging debate within the management accounting profession, concerning the relevance and evolution of new approaches to performance measurement and decision support, is of fundamental importance to an investigation into the use of cost oriented information across the broad range of manufacturing activity. Of interest also are the perceptions of management accountants with respect to their role as providers and controllers of cost oriented information [13] and [14]. It has been suggested however that if performance criteria relate only to consideration of cost, the motivation and pre-occupation of managers, engineers etc., will focus on this criterion to the exclusion of marketing, managerial and strategic issues [16], [17] and [18].

1.1.2 Application of Cost Oriented Information

While it may be argued that the major responsibility for establishing, maintaining and developing systems for the acquisition, analysis and dissemination of cost oriented information, together with the publication of appropriate cost performance indices, lies with the management accounting function, responsibility for the effective application of such systems, indices and information is less well defined. A wide range of functions, from marketing and design to production and distribution, are involved in making decisions which could/should make use of cost oriented information. There is much evidence to suggest that production managers, engineers and others use and/or respond to cost information and performance indices in an unstructured and ill informed manner [8]. Functional divisions and behavioural factors often result in the pursuit of local objectives which are counter productive in terms of achieving the overall objectives of the firm. The need for a structured model for the application of appropriate concepts, techniques and performance indices, as a basis for integrated and effective decision-making, has been identified [15], [2] and [7]. Tayles [7] goes on to stress the need for collaboration between management accountants and engineers in such developments.

While there is ample evidence of well directed research, on the part of the accounting profession, concerning the development of more appropriate concepts and techniques, relatively little or nothing has been published with respect to the practical application of the new approaches across the broad range of manufacturing activity. What activity there is tends to be rather specialised and does not emphasise the effective application and integration of new approaches. Notable exceptions to this general trend include the work on investment analysis by Primrose and Leonard [18] and Hamblin and Hundy [19], the work on quality costs by Plunkett and Dale [20] and the work on assembly costs by Dewhurst and Boothroyd [21].

Recent initiatives in the area of "concurrent engineering" (CE) [22] and [23] provide an excellent basis for formalising the integration/co-ordination of engineering and business activity. There is however little integration of such initiatives with the new approaches to management accounting referred to in section 1.1.1 (a notable exception is the work of Dolinsky and Vollmann [24]).

1.1.3 Strategic Issues

In today's volatile and competitive markets the need for an appropriate, well communicated and well implemented business/manufacturing strategy is recognised widely as being a pre-requisite for long term profitability, It is essential that the management accounting and decision support systems are supportive of the strategy and promote rather than hinder its effective implementation. There is ample evidence to suggest that this is not the case for large sections of UK manufacturing industry [16]. A report by Ingersoll Engineers [25] in 1991 gave "a picture of financially driven companies with short term objectives" and is supported by Keegan and Eiler [26].

1.1.4 Market Trends

The increasing variety, complexity and technological content of products, together with reductions in product life expectancy, has placed enormous demands on the functions of engineering product design and process planning. It is widely acknowledged that 70%-80% of the cost of a typical manufactured product is built in at the design stage [27] and [28] and yet this area remains the least well served in terms of management accounting and other cost related information [3], [27] and [29]. The situation is exacerbated by the beliefs, attitudes, perceptions and education of most engineers (design and manufacture) with respect to cost issues. This is compounded by the fact that many engineers have little or no understanding of the costing systems employed in their organisation and therefore have little idea of what really "drives" the cost of their product. Many engineers tend to view cost issues as the domain of the accountant and therefore peripheral to their own area of activity [27].

1.1.5 Advanced Manufacturing Technology (AMT)

The increased application of AMT to the manufacture of products, in the form of CAD, automation, information technology (IT), etc., is both an opportunity and a threat. The rapid deployment of these new technologies is one of the primary reasons for the accelerating loss of relevance of traditional management accounting [4]. Information technology, in the form of integrated systems for collecting, analysing and disseminating information quickly and accurately, does however offer the scope for dramatic improvements in the effectiveness with which cost oriented information may be employed. For such systems to be effective they must be based upon an integrated model for decision-making across the whole range of manufacturing activity.

1.1.6 Conclusion

It is clear that the development of an effective model for the use of cost information must be built upon a sound understanding of current practice across the "boundaries" of engineering, accounting and operations management. Such an approach must therefore combine and co-ordinate the expertise and judgement of management accountants, operations managers and engineers at all "levels" of the organisation[7].

1.2 RESEARCH OBJECTIVES

1.2.1 Critical Review

To provide a critical review of the effectiveness of current approaches, techniques and practices with respect to the determination communication and use of cost information in decision support and thus to provide a basis for the development of more effective approaches.

1.2.2 Development of a Conceptual Model

To provide a model which may act as a logical framework for helping organisations to understand the contributions which may be made by the integrated application of modern approaches to the provision and use of cost information and to implement systems relevant to their particular circumstances. A considerable amount has been published concerning work in the individual areas of accountancy, engineering and management but relatively little of the work addresses the issue of applying new concepts, techniques and approaches in an integrated and effective manner.

1.2.3 Recommendations for Further Work

Identify the scope and need for further work, at a more detailed/specialised level, to implement and develop the model in practical industrial situations.

1.3 APPROACH

1.3.1 Phase One

A. A review of current practice and attitudes with respect to the use of cost oriented information in the various functional areas of manufacturing. Particular emphasis was given to the areas of engineering product design and process planning and manufacturing system design. Inputs to this aspect of the work included: published material, expert advice, Teaching Company experience and interviews with industrial personnel.

B. A review of recent and current developments in the area of management accounting, which was carried out largely by reference to the extensive published material in this area. The need for an extensive survey into current practice, with respect to management accounting, was made unnecessary by the publication of a comprehensive survey by Prof. J C Drury et. al. [2], the survey did not however provide information relating to why particular techniques/practices were employed. Information relating to why particular techniques are employed was obtained from other sources of published material and from interviews with accountants in the collaborating organisations.

C. Consideration of the current and potential role of IT in its widest sense. Input in this area was largely on the basis of published material, attendance at seminars and personal experience relating to the practical application of computers in the areas of: project management, process planning/estimating and manufacturing system simulation.

1.3.2 Phase Two

Evaluation of the work carried out in phase one and development of a general approach/structure, together with a strategy for its effective implementation. It was determined that the approach/structure should take into account the following:

Management accounting/costing issues

Information systems

Organisational issues

New technology (in particular IT)

Strategic issues

Operational issues

Behavioural issues

One of the most important aspects of this phase was the search for a common vocabulary for cost oriented information across the various functional areas.

1.3.3 Phase Three

Identification of the scope for further work, in particular that associated with practical industrial implementation of the model.

1.4 HYPOTHESES

In order to provide a clear aim for the research it was decided to establish an initial hypothesis to focus the information gathering and analysis associated with the first stage of the work. Following completion of the first stage (and validation of the initial hypothesis) a supplementary hypothesis was established as a focus for the innovative work which was to follow.

1.4.1 Initial Hypothesis

Traditional approaches and practices with respect to the determination, communication and use of cost information do not provide a satisfactory basis for decision support in today's highly competitive and technologically advanced markets.

1.4.2 Supplementary Hypothesis (Following Review and Analysis of Current Practice and Published Research)

Integration of the concepts, principles and techniques associated with "activity based costing", "throughput accounting", "structured" project management and "concurrent engineering" provides a foundation for the effective use of cost oriented information in AMT environments. Implementation of such an approach may act as a focus for providing organisation structures and manufacturing strategies appropriate to the competitive challenges of the 21st century.

2.0
REVIEW AND ANALYSIS OF CURRENT PRACTICE AND PUBLISHED RESEARCH

The majority of manufacturing organisations employ organisation structures based upon relatively traditional "functional" division of activity. Typical division would be as follows:

Corporate/Strategic Activity
Marketing/Sales
Research and Development/Product Design
Manufacturing Systems Engineering (System Design and Process Planning)
Production Planning , Procurement, and Shop Floor Operations
Shop Floor Operations and Supervision
Quality
Finance and Accounting
Maintenance
Personnel
Distribution and Customer Service

It was decided that the most sensible approach to a review of current practice would be to structure it around the functional divisions listed above - concentrating on the areas of product design, manufacturing systems engineering, production management and shop floor operations and supervision.

As stated in 1.3.1 inputs to this aspect of the research included: published material, expert advice, Teaching Company experience and interviews with industrial personnel. Appendix 1.1 details the basic information sought and Appendix 1.2 shows a questionnaire which was originally intended to form the basis for detailed interviews in the collaborating companies i.e. David Brown Vehicle Transmissions, Joseph Rhodes Ltd and Kent Introl. In practice it was found more productive to use a less structured approach for the interviews and staff from the key areas of: product design, manufacturing engineering, production management and accounting were interviewed over periods ranging from 2 hours to 4 hours. It was encouraging to find frequently that staff who had originally agreed to a "short" interview of 30 to 40 minutes were sufficiently interested in the project to spend a considerable amount of time in discussion, following the information gathering.

In addition to the detailed interviews carried out within the collaborating companies, 30 of the basic questionnaires were completed by part-time students currently in full-time employment in a wide range of functions and industries. The main aim of the survey was to establish:

- The nature and availability of cost information.
- Use of cost information.
- Techniques and approaches used to support decision-making.
- Knowledge and understanding of costing systems employed in the company.
- Knowledge and understanding of general principles of costing and new developments.
- Perceptions and attitudes to the use of cost information.

2.1 CORPORATE/STRATEGIC ACTIVITY

Twiss [30] points out that the need for "strategic thinking" has been widely appreciated in recent years and that most large companies now have some form of strategic planning. Strategic planning may be defined as a systematic analysis of all the factors which impinge on the current and potential operations of the firm, both internal and external. This would include consideration of the company's "strengths and weaknesses", together with potential "opportunities and threats", leading to the identification of an appropriate set of corporate objectives and policies appropriate to their achievement. The formulation of corporate objectives and corporate strategy is influenced and constrained by the aspirations/mission of the owners and senior managers of the company.

Strategic planning at the corporate level provides the basis for strategic planning at the functional level e.g. in the areas of marketing, manufacturing and product development. The process is iterative rather than sequential, in that detailed consideration of strategic issues at the functional level may necessitate a review of particular aspects of corporate objectives/strategy. The process of strategic planning is covered extensively in the "literature" and numerous models for strategy formulation have been proposed [31], [32] and [33].

A key issue in strategic planning is determination of the profitability associated with current and potential areas of activity. As stated in section 1.1.1 there is a widely held belief that current management/cost accounting systems do not provide accurate/relevant information at the product level. It follows therefore that an organisation wishing to base its business development on its more profitable areas of activity may find it difficult, if not impossible, to accurately identify/quantify these areas. This may be one of the factors contributing to Ingersoll Engineers "picture of financially driven companies with short term objectives" referred to in section 1.1.3. This "picture" of manufacturing industry is supported by evidence gained from research into current practice; the majority of respondents/contributors had little or no confidence in the ability of their company's costing system to quantify accurately the cost of particular products and activities.

One of the companies has, in recent years, moved from a cost accounting system which provided an hourly rate for each individual machine tool, to a system which provides a uniform hourly rate for machining operations in specified work centres, the work centres comprising machine tools of different type, age and level of sophistication. This action was taken in order to "simplify the financial accounting system" and to "reduce the tendency of internal customers to specify the use of lower cost machines, leaving higher cost machines (typically relatively new and sophisticated machine tools) idle". It was stated by one respondent that as capital invested in equipment could not be "uninvested" there was little point in wasting effort trying to identify the costs associated with particular machine tools. Performance measurement within the company was on the basis of actual hours versus standard hours. While this approach has some merit in providing simplified systems for financial accounting and the monitoring of manufacturing productivity/efficiency, it makes it difficult if not impossible to provide useful information relating to the cost implications of medium/long term decisions relating to product mix, product development and investment. It creates also an environment in which the performance of new capital plant is difficult to access in terms of cost/profit and the special costs of individual machines/facilities which require a relatively high level of support (e.g. the programming and maintenance costs of CNC machine tools) are lost in the general overhead. Strategy formulation and strategic investment in this company was, in practice, based upon operational and market factors such as capacity, quality and delivery, without reference to accurate/meaningful data concerning the cost implications of various alternatives.

A second company, involved in the manufacture of large, special purpose machinery operated costing systems which allocated cost on the basis of direct labour i.e. a universal allocation of "factory overhead" per direct labour hour. While this approach appeared to facilitate "balancing of the books", in that manufacturing costs were allocated to orders, there was little faith that the allocation reflected, accurately, the actual resources and effort expended on the various machine configurations. In periods of boom, profit margins had been such that the "bottom line" had been satisfactory, however as markets became more competitive and margins were reduced, the need to identify and control the cost of particular machine types and configurations became of paramount importance. The company's costing system was not capable of providing accurate information at the product level and this presented a serious handicap to strategy formulation and implementation. It is perhaps significant that this company has "ceased to trade".

A third company operated two different systems for the estimation of product cost: one operated by the marketing department (based on historical costing) and one operated by the production engineering department (based upon process planning and synthetic data). There was no integration or correlation between the two systems and considerable confusion as to which set of data would provide the most appropriate basis for medium to long term decision-making.

The general impression gained from the research was one of firms being reactive, with respect to "bottom line" problems i.e. tending to resort to "across the board" cost cutting and contraction rather than the selective contraction and expansion/development which may be more appropriate to long term profitability. This tendency towards cost reduction at the operational level, as opposed to cost management at the strategic level is corroborated by Shields and Young [34].

Capital investment is one of the most important issues associated with the implementation of corporate strategy and it would appear logical that the method used to allocate the capital cost of new plant to particular products (depreciation) should be compatible with the approach/assumptions used for its financial justification. In general terms this would mean that investments would ultimately (i.e. after their implementation) be identified as good or bad by their effect on the costs associated with the products against which they were justified and by reference to the company's performance measures. This, however, is frequently not the case - accountants select a standard method of depreciation, appropriate in terms of financial accounting and tax requirements, which may be totally out of line with the assumptions made for justification of the investment [35]. This promotes a situation where there is a mismatch between information used for the purposes of product costing and information used for decision-making. The situation is further complicated by the "cavalier" attitude of many engineers and managers to the issue of investment analysis, typified by this quotation from one of the respondents: "If we declared all the costs associated with new capital plant the accountants would not let us buy anything". A common objective for engineers and managers, when involved in capital investment decisions, is to "beat the accountants" rather than to ensure that they are proposing a sound business investment for the company. The lack of co-ordination between approaches to capital investment, product costing and performance measurement, apparent in the majority of the firms considered, is a barrier to the effective formulation and implementation of corporate strategy. This issue is discussed further in section 2.7.3.

2.2 MARKETING/SALES

Marketing is the primary link between an organisation and its environment [36]. Manufacturing organisations prosper in relation to the extent to which they identify and satisfy the needs/wants of their customers in the long run. The initial role of marketing is therefore to identify and quantify the needs/wants of existing and potential customers and to disseminate this information to other functional areas within the organisation, as a basis for decisions concerning corporate and manufacturing strategy, product design and product support. A further more obvious role is in the promotion, sale and distribution of the firm's products/services. Information provided specifically by the marketing function includes: product opportunities (types of product), magnitude and distribution of product demand, product pricing and product requirements in relation to reliability, maintenance, product life and customer support. An effective marketing approach will accommodate the constraints of capability and capacity inherent in the firm's manufacturing facilities, together with consideration of the profitability associated with various combinations of product mix.

Marketing professionals regard themselves as "business oriented" individuals, at the "sharp end" of the company/customer interface and would claim to give detailed consideration to the issues of price, cost, and profit in their approach to decision-making. In practice the situation with most of the companies considered appears rather different, with marketing/sales personnel concentrating on volume, price (as determined by the market) and delivery (as determined by the market). There appears often to be a belief that it is solely the responsibility of the manufacturing function to ensure that total manufacturing cost for a particular product is below selling price and that delivery "promises" are met. The belief that a full "order book" is in its own right an indication of marketing/sales success appears to be common.

In two of the companies considered, major orders were undertaken on the basis of fixed price and delivery with little or no reference, on the part of the sales personnel, to their colleagues in design, manufacture, procurement and production planning. In one of these companies (manufacture of large special purpose machinery) new orders were treated as projects and a formal approach, which included the use of project management software, was taken. The project planning did not, however, commence until after the price and delivery date of the new order had been agreed. Short time scales and a lack of useful information systems were quoted as a major reason for this situation.

Two of the companies considered had introduced a "project team" approach, along the lines set out by Parnaby [37], with multi-disciplinary teams, including design engineers, manufacturing engineers, marketing personnel and accountants, working on the development of new products. While this approach was considered to be highly effective it placed considerable demands upon staff time and was therefore restricted to large/expensive projects, with the more mundane day to day activity being managed by more "traditional" approaches.

The competitive advantages offered by AMT/CIM are frequently understated in the financial appraisal of manufacturing systems [38] and are not capitalised upon by marketing/sales personnel. Quantification of the financial benefits associated with:

reduced lead time, increased flexibility, increased quality and improved information systems is essential to manufacturing decision-making and the marketing function must increasingly play a role in this area.

The general impression gained from the research is that sales and marketing personnel tend to operate largely on the basis of experience, intuition and various "rules of thumb" for the estimation of cost. Company information systems did not appear to be geared to providing cost information appropriate to the sales/marketing function and as stated in 2.1, in one company the sales department operated its own cost estimation system without reference to other cost estimation systems in the company.

2.3 PRODUCT DESIGN

2.3.1 Background

Numerous models of the "design process" have been proposed over many years e.g. [39], [40], [41] and [42]. A common feature of such models is the portrayal of product design as a wide ranging activity which extracts, synthesises and analyses information from most if not all of the functional areas of the organisation, in the pursuit of designs which will be successful in the market place and be economic in their manufacture. Nevins [42] suggests that the traditional approach to product design involves discrete sequential progression from identification of market need/want to product production see Figure 1. It is suggested that the process is iterative in that problems identified at later stages of the sequence may necessitate modification of decisions made earlier in the sequence. A working party of the I Prod E [43] described a detailed drawing as "not just an instruction to manufacture; it is a financial authority stating tolerances, materials and construction that will demand the inevitable and irreversible expenditure of money". In the majority of cases the models treat the issue of cost as part of "design optimisation" and promote the use of techniques such as "value engineering" and "value analysis". Consideration of cost tends to be at the detail level with little discussion concerning the sources of cost information [44] and it is suggested that much of the cost information which is used is flawed [38]. Pahl and Beitz [39], Sheldon et al [44] and Dewhurst and Boothroyd [45] stress the importance of using cost information at the conceptual design stage and this is supported by the results of work carried out at Rolls Royce [43] see Figure 2. Sheldon et al [44] refer to the high "leverage" associated with design activity, it follows therefore that a move towards consideration of cost at the conceptual stage of design may have a considerable negative effect if it is based upon poor/inappropriate cost information.

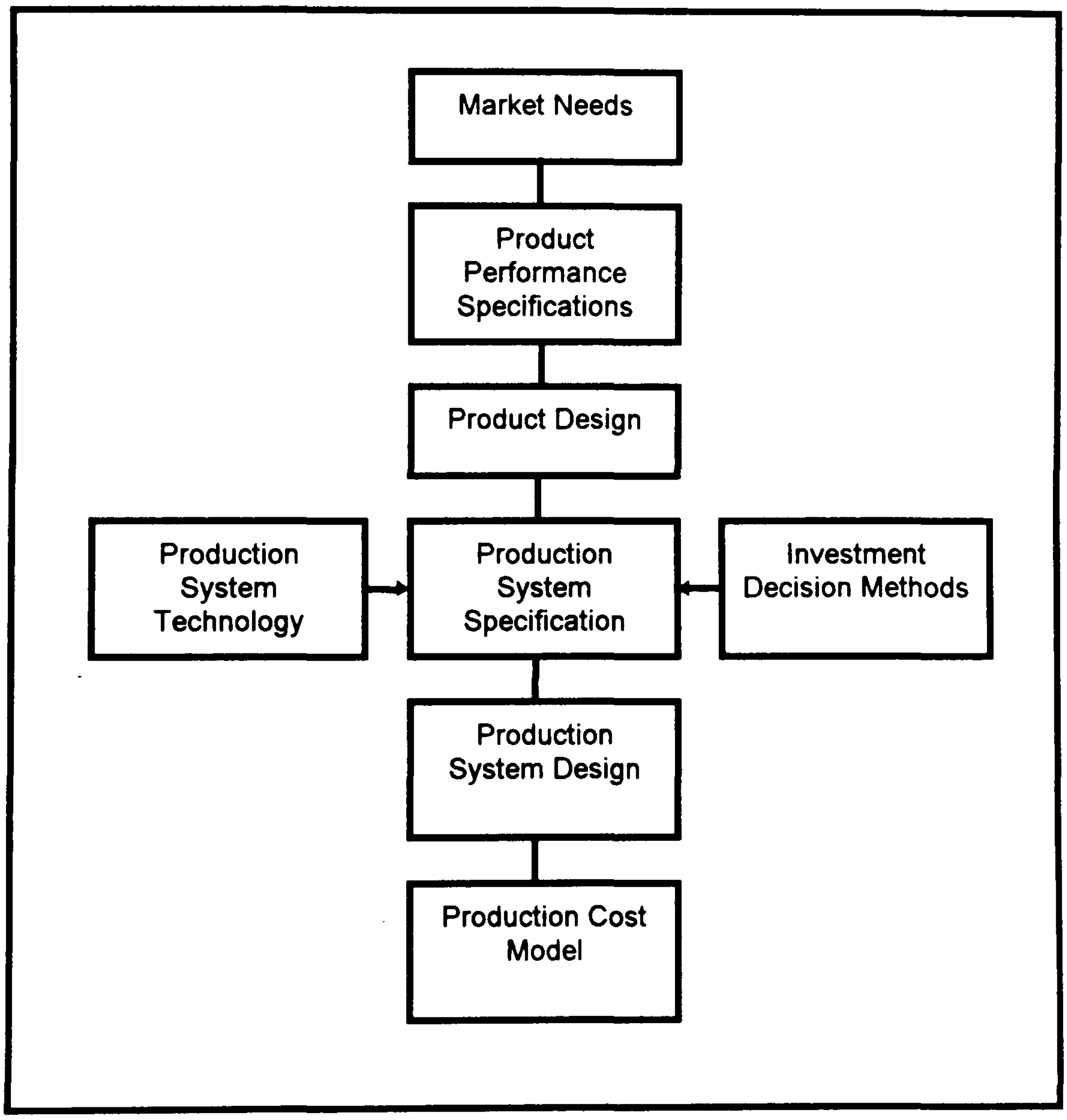

Figure 1 Traditional Approach To Product Design (Nevins [42])

Criticism of engineering design over recent years has been associated with the tendency for it to be carried out in what might be described as an "information vacuum" and to the tendency to concentrate on consideration of function rather than manufacturing cost and profitability [24], [43], [44], [46] and [47]. This situation arises in part as a result of the organisational structures and cultures within which engineers operate and in part as a result of the traditional education, attitudes and beliefs of engineers themselves.

Traditional organisation structures in the UK have encouraged functional separation rather than integration [48]. A tendency for over specialisation and narrow focus results from this situation and is particularly prominent in the "technical" functions associated

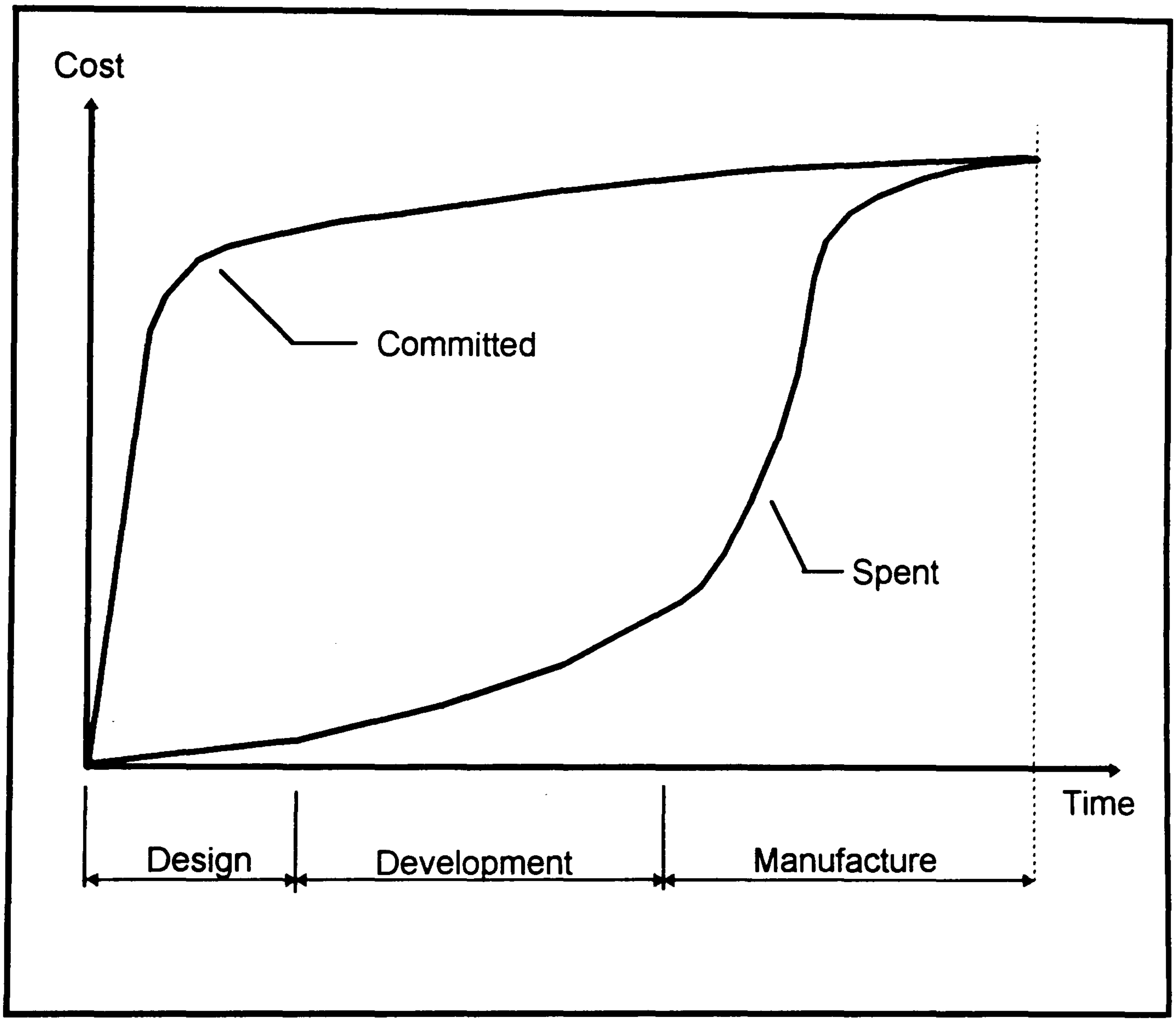

Figure 2. Typical Proportion Of Cost Committed And Actual Spend At Successive Project Stages (I Prod E [43]).

with manufacture [49]. The pursuit of functional/departmental goals is often reinforced by the presence of local performance indices (usually based upon some measure of efficiency) which may hinder rather than promote the achievement of overall company objectives [8]. Functional separation appears to be at its greatest between business oriented and technically oriented personnel.

It has been suggested [50] that engineers are task oriented and have occupational/professional loyalty rather than organisational loyalty. This is explained to some extent by the education and training of engineers; Kidd [51] suggests that engineers have traditionally been trained in narrow technical disciplines and lack the knowledge and ability to deal with non-technical issues. The engineer's lack of business awareness in particular results in a poor ability to operate as part of a "business team" [33] and may explain the apparently poor relationship between engineers and accountants [52]. It has also been argued that accountants have a narrow "focus" and tend to emphasise the role of external financial reporting [7].

The "information vacuum" associated with product designers is at its greatest in the area of cost data; cost/accounting information is not generally available to engineers and even if it were is unlikely to be understood by them [21]. Cost accounting information tends to be in a form appropriate (at least by tradition) to the reporting aspect of business management and not to the support of decision-making with respect to product design [24]. The lack of timely, appropriate and understandable cost information to the design function reinforces the attitude of traditional designers i.e. that consideration of cost is peripheral to their activity and is the domain of the accountant. The situation is something of a "vicious circle" in that while product designers are content to work without appropriate cost information they are unlikely to actively promote change in the company's reporting systems, but until such time as the reporting systems provide timely, appropriate and understandable information they are likely to be content with the "vacuum". It is possible that the introduction of "target costing" (discussed in more detail in 2.3.2) may help in breaking the "circle".

2.3.2 Design For Economic Manufacture And Concurrent Engineering

In recent years considerable and well directed effort has been expended in providing more effective models/approaches for "design for manufacture", typified by the work of Parnaby et. al. [37]. The evolution of formal approaches to "concurrent" or "simultaneous" engineering (CE and SE) is typified by the model proposed by Nevins [42], see Figure 3. CE has two primary objectives:

1. Compression of product lead times by means of parallel rather than sequential completion of the activities associated with the design and launch of new products, see Figure 4a. and 4b.
2. Optimisation of the "whole life" costs associated with developing, launching and supporting new products. This is achieved by means of integrating decision-making across the various functional activities. Whole life costs include marketing, conceptual design, detail design, product testing, manufacturing system provision, process planning, product manufacture, packaging, distribution and product support (warranty claims, maintenance, customer support etc.). Some researchers (Sheldon et. al. [44]) suggest that the whole life costs should include those associated with the operation of the product, as this will influence the ultimate success of the product in terms of the market. It must be noted however that this last premise assumes a rational, economic and well informed market.

The benefits claimed for a CE approach may be summarised by reference to Figure 5. (based upon a paper by Gould [53]). CE usually involves a project team approach to the development of new products and often includes a "target cost" for the product being developed.

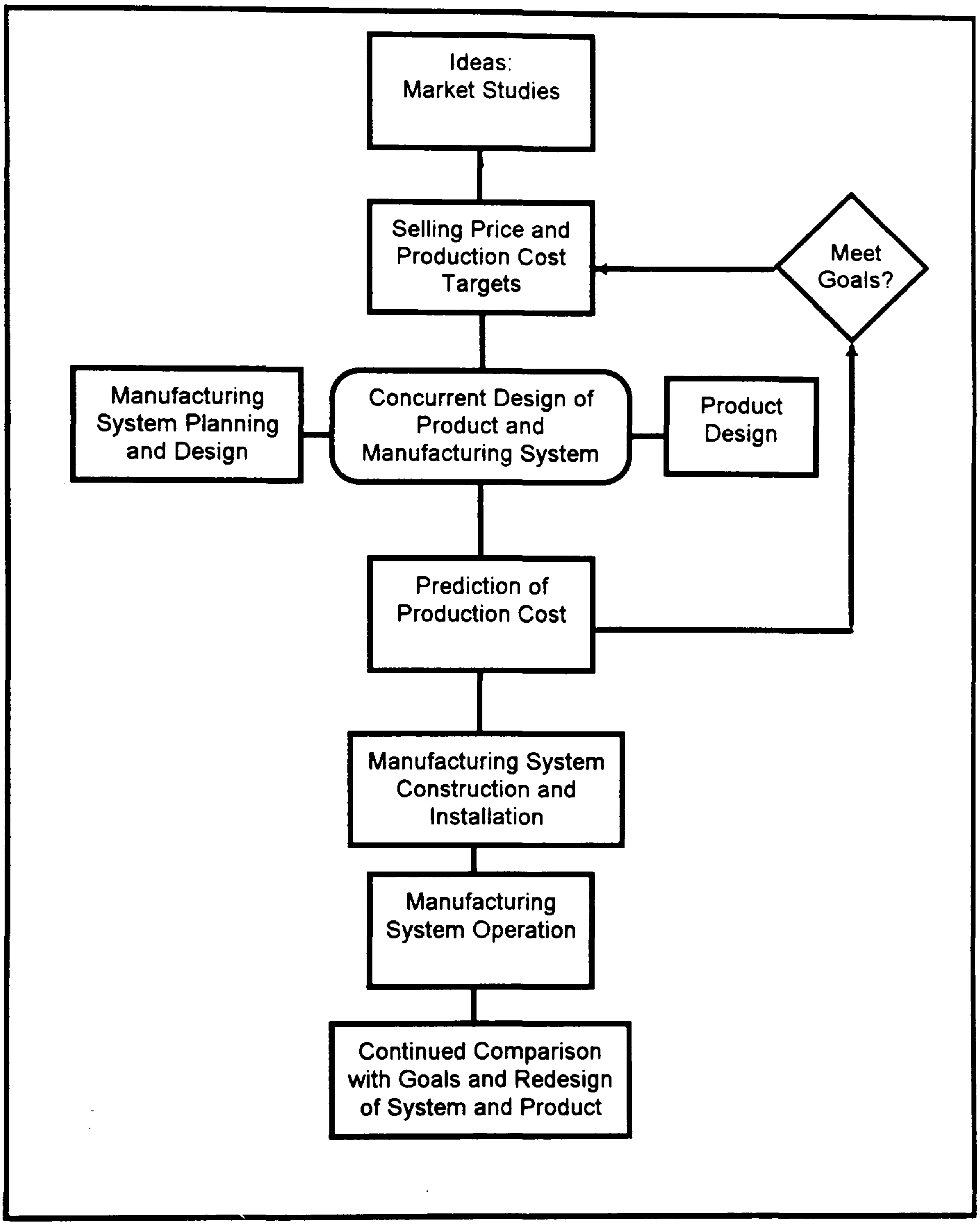

Figure 3. Product Stages During Concurrent Design.

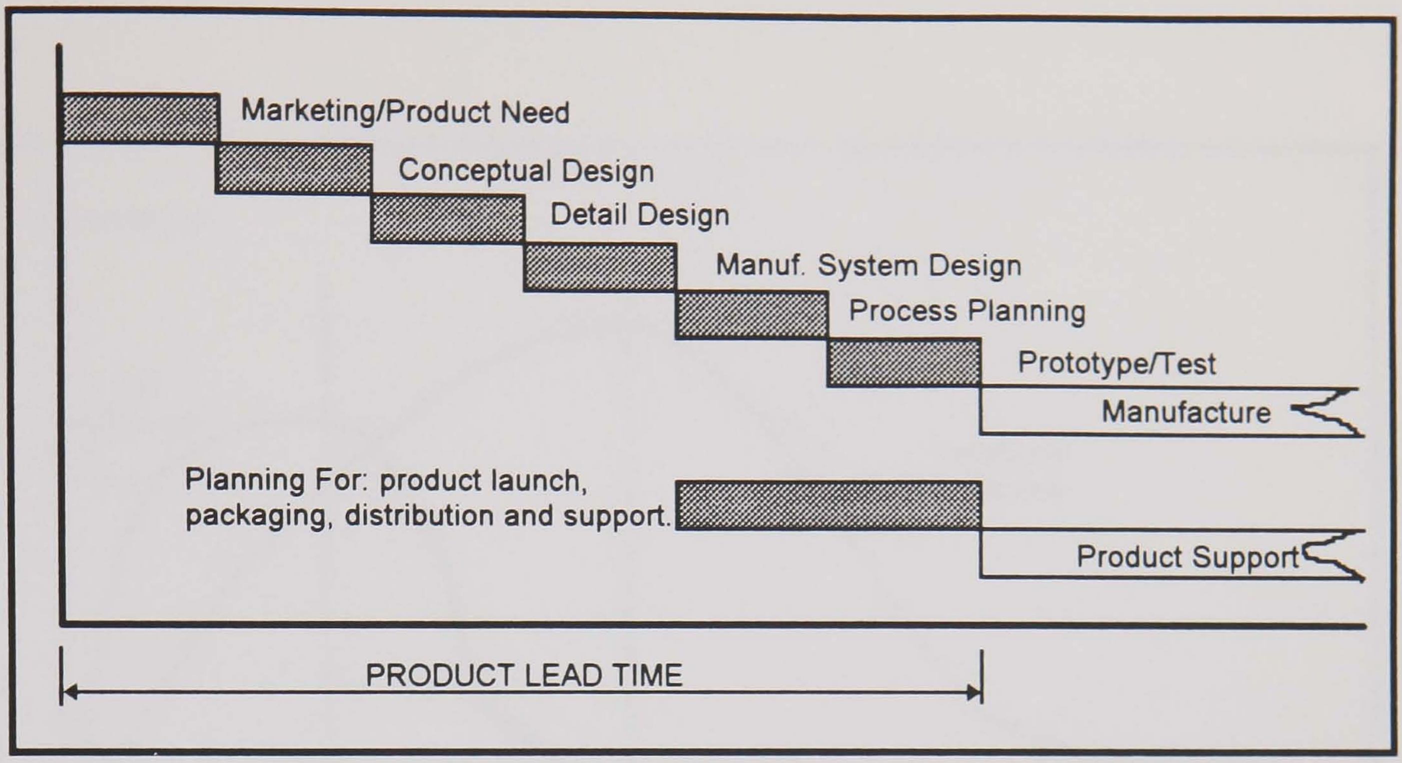

Figure 4a. Traditional Approach To Product Design.

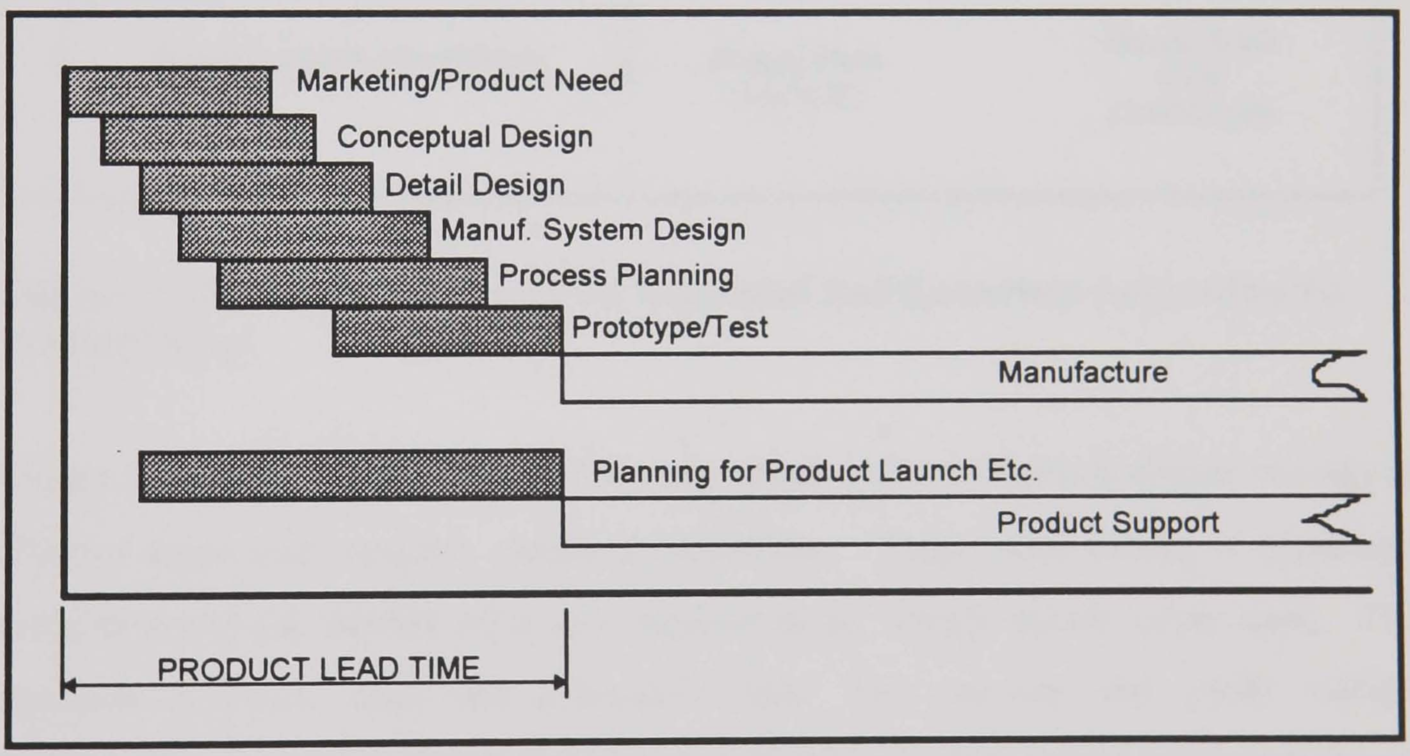

Figure 4b. CE Approach To Product Design

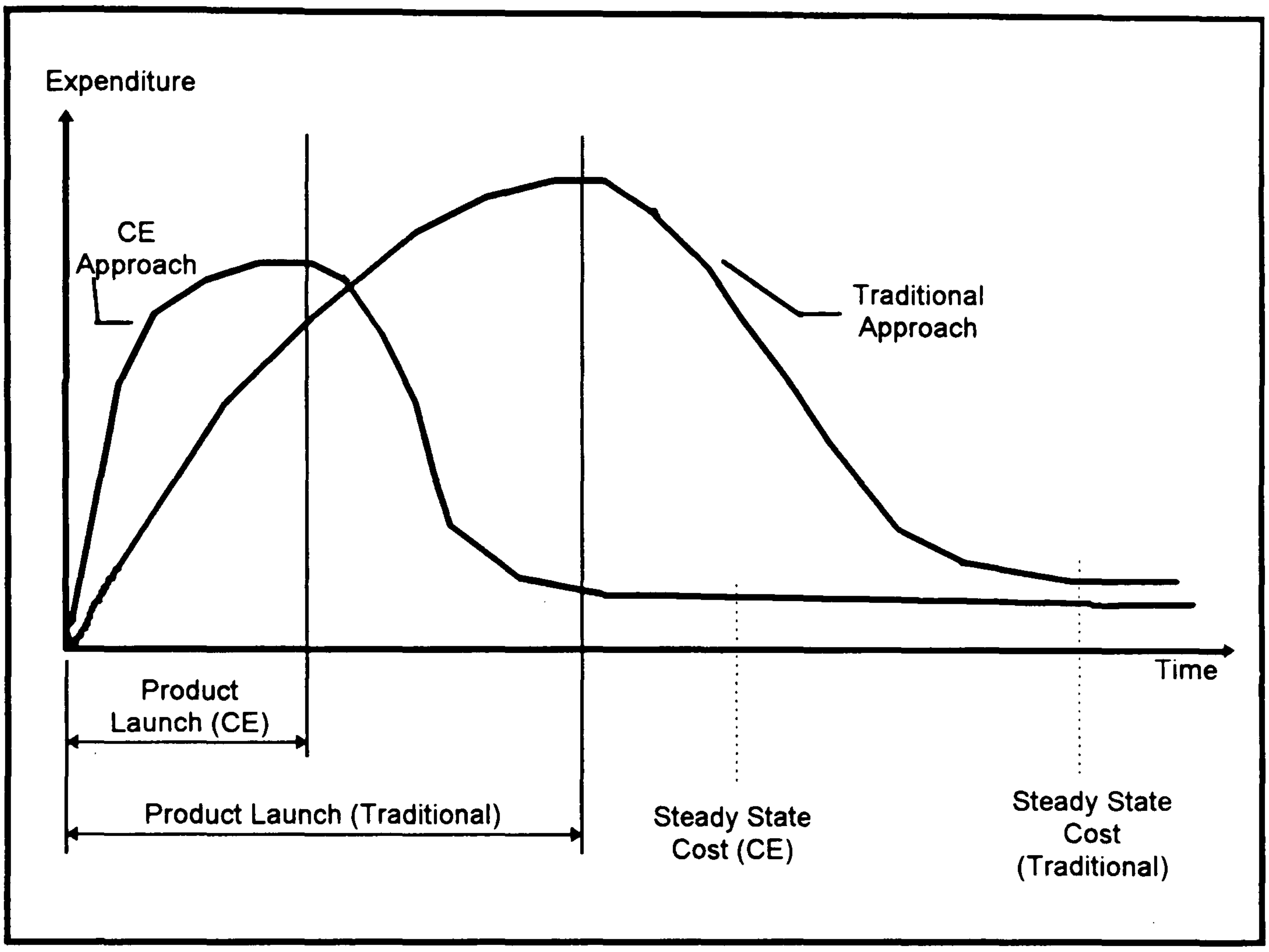

Figure 5 "Life Cycle" Cost Curves For Traditional And Concurrent Approaches To Product Design.

Target Costing - While target costing may appear to be a relatively simple concept its effective application requires careful consideration. Target cost setting is apparently straightforward i.e. market price less required profit margin equals target cost. This approach however does not necessarily take into account the profit volume considerations; a lower selling price may provide an increased level of sales which may in turn allow more efficient/effective manufacturing methods to be employed. The product design team must therefore have the capability of carrying out "what if" analysis on various combinations of total cost, selling price and sales volume in order to establish the most appropriate target cost **and** target volume for the product. This is a "non-trivial" exercise and requires sound information with respect to the costs associated with various options (i.e. the very basis of target costing rests upon the availability of accurate product cost information).

Having expressed these reservations it must be stated that target costing does provide a good initial focus for the project team but does not in itself lead to the search for "continuous improvement" promoted in many companies. There remains a need to provide performance criteria which will promote iteration in the design process to provide the most appropriate combination of product price and product cost. In some cases the overall profitability of a company may be maximised by a combination of "optimum" processes with respect to some products and "sub-optimum" processes with respect to others. There is need for the development of an approach that uses "product models" and "system models" in the determination of appropriate designs, this is discussed further in sections 4.2 and 7.0. It is possible that the concept of "flexible" product design, where the actual design/process route is not fixed until the point of manufacture, may be of value in this respect. The concept of flexible product design/process planning is discussed in section 2.4.2 .

Comprehensive coverage of the basic principles of CE is provided by references [42], [54] and [55] and the increasing relevance of IT with respect to the effective implementation of CE is discussed in section 4.2.

Axiomatic Design - Development of approaches to design for economic manufacture has often been based upon the principle of "axiomatic" design [55] and [56] i.e. a set of rules which if adhered to will "optimise" a design under various headings.

Examples

1. Use as few separate parts as possible - reduce assembly cost.
2. Use symmetrical parts - reduce machining cost.
3. Avoid separate fasteners - reduce assembly cost.
4. Minimise the number of holes - reduce machining cost.

The axiomatic approach does however have a major weakness in that it does not provide any means of quantifying the "trade offs" between alternatives posed by "competing" axioms in a particular design situation. Boothroyd [21] provides an example: An axiom to minimise the manufacturing cost of sheet metal parts might be stated as "all bend lines in sheet metal should be in a single plane; avoid side holes and depressions". In practice the inclusion of side depressions may allow the piece to be multi-functional, containing fastener holes or other functional pieces - this may increase the cost of the sheet metal part but reduce the overall cost of the product.

In industry experienced product designers use their judgement in assessing trade offs and make decisions accordingly. It is clear that the ability of product designers to make good decisions would be improved if they had access to cost information which could indicate the order of cost associated with particular decision combinations. Two approaches in particular appear to lend themselves to the indication of cost implications at the conceptual design stage:

1. Feature based cost estimation.
2. Parametric cost estimation.

Feature Based Cost Estimation is a concept that has been in existence for some considerable time. A feature based system using a commercial CAD system was developed by Plummer and Hannam in 1983 [57] but emphasised the rationalisation of "turned" components rather than the provision of comparative cost estimates (an axiomatic approach was taken). More recently work has been carried out by Wierda [58] and Gao [59]. The work of Wierda is of particular relevance as he suggests that a feature based product model may act as a central reference for several disciplines/locations, see Figure 6.

Parametric estimating is based upon the underlying empirical relationship between certain key parameters/attributes of classes of products and their cost. It may be appropriate in some circumstances to take a parametric approach to estimating the cost of individual features but in such cases care must be taken to avoid any tendency to "optimise" at the feature level rather than at the overall product level. The empirical relationships may be determined by means of regression analysis, similarity analysis etc.

of existing data relating to actual products and actual costs. Such systems however, are of value only in cases where a company's cost accounting system is able to identify with sufficient accuracy the cost of manufacture of particular products. Parametric systems must of necessity be adaptive i.e. they must automatically track trends in parameter/cost relationships caused by changes in manufacturing capability, material costs, labour rates etc., such systems may therefore respond automatically to changes associated with any re-structuring of the cost accounting system. Periodic re-evaluation of parameter/cost relationships could be influenced more strongly by recent data e.g. the equivalent of the adaptive exponential smoothing techniques used in demand forecasting. Parametric estimating requires the introduction and maintenance of a structured data base of products and associated costs i.e. it can operate only in situations where information

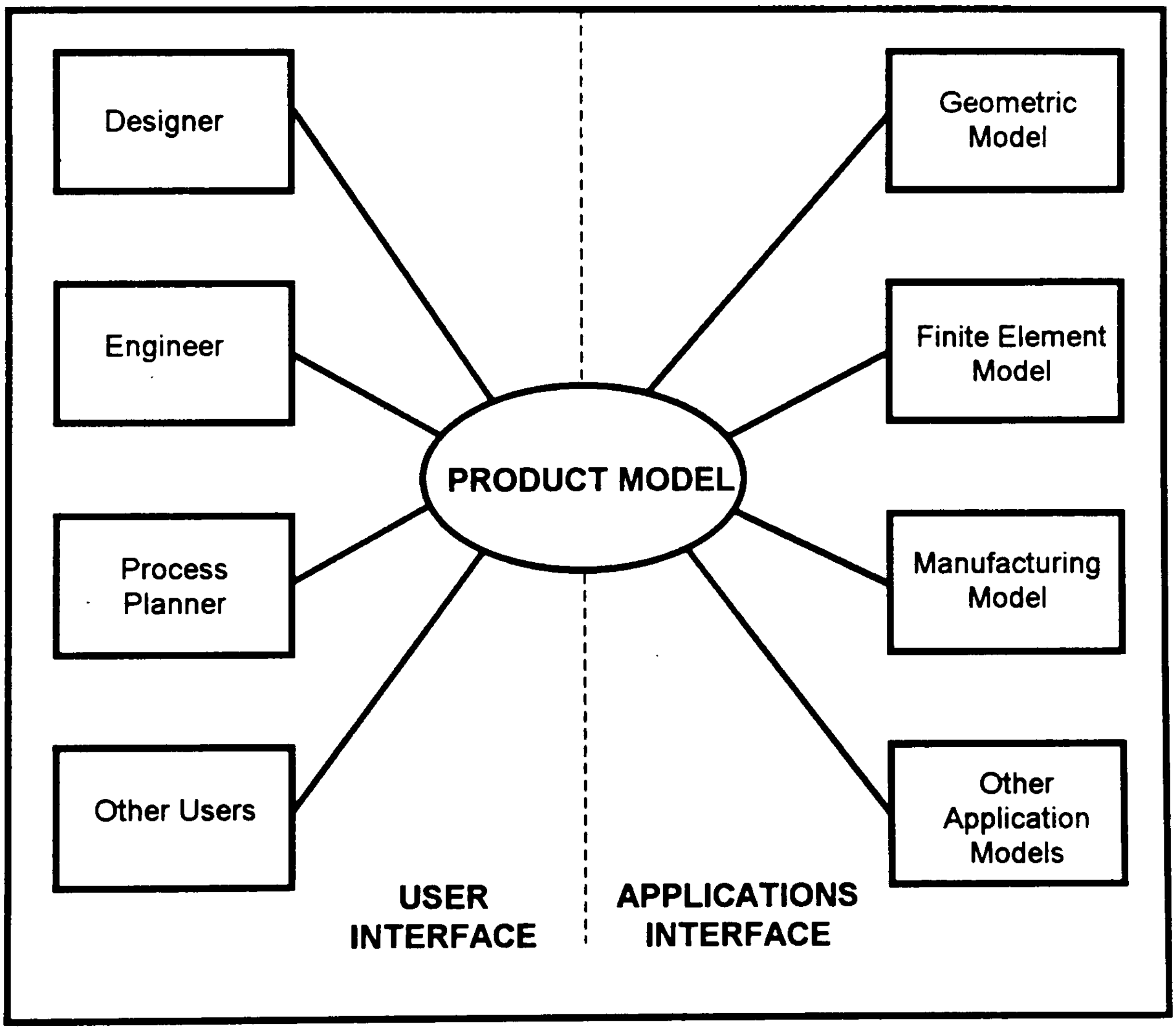

Figure 6 Feature Based Product Model - As A Data Base For Several Disciplines And Applications (Wierda [58]).

systems are formalised and effective. Valuable work has been carried out by Mileham et. al. [60] in the development of a parametric system to aid the effective design of injection moulded components. The practical application of multiple linear regression is discussed in section 4.2.2 and an example of an industrial application (which originated from this research) is decribed in Appendix 3.1.

It follows that the effective implementation of CE principles must be accompanied by cost information systems which support the designer in making complex decisions across traditional functional boundaries. The requirement to consider the various functional aspects in parallel leads to a situation where engineers must make decisions with only partial information [61] - something for which they have traditionally been ill equipped. CE requires the product designer/engineer to make the transition from technologist/technician to co-ordinator see Figure 7 [62].

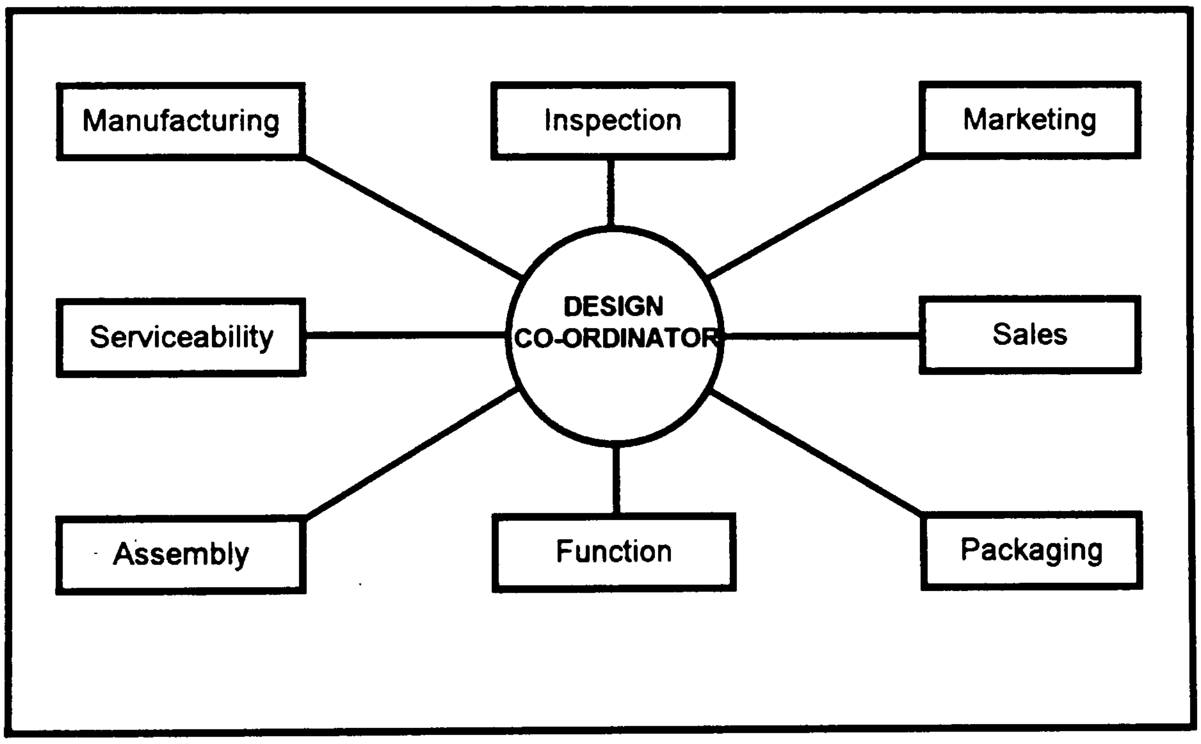

Figure 7. The Engineering Product Designer As Co-ordinator(McNeil [62])

2.3.3 An Information Model For Engineering Product Design

Against the background provided in 2.3.1 and 2.3.2 and in the context of this research it is appropriate to formulate an information model for the engineering design process. The model is illustrated in Figure 8. Consideration of the range of information flows which could/should form part of the design process will help in establishing a bench mark against which to evaluate current practice and may also help to provide a basic structure for the development of improved approaches.

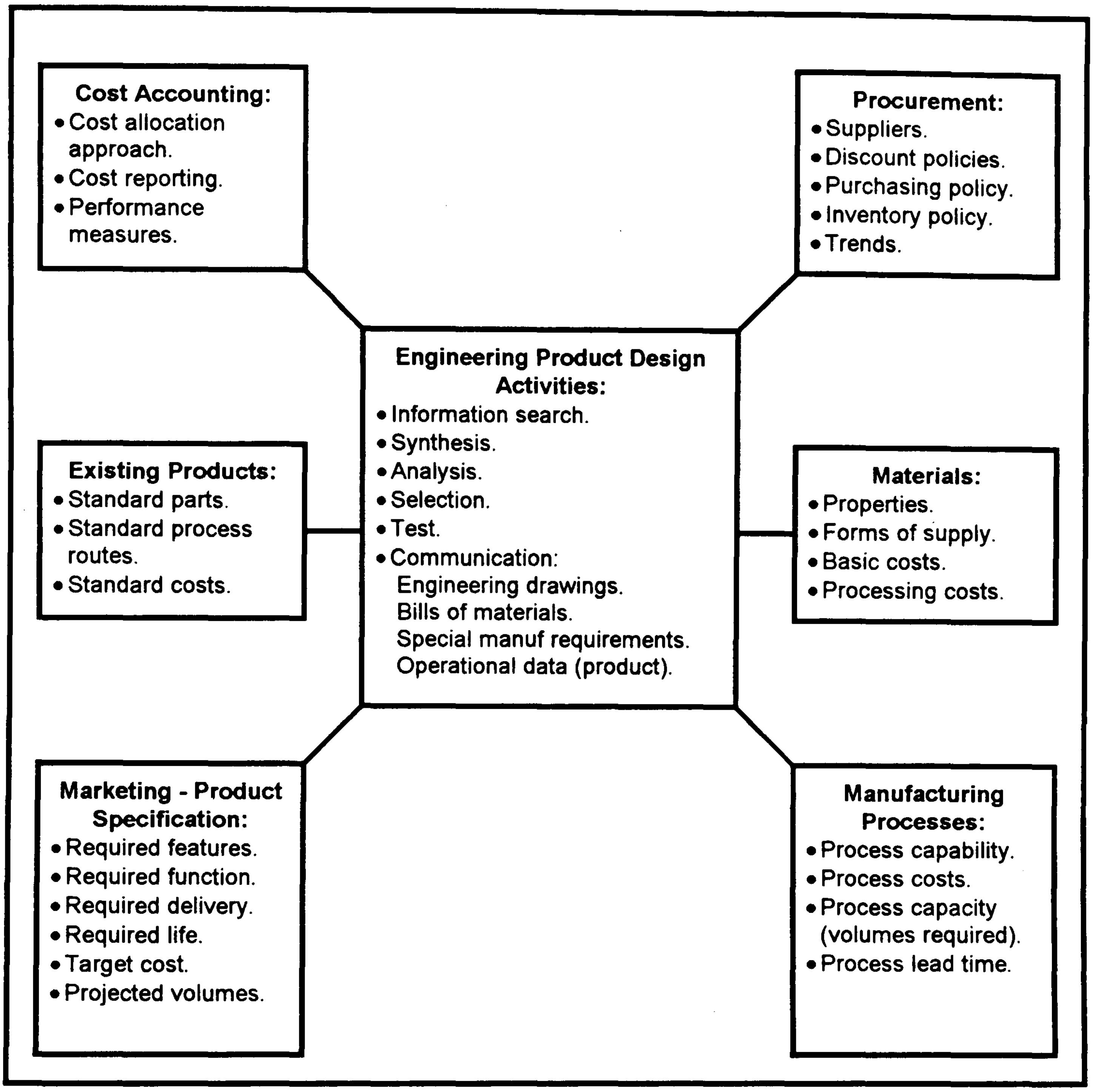

Figure 8 An Information Model For Engineering Product Design.

2.3.4 Industrial Survey

Extended interviews with senior engineers responsible for the activity of product design were carried out in three different companies and this was supplemented by information gained from other sources e.g. respondents from other disciplines within the companies, part-time degree students, project students, placement students and TCS associates. The interviews provided ample evidence to support the suggestion that engineering product designers, in general, work within an information vacuum with respect to cost information, having little or no understanding of, or contact with, the cost accounting systems employed within their companies.

Company A

In company A the senior designer had a wealth of experience in engineering design and business. He understood and was "reasonably satisfied" with his firm's cost accounting system, which involved the allocation of a "blanket" overhead on the basis of "direct" hours. There was no direct use of cost information at the conceptual design stage - it was stated that the main input was the experience of the designer i.e. the design process being seen as the application of solutions which had been adequate in the past. Estimates of product cost were established after detail design and in some cases this was after the communication of a quotation to a customer. The respondent appeared to be relatively satisfied that the estimating and cost accounting systems were valid, because estimates (based upon a blanket overhead per direct hour) were broadly in line with costs eventually allocated to actual products by the firm's accounting system. In this company this equates effectively to a comparison between direct hours estimated and direct hours charged. On further consideration the respondent agreed that the costing system was not likely to reflect accurately the real cost of particular products.

Detail design i.e. specification of drives, component parts etc. was left to a team of detail draughtsmen who again used experience to establish details which would result in "ease of manufacture" and minimum expenditure on materials and component parts. No input in terms of the estimated overall cost of particular options was used in the design process.

The idea of a "feature based" cost estimation system (see section 2.3.2) was discussed and met with a favourable response. It must be accepted that the actual cost associated with the production of a particular feature may vary, given alternative process routes and a dynamic environment. It would be logical therefore to refer to the cost associated with the preferred/normal process route for the feature (or combination of features).

Company B

In this company a project approach to major design schemes had been adopted. Formal procedures for design project management existed as part of a new ISO9000 proposal. The project stages covered are:

preliminary design

quotation

detailed design

prototype costing

*audit

* It was stated that in practice the design audit was carried out rarely, due to pressure of work.

Staff involved in engineering design had no formal training with respect to the firm's cost accounting systems and knew little or nothing about the actual build up of cost for particular products. The design function rely upon informal input from the production engineering function to provide a "design for manufacture element" but no procedure or mechanism exists to ensure that this input is effective. A suggestion that this approach may represent simply an attempt to remove the "rough manufacturing edges" from a design rather than being an effective procedure for minimising production cost, commensurate with quality, function and delivery was not refuted.

Routine design work in the form of: new products with relatively low value, customisation of existing products and modification to existing products is a significant proportion of design activity and has little input from production engineering prior to process planning. Feedback tends to be provided only in situations where some aspect of a design provides severe difficulty for its manufacture.

It was stated that the design function has "little or no interaction with the cost accounting function of the company." Thus the only real feedback on design performance from a manufacturing cost aspect is provided from the review of products which have not provided an appropriate "contribution" to the business i.e. in practice the only designs to be reviewed are those which have resulted in observed apparent losses (a standard time/cost is determined after process planning). This situation may tend to promote mediocre, safe designs rather than the innovative designs which might be promoted by effective techniques for assessing the cost of particular designs before they move to the stage of process planning.

The design team were highly motivated and aware of the major influence that their decisions would have upon product cost but did not feel that they had sufficient information (in an appropriate and understandable form) upon which to base cost oriented decisions. It was stated that information relating to current costs of various materials in different forms of supply and standard component costs would be of great value. The idea of a "feature based approach" to cost estimation was discussed and met with a favourable response

Company C

Company C manufacture a range of specialised equipment, with the organisation being split into a number of "business units" in terms of marketing, design and development. The different business units share a common manufacturing resource. Design staff have little or no contact with the accounting function. The company operate a full cost system which provides: a material overhead (% cost), a factory overhead (common rate per direct hour for all activities i.e. machining, assembly and special processes) and an administrative overhead (% total cost). The engineers and operations managers appreciate that the system provides a distorted picture of the distribution of cost across the product range and use their judgement to compensate. For example they believe that one-offs and complex products tend to be "under costed" and that standard products tend to be "over costed" - hence they may accept an order for a relatively large number of a standard product which appears to have little or no profit associated with it (i.e. sales price minus estimated cost.

The company operate a business team approach in particular product areas - it was observed that the team in the business area studied did not include an accountant. A computerised data base for cost estimation based upon historical cost is being set up. While this will improve the speed of providing quotations it will do nothing to improve the accuracy of cost estimation or feedback to product designers.

2.3.5 Discussion and General Conclusions

The literature survey and the industrial survey indicate that engineering product design is in fact carried out in what may be described as a partial "information vacuum". Figure 9 (Actual Information Flows In Engineering Product Design) is a modified version of Figure 8 (Information Requirements For Effective Engineering Product Design). Figure 9 illustrates the poor and in some cases non-existent links between the design function and the functions of: cost accounting, purchasing and capacity planning/scheduling.

The major sources of information actually used by designers are highlighted in Figure 9 and relate to:

- Product Function and Product Features, supplemented by:
- Ease of Manufacture (standard parts, standard processes etc.)
- Materials Properties
- Forms of Material Supply
- Material Cost (basic)

The evidence provided in previous sections suggests that:

A. Engineers do not make effective use of the information available within their organisations.

and

B. Much of the cost information available is either inaccurate, inaccessible or in an inappropriate form.

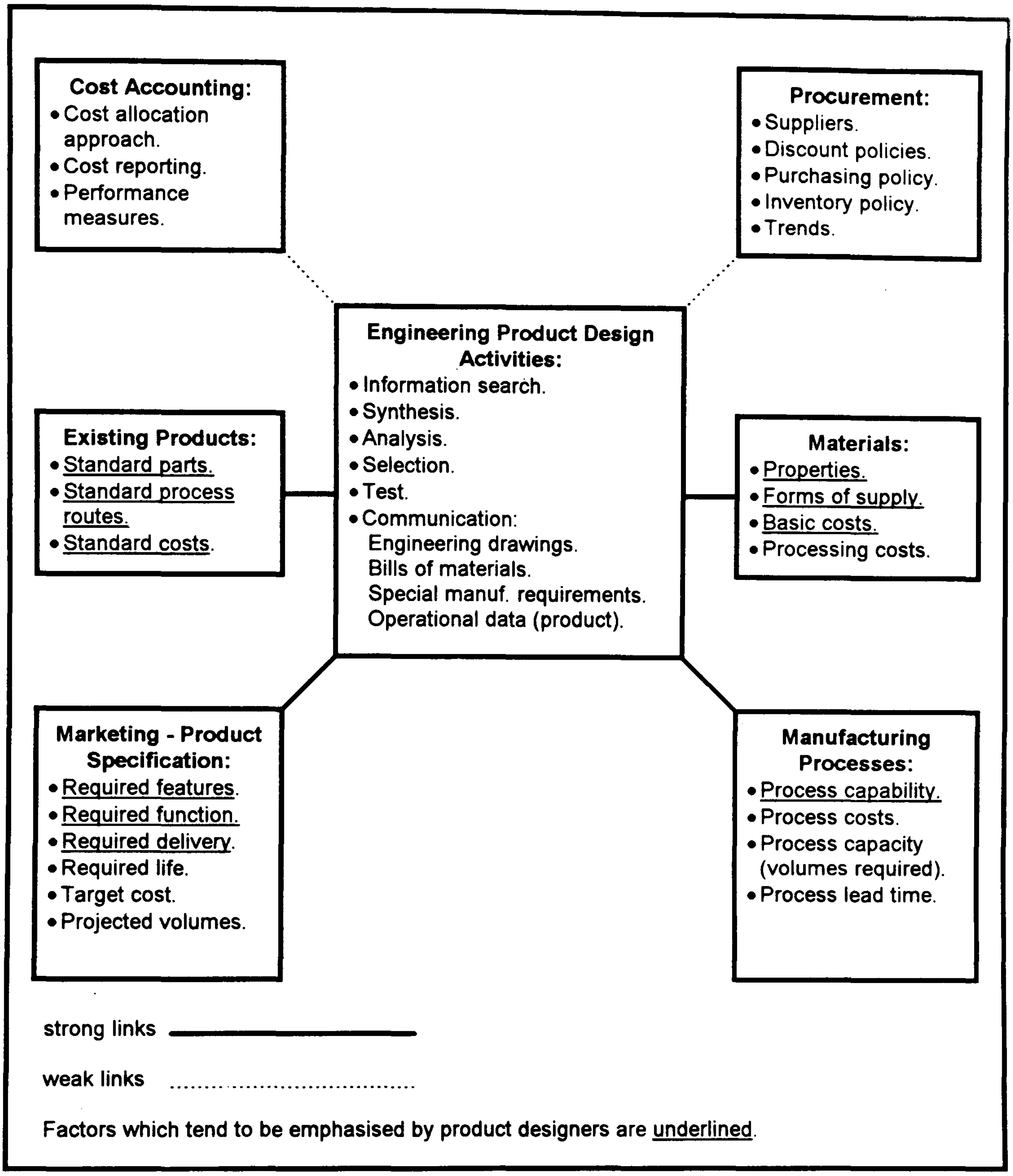

Figure 9 Actual Information Flows In Engineering Product Design.

Table 1 summarises the factors involved, together with their ramifications. It is clear therefore that an improved approach to engineering product design must embrace each of the following:

1. The basic understanding of engineering product designers with respect to concepts, techniques and approaches for the costing of engineering products.

FACTOR	RAMIFICATIONS
Multi-level organisation structures with strong functional divisions.	Departmental/functional loyalties may result in pursuit of localised objectives. Little "cross fertilisation" and integration of decision-making. Poor communication.
Engineers general lack of knowledge and understanding with respect to principles of costing and costing systems.	Poor ability in interpretation of available cost information. Inability to understand, in detail, how the build up of product cost is influenced by design decisions. Poor communication between accounting and design functions.
Perception of many engineers that cost is an issue peripheral to their activity.	Lack of motivation to acquire understanding of costing concepts/principles in general and their company's costing systems in particular. Tendency to regard product costing as an activity which follows product design and is the responsibility of other functions.
Narrow focus of engineers - in particular the tendency for professional rather than business orientation.	Limits the ability of engineers to make effective contributions to the "business team" and the ability of the business team to make effective contributions to product design. Tends to reinforce the isolation of the engineering function. Tendency for engineering designers to strive for technical excellence to the detriment of product cost/profitability.
Accountants and accounting systems tend to focus on reporting for external consumption.	Accounting function may regard themselves as providers of external reports and controllers of monetary resources i.e. not providers of information in forms appropriate to the support of decision-making in product design.
Lack of integrated, company wide information systems.	Information tends to be out of date, difficult to access, duplicated and in non-standard formats. Lack of time and the barrier of a poor "interface" may lead product designers to make decisions without reference to relevant data.
Lack of cost oriented information in a form understood easily by non-accountants.	A barrier to the use of cost information as an input to product design.
Lack of cost oriented performance measures which promote the pursuit of overall business effectiveness.	May promote the pursuit of local objectives which are against the interests of overall company objectives

Table 1. Factors and Ramifications In Product Design

2. The attitudes, values and beliefs of engineers in general and product designers in particular.

3. The attitudes, values and beliefs of accountants.

4. The organisation structures within which engineering product design is carried out.

5. The information systems which operate within companies.

6. The nature and form of the cost information which is provided and its relevance to decision-making.

Possible approaches are introduced, developed and discussed in section 7.3.

An important factor which came out of the industrial survey was a general acceptance, on the part of engineering product designers, that there should be closer links between the accounting function and engineering design. There was also a willingness and enthusiasm to become more knowledgeable about costing principles in general and their companies' costing systems in particular. The "no mans land" between the costing/accounting function and the design function does not appear to separate protagonists, as is suggested frequently. The functions are separated by barriers of: "language", culture, education, perception and organisation structure rather than any real reluctance to work as a team. Hence solutions/improvements will arise only from approaches which embrace the issues as a whole.

2.4 MANUFACTURING SYSTEMS ENGINEERING - SYSTEM DESIGN AND PROCESS PLANNING

Manufacturing System Design is a medium to long term activity and includes the specification, design, acquisition, implementation and development of productive facilities and support systems, appropriate to the current and proposed business activities of a manufacturing organisation. It involves consideration of required process types, process capabilities and process capacities, together with strategies for their effective deployment and operation.

Process Planning involves identification of the sequence of processes and operations which must be carried out in order to manufacture particular products and the provision of a set of clear and unambiguous instructions. Such planning will include consideration of material requirements, process requirements, process parameters (e.g. cutting speeds and feeds), tooling requirements and quality requirements. Outline process planning is an essential input to manufacturing system design i.e. determination of the general process requirements associated with the forecast mix of product types. The majority of process planning activity is however at the detailed level i.e. preparation of the detailed sets of instructions for particular products prior to their manufacture.

2.4.1 Manufacturing System Design

A manufacturing system comprises:

A. Production process capacity in the form of machine tools, process plant, handling systems and direct labour, for the manufacture of the company's products.

B. "Support" manufacturing capacity (in the form of machine tools process plant and labour) to provide tooling and other specialised equipment necessary for the production process.

C. Support systems/services to provide an appropriate infrastructure for co-ordinating the operation of productive and support capacity in the manufacture of the company's products. Such systems and services would include: process planning, tool design, materials planning, production planning, quality assurance and supervision.

It is worth noting at this point that the characteristics of manufacturing systems which are similar in terms of elements A. and B. above may be radically different as a result of variations in the configuration of equipment and approaches taken to process planning, production scheduling and quality assurance.

Long term decisions with respect to system design tend to be associated with the acquisition of additional process capability and additional process capacity. Such decisions will normally involve capital investment and/or major reorganisation of facilities and labour. It follows therefore that effective manufacturing system design over the long term will arise out of a decision process which integrates marketing and business strategy with product design and manufacturing (process planning) considerations. If the major long term objective of the company is to maximise profitability then it is clear that approaches to this investment in facilities should be based upon realistic information concerning the costs and revenues associated with particular combinations of product mix, product design, process planning and manufacturing system design (see Figure 10).

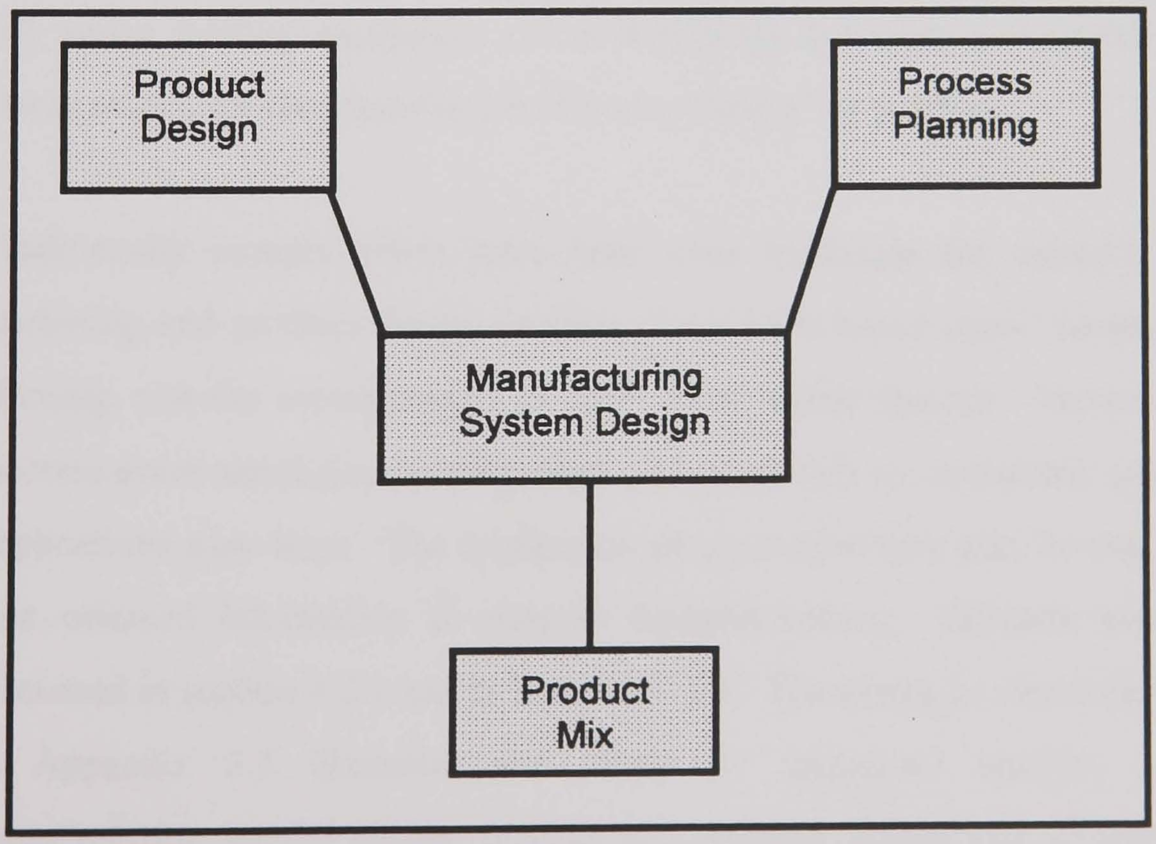

Figure 10 Inputs to Manufacturing System Design

The relationship between the variables illustrated in Figure 10 is highly complex and is made more so by the uncertainty associated with business/market forecasting and technological development (i.e. effect of new technology on products and on processes). The development of detailed analytical models to support decision-making in this area would be prohibitively expensive in terms of both time and resources. It is however feasible to consider the development of simplified models which may be of help in identifying the cost trends associated with particular combinations of product design, process planning, manufacturing system design and product mix. Such models would provide decision-makers with a clearer picture of the cost "drivers" associated with their business and a sensible base for analysis of investment in manufacturing plant - an aspect of manufacturing management which has been criticised heavily. The issue of investment analysis is discussed in section 2.7.3.

Medium term issues in manufacturing system design relate in the main to system configuration (change in the physical layout associated with existing facilities) and system management (change in the approach to scheduling, inventory management, quality management, etc.). An example would be the creation of a small manufacturing cell, using existing equipment and a KANBAN approach to material and production management, for the manufacture of a new "family" of products.

Traditionally models which have been used to assess the capacity implications of marketing and product design decisions have been based upon "rough cut", aggregate planning and the incorporation of appropriate safety factors. Increasingly the use of discrete event simulation is being employed to provide more realistic analysis of capacity implications over time. The application of simulation may also be extended to provide cost oriented information to support decision-making. Discrete event simulation is discussed in section 4.2.1 and in Appendix 3.3. The exemplar simulation model included in Appendix 3.3 illustrates the scope for integrated analysis with respect to manufacturing system design, product mix, product design and process planning. The model provides an innovative approach to the provision of "business oriented" measures of performance.

2.4.2 Process Planning

As stated previously the majority of process planning activity occurs at the detailed level i.e. preparation of the detailed sets of instructions for the manufacture of particular products. In this context process planning may be defined as: Determination of the processes and process parameters required to produce a particular product/component (this may include reference to a particular machine tool or item of process plant) and specification of any constraints which apply to the sequence in which the processes/operations may be carried out.

There is clearly a close link between process planning and shop floor scheduling, where shop floor scheduling may be defined as: Determination of the timing and/or priority associated with operations to produce a particular product and where appropriate (i.e. where more than one facility may provide the process) which facility will be used. A sensible objective for "day to day" process planning may be stated as: Making the most effective use of current capability and capacity given short term production requirements. With this in mind flexibility in a process plan (i.e. an alternative process or machine tool possible for one or more operations) may be used to "optimise" the operation of manufacturing plant in the short term. In the majority of practical situations however process plans tend to be prescriptive i.e. they are based upon the process planner's perception of the single best approach to producing the product in question, taking no account of constraints with respect to production capacity [63]. The latter statement is corroborated by observation of practice in the collaborating companies and by the author's personal experience. Change to shop floor schedules based upon "interpretation" of process plans by supervisors and "progress chasers" is however common on an ad hoc basis.

Halevi [63] suggests that process plans should contain as much flexibility as possible so as to provide the scope for "dynamic" shop floor scheduling i.e. scheduling approaches which attempt to identify the most effective combination of process plans for the current product mix given current productive capacity. The development of an approach to "dynamic process planning and scheduling" using an expert system is the subject of a recent research supervision by the author [64] and [65].

The scope for providing flexible process plans will be determined at the product design stage. Halevi [63] states that on average only 30% of the dimensions in a typical detail drawing are "functional" i.e. are essential to the successful function of the product/component. The remaining 70% of dimensions are termed "filler" dimensions. In principal many if not all of the "filler" dimensions are "frozen" by the product designer (i.e. an arbitrary dimension together with a standard engineering tolerance is specified) and are therefore less capable of being incorporated into a flexible process plan. Halevi contends that "filler" dimensions should be left open and that decisions concerning final product details and hence the adopted process plan and schedule should be left as late as possible in the production cycle.

The adoption of flexible designs, flexible process plans and dynamic scheduling provides scope for "optimisation" of manufacturing effectiveness in the short term. However the selection of criteria upon which to base the optimisation process is complex. Possible criteria include operational efficiency, maximum throughput, minimum cost, maximum profitability and minimum work in progress. The central theme of the current research is the use of cost oriented information as a basis for decision-making and with this in mind various approaches to providing cost/business oriented criteria are discussed in section 4.2.1.1. The expert system approach to "dynamic" process planning and scheduling developed by Palmer [64] and [65] provides a methodology for optimisation and will accommodate "objective functions" of various types. The criteria used by Palmer (and the majority of other researchers in this area) is time oriented rather than cost oriented and may benefit from the inclusion of cost/business oriented criteria.

2.4.3 Computer Aided Process Planning (CAPP)

As much as 40% of the process planning task is associated with "clerical" aspects i.e. data retrieval and documentation [66] and [67]. Given this situation CAPP has been a rich area of development over recent years. There are two basic approaches to CAPP:

Variant Process Planning retrieves similar existing parts to the part being considered (usually on the basis of a classification/coding system) and allows easy customisation of existing plans and a facility for automatic generation of standard documentation.

Generative Process Planning generates automatically a process plan from an engineering design specification (graphical and textual). This is a highly complex approach and is the subject of considerable research activity. There is little practical application of such systems as yet.

A large number of automated process planning systems have been developed commercially, the vast majority being of the variant type and based upon some type of classification and coding system which will bring up a standard process plan for parts of a particular part/family. Such systems are a great aid to the process planner and support the efficient use of resources by promoting the use of standard process plans (and hence tooling etc.). There does not however appear to be any evidence that such systems promote process selection on the basis of cost consideration given particular manufacturing circumstances.

"In house" development of software for the estimation of product cost using standard spreadsheets and databases is becoming more common. However in many situations such systems appear to concentrate on reducing the time associated with producing estimates rather than improving the accuracy/relevance of estimated costs (evidence to support this has arisen from a significant number of industry sponsored final year student projects).

Detailed consideration of automated approaches to process planning is provided by reference [67].

2.4.4 Industrial Survey

Company A

This company manufactures special purpose machinery with a high level of customisation. Most of the machines produced are variations on relatively standard configurations but some machines are effectively "one-offs". Production facilities are set out in a traditional process layout, with general areas being provided for assembly and fabrication.

Decisions relating to the purchase of new manufacturing plant tend to be made on the basis of "bottleneck analysis" and "strategic need" rather than on the basis of formal investment appraisal. The level of investment in new machines appeared to be relatively low. Links from design to process planning tend to be restricted to situations where a design was difficult to manufacture or where production engineers saw an opportunity to rationalise the range of tooling employed. Cost information was not used to support decision-making in process planning. The only cost information available to the process planner was in the form of standard "marginal rates" for machining (all machines carried the same rate), assembly and fabrication. It was stated that shop floor supervisors frequently modified the schedules and process plans (this being facilitated by the low incidence of special tooling).

The production engineering function were responsible for providing cost estimates for spares and used estimated or actual (historical) times and the standard machine shop rate, together with a "contribution factor" (approximately times 3) to determine the cost/price.

The respondent did not fully understand the costing system and did not believe that it would be accurate. He had worked previously for a company which operated a full cost system and expressed his doubts about the accuracy of that system.

Company B

This company produces complex engineering products to stringent specifications for performance and reliability. A highly experienced team of process planners is employed and is comprised of staff who have gained technical qualifications and have progressed from the shop floor. The company have over the last three years implemented a commercial computerised system for process planning/estimating (based upon variant process planning).

It was stated by the production engineering manager that process planners were responsible for providing methods, details, tooling and numerical control (NC) part-programs for the company's products together with estimates of production time and special tooling costs. It was stated also that process planning performance was measured against:

Delivery - are plans and tooling delivered on time.

Accuracy - are plannings and tooling accurate i.e. do they facilitate manufacture of the product to the required specification.

Quality of NC part-programs - conformance to specification and minimum cycle times.

The process planning function was not measured directly against any cost criteria. However as the company was making profits it was suggested by the respondent that the current approach was probably sound. Process planning decisions did not include any direct consideration of cost, they were based rather on a set of rules/perceptions of "good engineering practice" and a belief that this would lead to good performance with respect to cost. It was stated that "the costing system is not allowed to get in the way of what is seen as good process planning practice".

Many examples were quoted of "fixed" designs resulting in high manufacturing cost, the design function asking frequently for advice and then saying that too much design time would be required to implement it. Designers work to deadlines for the provision of detail drawings and tend to have them virtually complete prior to the involvement of process planning. The production engineering manager was involved at the preliminary design stage of major items of new business.

The production engineering manager considered himself as having a good understanding of the company's costing system, which was based upon standard hourly rates for processing within given process "centres". A process centre may comprise a mixture of relatively high cost machines and low cost machines, with no attempt being made to allocate higher rates to more expensive machines. The major criteria for performance measurement at shop floor level is based upon a comparison of actual hours versus "standard" hours (where standard hours relate to the estimates provided by process planners - these are incorporated in the data base of the company's MRP system). It was difficult to establish whether the use of standard hours as the primary criteria for performance measurement was the result of a lack of "precision" in the accounting system or vice versa.

The perception that time is a more reliable and meaningful criteria than cost is relatively common in practical engineering environments. Birdwell [68] suggests that engineers should "reject the idea that monetary costs are good enough and think in terms of direct hours and material costs". The situation appears to arise in part from a mistrust of cost data provided by accounting systems and in part from a lack of understanding of costing principles and company systems on the part of engineers.

A senior process planner in the company stated that he was required to provide the plannings for a component, an estimate of the production time and a specification and estimated cost for any special tooling. He did not provide an overall cost for the product and was not familiar with the company's cost accounting system i.e. he was unaware of the specific cost implications of his decisions. It is worth noting that the computer based system will ultimately provide an estimate of total cost at the process planning stage, based upon the cost structure referred to previously. The respondent felt that an understanding of the company's cost accounting procedures would be of considerable value in his work.

The actual approach taken by process planners was to provide a single process route based upon the "best machine for the job" with no account being taken of any capacity implications. No information concerning the current capacity situation was available to the process planner. It was pointed out that the sales office provide a delivery promise and quote a price before process planning is involved. The lack of communication between sales and process planning appears to be common.

Production control feed back information concerning routings only when there have been problems. Occasionally shop floor supervisors make requests for changes in process routes where there is the need for a change in special tooling or a new NC part-program. There is no attempt to calculate the cost of alternative process routes.

Company C

This company manufactures a range of highly sophisticated equipment with a high degree of customisation. Batch sizes tend to be low and "one off" manufacture is common. The production engineering manager had no contact with the accounting function and did not fully understand the company's system for product costing. For the purpose of cost estimation he used a standard rate per hour, but had little faith in its accuracy. The production function was not involved in cost estimation for the purpose of quotation - this being carried out by marketing personnel on the basis of historical/comparative estimating. Production engineers were responsible however for the sub-contracting of significant amounts of machining. The use of a universal hourly rate for all the machines in the machine shop led to some difficulty in comparing the cost of sub-contracting particular components with the cost of machining "in house". This made decisions relating to the acquisition of additional capacity most difficult.

None of the decisions made in the area of process planning, sub-contracting and machine tool acquisition were supported by meaningful cost information. The respondent would welcome the opportunity to learn more about the company's costing system and to have involvement in its development.

2.4.5 Discussion And General Conclusions

The general picture presented is similar to that for product designers in that process planning is carried out with limited information and with little or no direct consideration of cost implications. Process planners tend to concentrate upon provision of the single best "engineering" solution for individual component parts, emphasising conformance to specification and minimum cycle time. They work on the basis of perceived "good practice", utilising experience rather than analysis.

Process planners in general appreciate the need to consider the cost implications of their decisions but do not appear to have an understanding of costing principles and company systems, nor do they have access to cost information in an appropriate form. Some of the major factors and their ramifications are summarised in Table 2.

FACTOR	RAMIFICATION
Localised performance measures based upon: output efficiency e.g. machine utilisation, performance against standard hours, product cycle times, etc.	Emphasis on producing components (rather than complete/saleable products) quickly and with most efficient use of production capacity. Misguided assumption that maximising efficiency in sub-areas of production will maximise effectiveness with which the whole range of products is produced. May also lead to disruptive competition between functions.
Lack of co-ordination/integration of policies for evaluating investment in new manufacturing technology with the product costing and performance measurement systems employed after acquisition and implementation.	Tends to promote intuitive/arbitrary approaches to the acquisition of new capacity. Costing systems may not reflect accurately the true cost of operating new manufacturing plant and this may lead to poor decisions concerning product development and investment in further manufacturing capacity.
Tendency on the part of process planners to specify the "single best process" plan regardless of short/medium term capacity implications.	Creation of production bottlenecks leading to scheduling problems and shop floor modifications to process plans and schedules based upon expediency. Limits the scope for "dynamic scheduling approaches (see section 2.4.2).
Continuous changes in the product mix associated with the company's product range and hence process/capacity requirements.	Difficulty in maintaining acceptable levels of efficiency and effectiveness. Promotes the need for flexible product design and dynamic process planning and scheduling, to facilitate effective use of production capacity.
Time pressure associated with management's emphasis on production rather than planning.	Pressure on process planners to come up with a quick feasible plan rather than an "optimum" or "flexible" plan.
Lack of basic understanding of cost principles and company systems on the part of process planners together with lack of access to cost information in an appropriate form.	Tendency for process planners to make decisions on the basis of time and efficiency without consideration of cost.

Table 2. Factors And Ramifications In Manufacturing System Design And Process Planning

2.5 PRODUCTION PLANNING PROCUREMENT AND SHOP FLOOR OPERATIONS

For the purpose of this report the following definitions apply:

Production Planning - Policies for planning the production of the company's products in the medium to long term and the provision of schedules for the production of products in the medium and short term.

Procurement - Policies and procedures for the purchase of raw materials and component parts to support effective manufacture of the company's products. This will involve consideration of production schedules and the management of inventories of raw materials and component parts.

Shop Floor Operations - Actual implementation of short term plans/schedules. Modifications to production schedules (and in some cases process plans) in the light of current circumstances. There is frequently a significant difference between the plan/schedule issued for a product and that which is implemented.

The general relationship between these areas is illustrated in Figure 11.A. The information flows suggested in Figure 11.A. are not as comprehensive as those suggested in Figure 8 (An Information Model For Product Design) section 2.2.3, but are adequate to provide a model for discussion of the cost issues associated with production planning, procurement and shop floor operations.

2.5.1 Production Planning

In the long term production planning provides input to business policy formation, in particular the capacity and cost implications of policy decisions concerning markets to be addressed, company growth and product mix. Provision of appropriate information therefore requires the availability of suitable models of the capacity and cost characteristics of the company's existing facilities and any additional facilities which are being considered. As stated in 1.1.1 there is widespread doubt concerning the ability of existing accounting systems to determine accurately the costs associated with particular

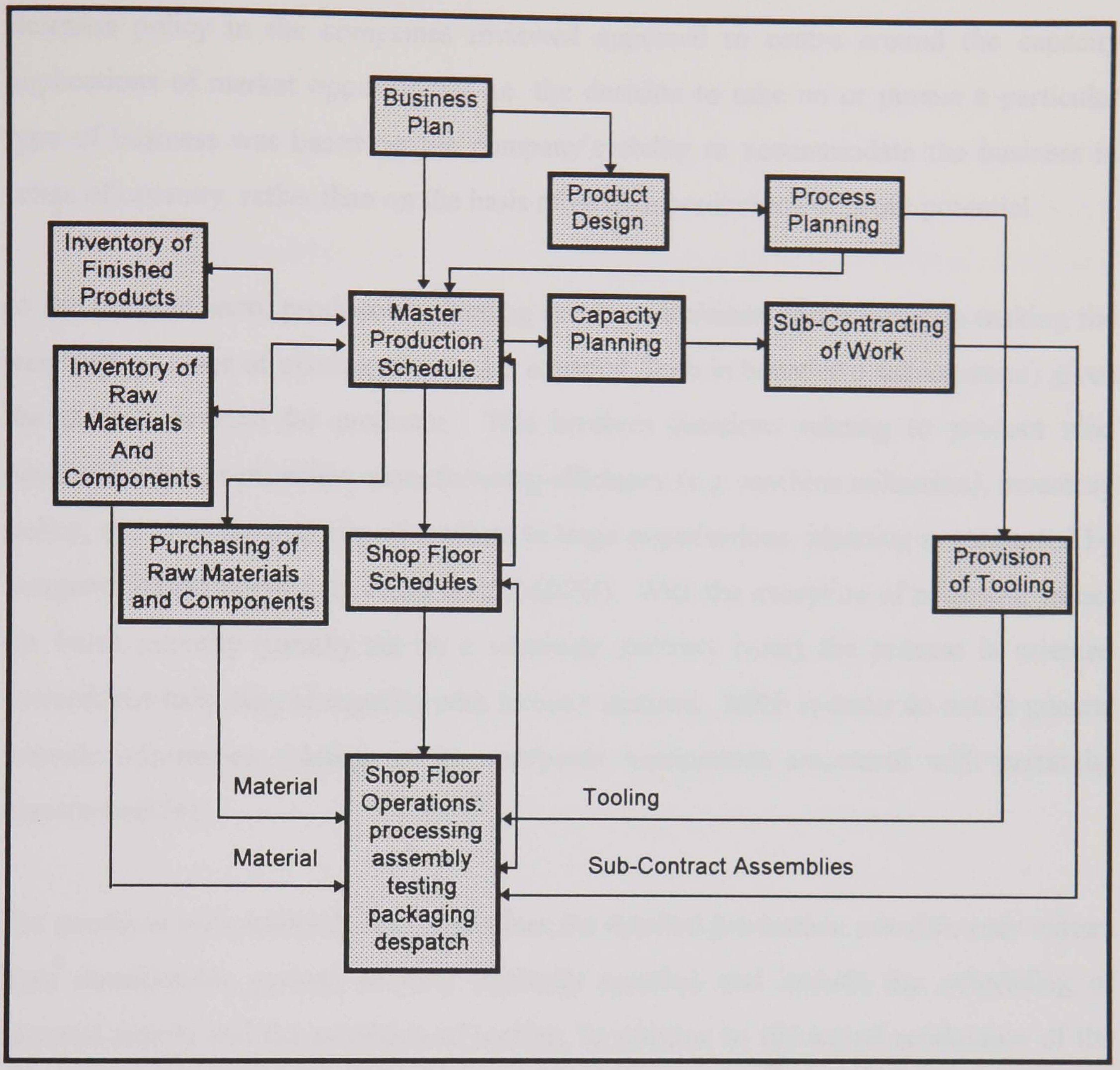

Figure 11.A. General Relationship Between Production Planning, Procurement And Shop Floor Operations

products. There is therefore a tendency for long term production planning and hence business policy formulation to emphasise capacity issues rather than cost issues.

An alternative approach to the use of detailed capacity and cost models would be a knowledge with respect to the activities which have the major effect on cost i.e. "cost drivers" (more will be said about the use of "cost drivers" in section 3.1.2), however it is unlikely that adequate knowledge of cost "drivers" could be achieved without some attempt at "modelling".

Business policy in the companies reviewed appeared to centre around the capacity implications of market opportunities i.e. the decision to take on or pursue a particular type of business was based on the company's ability to accommodate the business in terms of capacity, rather than on the basis of reliable predictions of profit potential.

In the medium term, production planning involves decisions which relate to making the most effective use of existing production capacity (both in house and sub-contract) given the current demand for products. This involves decisions relating to product mix, product/customer priorities, manufacturing efficiency (e.g. machine utilisation), inventory policy, etc. For the majority of medium to large organisations, planning is supported by computer based systems (typically MRP/MRPII). With the exception of minimum values for batch quantity (usually set on a relatively arbitrary basis) the process is oriented towards the balancing of capacity with forecast demand. MRP systems do not in general provide information relating to the cost/profit implications associated with particular plans/schedules.

For products with relatively long lead times the detailed production schedule may extend over considerable periods of time (typically months) and include the scheduling of material supply and the provision of tooling, in addition to the actual production of the product. In the relatively short term, feedback from shop floor operations with respect to the current availability of material and tooling, together with information concerning short term capacity dictates the short term (typically 1 to 2 weeks) schedules which are issued to the shop floor. A number of organisations would claim to operate formal planning on a daily basis but they are few.

2.5.2 Procurement

There is clearly (or at least there should be) a close link between the activity of procurement and that of production planning. Procurement involves the selection of appropriate suppliers of raw materials, components and services (including sub-contractors) and the negotiation and progression of contractual arrangements on price and delivery. Bearing in mind the high costs associated with excess inventory, decisions must be made with respect to the timing of orders (safety margins), safety stocks, quantity discounts and quality/reliability of supply. The relationship between production planning and procurement is therefore a complex one and requires careful co-ordination of policy and information. The survey revealed an apparent lack of such co-ordination - purchasing personnel often operating policies for the purchase of raw materials, component parts and consumables which were not compatible with effective implementation of production plans. Examples included mandatory selection of least price /least tender, multiple suppliers (to maintain "competition" and "security of supply"), standard delay on payment of invoices and the standardisation of raw material supply to facilitate bulk discounts.

2.5.3 Shop Floor Operations

As may be deduced from Figure 11.A. the degree to which shop floor operations conform to the production plan will be influenced by a number of factors:

- Physical availability of raw material and component parts.
- Physical availability of tooling - jigs, fixtures, etc.
- Physical availability of components and sub-assemblies supplied by sub-contractors.
- Availability of plant and labour.
- Ability and motivation of shop floor supervisors to interpret and implement shop floor schedules.

In practical situations shop floor supervisors and expediters ("progress chasers") have to contend with problems associated with: material shortages, quality, lack of required tooling (not delivered or in use elsewhere), changing priorities with respect to customers (e.g. replacement product required for an important customer), the tendency of shop floor personnel to opt for straightforward long production runs where possible, shortages of labour due to illness, machine breakdowns and many other practical problems which arise on an hour to hour basis. The final decision on scheduling is therefore often the domain of the shop floor supervisor and/or progress chaser rather than the production planner. Shop floor supervisors respond frequently by loading what is apparently the most urgent job on to the first available machine with little or no reference to the production plan. In some cases management accept the inevitability of this situation and provide a general "work to" list rather than a detailed schedule. In these circumstances there is no direct consideration of cost in the decision process. Several respondents in the survey suggested that the actual production of parts was based upon expediency and personality rather than any formal set of priorities/rules. In one of the companies the production manager stated that there would be far fewer problems if planning decisions were not overridden, on a routine basis, by production supervisors.

In several cases respondents stated that their performance (or the performance of the system) was measured against a particular performance index, but when asked to explain the basis of the measure admitted that they did not know it or that they did not understand it. It would appear reasonable to suppose that in these circumstances the respondents would find it difficult to tailor their decisions so as to improve their measured performance. The most common measures were performance against time (e.g. standard hours) and delivery performance (e.g. number of overdues). None of the respondents quoted cost oriented criteria.

2.5.4 Discussion And General Conclusions

Table 3 summarises the major factors and their ramifications. In general the production planning function appears to provide a basis for the release of orders for material, component parts and services and provides in essence an "authority to manufacture". The actual schedule which is implemented for the manufacture of products is determined frequently on the basis of expediency, at shop floor level.

Delivery performance and manufacturing "efficiency" are the most common criteria for decision-making in production planning. However, at shop floor level decisions are based more upon the provision of capacity for the most urgent (most overdue or most important) products. Procurement policy is based frequently upon "buying efficiency" and is not supportive to effective production planning.

FACTOR	RAMIFICATION
Functional divisions between staff responsible for production planning, procurement and shop floor supervision.	Poor co-ordination of activity; conflicting priorities of different decision makers.
Lack of appropriate models of system capacity i.e. lack of models which allow consideration of cost implications.	Decisions based upon capacity balancing criteria rather than cost/profit criteria.
Short term pressures at shop floor level, i.e. overdues, irate customers, breakdowns, etc.	Shop floor decisions concerning changes to schedules and/or process routes based often on expediency without consideration of cost implications.
Performance measures based upon manufacturing "efficiency" and delivery performance.	No perceived reward for performance in relation to cost (with the exception of procurement). Focus on maintaining and improving profitability may be reduced or even lost.
Lack of understanding and lack of information with respect to cost issues, in particular at the shop floor level.	Decision makers may be willing but unable to take cost issues into account. Reliance on perceptions of good practice which may be counter to cost effectiveness.

Table 3 Factors And Ramifications In Production Planning, Procurement And Shop Floor Operations.

2.6 QUALITY COSTS

Evans and Lindsay [69] and Ostrenga [70] state that quality costs may be classified as follows:

- Prevention costs.
- Appraisal costs.
- Internal failure costs.
- External failure costs.

Table 4 is taken from Ostrenga [70] and describes the relationship between the four categories of cost.

FUNCTION	PREVENTION COST	APPRAISAL COST	INTERNAL FAILURE COST	EXTERNAL FAILURE COST
ENGINEERING	• Design reviews developing quality characteristics and control plans. • Design checking. • Engineering changes.	• Prototype inspection. • Sample inspection. • Design evaluation tests. • Qualification tests. • Testing costs on samples.	• Redesign effort. • Scrap, rework, warranty, unplanned purchase and lost time costs due to design deficiencies. • Tool changes.	• Loss of customer confidence. • Scrap, rework, warranty, unplanned purchase and lost time costs due to design deficiencies. • Loss of sales.
PURCHASING	• Vendor capability surveys. • Purchase order technical data review and control. • Vendor product inspection.	• Source surveillance. • Incoming inspection and test. • First article inspection. • Qualification inspection and test.	• Evaluation, corrective action and re-purchasing efforts for purchased components rejects. • Scrap, rework, lost time and warranty costs due to defective purchased material.	• Evaluation, corrective action and repurchasing effort for purchased component rejects. • Scrap, rework, lost time and warranty costs due to defective purchased material.
PRODUCTION	• Machine and process capability studies. • Tool inspection and control. • Preventive maintenance. • Process control and inspection. • Inspection and test equipment design and procurement. • Prevention training progs. • Quality audits and admin. • Customer inspection liaison.	• Product inspection test. • Process control measurements. • Pack and ship inspection. • Stockroom audit. • Calibration and maintenance of measurement equipment. • Production environment tests.	• Review disposition and corrective action for non-conforming material • Scrap, rework, lost time and warranty costs due to deficient workmanship, tooling, maintenance, etc. • Rework costs for deficient manufacturing plans and procedures.	• Scrap, rework, lost time and warranty costs due to deficient workmanship, tooling, maintenance and operator instructions. • Loss of sales. • Investigating time and reporting activities.
CUSTOMER SERVICES	• Field installation and trial of prototypes and pre-production. • Customer test products.	• On site evaluations. • Contracted customer testing.	• Involvement in sampling and manufacturing problems concerning quality.	• Support costs associated with failure such as travel expenses and return shipment costs. • Analysis reporting and correction of warranty, extra service calls etc.
RESEARCH & DEVELOPMENT	• Existing products R & D to correct deficiencies/make improvements.	• Configuration and reliability engineering of projects..		

Table 4. Relationships between function and quality cost categories (Ostrenga [70]).

Until relatively recent years, companies wishing to increase their "quality" did so by tightening their regime for appraisal and hence raised the cost of internal failures. Current approaches however, based upon Total Quality Management (TQM) principles, put the emphasis on prevention, suggesting that a focus towards ever improving quality within the production process will result in lower overall cost [69]. This is supported by Ostrenga [70] who proposes the relationship illustrated in Figures 11.B.a. and 11B.b. Evans and Lindsay [69] go on to suggest that while prevention costs are the most important, it is usually easiest to collect appraisal costs, internal failure costs, external failure costs and prevention costs, in that order.

In order to make sensible decisions in relation to quality issues it is necessary to have appropriate information with respect to the various "quality costs". Plunkett and Dale [20] report the tendency of many organisations to lose quality cost information by collecting such costs under inappropriate headings and by including allowances for defectives and rework in their standard cost structures. They go on to state that the decision to scrap or rework is often taken by personnel who do not have access to the financial information necessary to make an economic choice. It was concluded that scrap versus rework decisions are based primarily upon ease of rework, output efficiency and delivery targets rather than on cost. The collaborating companies did not operate costing and information systems capable of supplying information under appropriate headings.

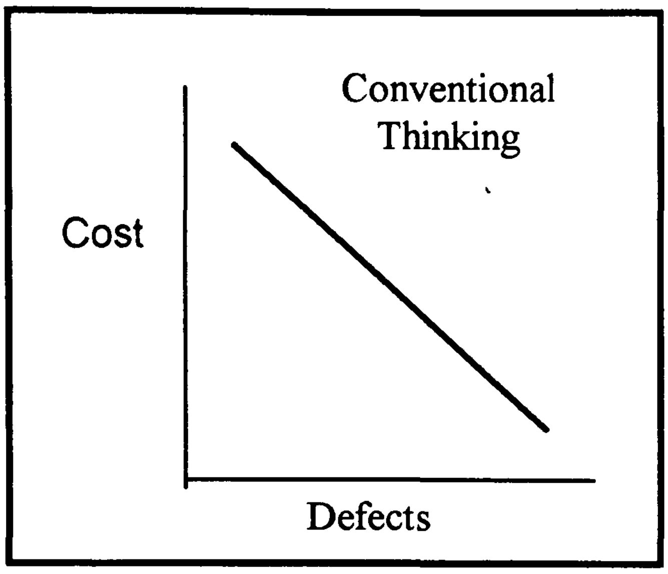

Figure 11.B.a.

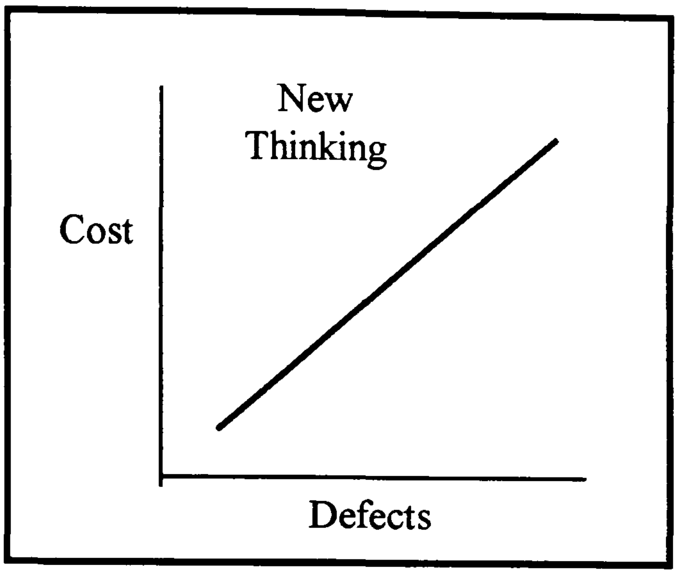

Figure 11.B.b.

2.7 FINANCE AND ACCOUNTING

The information and analysis presented in this section draws extensively from the comprehensive survey of management accounting practice in 303 U.K. manufacturing organisations, with turnovers in excess of £10m, carried out by Drury et al. [2] and is supported by additional published material and the industrial survey. It was stated by Drury et al. [2] that further work was required to examine how management accounting information is used in practical situations and it is in this area that the current research is based.

2.7.1 Product Costing

The survey by Drury et al. [2] provides the following general findings with respect to product costing :

- "Full costs" are used widely and "unsophisticated " practices are used for tracing overheads to products.
- Only 38% of firms used separate overhead rates for each work centre (or group of work centres) within a department. 26% of firms used a single overhead for the plant and 31% used a separate overhead for each department.

- 43% of typical manufacturing plants had fewer than six cost centre absorption rates and only 20% had over 20.
- 13% of firms have introduced or intend to introduce Activity Based Costing (ABC). 44% of firms have not even discussed the issue of ABC.
- 97% of firms prepare monthly statements of profit. Management accountants must therefore devote a considerable amount of time to tracking costs so that monthly costs may be allocated between cost of sales and inventories.

Drury [71] states that the majority of firms operating in an advanced manufacturing environment still recover overheads on the basis of direct labour. Consequently "management attention is directed to reducing direct labour by trivial amounts. To reduce their allocated costs managers are motivated to reduce their direct labour since this is the basis by which all other costs are attached to cost centres and their products". This process "overstates the importance of direct labour and directs attention away from controlling escalating overhead costs".

The survey by Drury et al [2] supports in many respects the contention by Kaplan [1] and numerous other researchers that current approaches to product costing are inappropriate to decision-making in AMT environments. For detailed analysis of the arguments reference should be made to [1], [3], [4], [9], and [17].

Two of the companies collaborating in the current research operate full cost systems and in each case the assignment of overhead is (on the admission of respondents) made on a relatively arbitrary basis. One of the companies operates what they describe as a marginal costing approach as a basis for commercial decisions and performance reporting but uses a full cost approach for cost reporting (cost estimates for new products are based upon historical cost data). The determination of marginal cost in the latter company is on the basis of a single rate for machining, a single rate for fabrication and a single rate for assembly. The accountants interviewed were burdened with a heavy load of period financial reporting and appeared to lack the resources necessary to identify and develop costing information in a form of value to design engineers, planning engineers, etc. Of the four accountants interviewed none believed that their accounting systems provided for accurate identification of the cost of particular products. In three cases their company's were involved currently in modifications which they believed would improve the accuracy of their costing systems, notably re-evaluation of methods of allocating overhead. While they were in general aware of the potential benefits of ABC only one company had seriously considered its implementation. The respondent in this latter company suggested that the effort required to initiate, implement and maintain an ABC approach was a significant barrier and was doubtful that the benefits would outweigh the costs.

To some extent the above may explain and justify the attitude of decision makers in the areas of design, manufacturing systems engineering, production planning and shop floor operations with respect to the use of cost information. The major barrier to improvement appears to arise from a lack of dialogue between accountants and design/manufacturing personnel, lack of cross functional understanding and lack of resources i.e. time and manpower.

2.7.2 Performance Measures

Keegan et al. [26] state that performance measures should provide linkage between business unit actions and strategic plans. Appropriate formulation of performance measures can ensure that focus is maintained upon achievement of the company's strategic objectives, at various hierarchical levels i.e. from shop floor to board level and also across the functions of the business at given levels. It is likely that performance measures at the strategic level i.e. business objectives will be of a generalised nature (e.g. improvement in long term profitability by means of increased product margins through improved customer service and product quality) and as such may have little relevance to personnel at shop floor operations level. Performance measures should support rather than inhibit the implementation of company strategy e.g. If company objectives include an increase in product quality it is unlikely that procurement performance based solely upon performance against "standard cost" would be appropriate. Equally there would be little sense in employing a production performance index based solely on throughput volume per period. Keegan et al. [26] suggest that in many companies performance measures are based upon "the ghosts of management past" and derived from a totally different strategy than that currently being pursued. Further evidence to support the view that performance criteria are frequently at odds with strategic objectives is provided by Dugdale [29]. Table 5 (based upon that attributed to Brimson in reference [29]) summarises some of the more common measures of performance together with the resulting actions and results.

Performance reporting in two of the collaborating companies was on the basis of standard hours/standard cost although in each case operational measures such as lead time, delivery performance and stock turnover were increasing in their importance. The other collaborating company used what they referred to as a marginal costing approach, i.e. contribution per product, as a basis for performance reporting - this company also was making increasing use of operational performance measures.

2.7.3 Investment Analysis

Quantification of the overall financial benefit of investing in manufacturing facilities or products is of fundamental importance in the pursuance of long run profitability. Management accounting and other decision-support systems may help to facilitate the most efficient/effective operation of existing facilities but can not turn bad investment decisions into good ones. There is wide spread criticism concerning the effectiveness of current practice and this is supported by evidence from the industrial collaborators.

Kaplan and Atkinson [17] state that practice is particularly suspect with respect to evaluation/justification of investment in AMT projects. They contend that a major flaw lies in the application of DCF techniques (the most widely used technique according to Drury et al. [2]) where managers:

- Require payback over arbitrarily short periods.
- Use excessively high discount rates.
- Adjust inappropriately for risk.
- Emphasise incremental rather than global opportunities.

- Fail to recognise all the costs of the new investment.
- Ignore important benefits from the new investment.

They are supported by New [72] who criticises high hurdle rates and the failure to incorporate less tangible benefits and by Davis [73] (John Brown Automation) who criticises the disparity between typical amortisation periods for flexible assembly automation between the U.K. and Japan (1 year versus 10 years).

MEASUREMENT	ACTION	RESULT
Purchase price of raw materials and component parts (often against a "standard cost").	Purchasing increases order quantity to get lower price. ignore delivery and quality.	Excess inventory. Supplier with best quality and delivery is overlooked.
Machine utilisation.	Supervisors run machines in excess of daily unit requirements to maximise utilisation.	Excess inventory. Wrong inventory.
Standard scrap allowance built into standard cost.	Supervisor takes no action if actual is less than standard.	Poor standards of quality may be built in.
Standard cost overhead absorption on WIP.	Supervisor overproduces to get overhead absorption in excess of expense.	Excess inventory. Wrong inventory.
Throughput volume.	Supervisor over produces.	Excess inventory. Wrong inventory.
Performance against "standard hours".	No action unless actual is greater than standard.	Inefficient methods built in.
Scrap value (£).	Scrap value drives corrective action priority.	Defective level impact on flow is hidden.
Cost centre reporting.	Management focus is on cost centres instead of activities.	Missed cost reduction opportunities. Major overhead activities not exposed.

Table 5. Traditional measurements and their effect (attributed to Brimson in ref. [29])

In general the non-accounting respondents in the survey regarded the investment justification process as an obstacle to investment in the equipment they need, rather than an opportunity to assess objectively the value of the equipment over its full life cycle. A tendency to understate expenditure (e.g. ignore all but capital and contract costs) and overstate revenue improvements and cost savings appeared to be regarded as legitimate by some respondents. This practice may be explained perhaps as a reaction to the situation situation described by New and Davis, on the part of managers and engineers. In general the accountants in the collaborating companies adopted a relatively pragmatic approach accepting that investment was made on the basis of "strategic" and "capacity" based criteria as much as direct measures of profit potential. All the companies used formal procedures for investment analysis, with varying degrees of rigor e.g. one company included only capital and contract costs on the debit side of the analysis. Two companies used DCF and one company used "payback" (three years) as the basic "hurdle" for investment decisions. None of the collaborating companies operated costing systems which would reflect the changed cost structure associated with investment in major items of plant and none had formal systems for post implementation audit of capital investment.

While it would appear logical that the criteria and assumptions used to justify an investment in manufacturing plant should be compatible with the method of depreciation used to allocate the cost of the plant to particular products over the period of its life, this is not necessarily the case in practice [35]. For example a particular machine tool may be justified on the basis of an estimate of total production volume over a relatively short period of time, yet the method of depreciation used to allocate costs to particular products following istallation of the machine may arise from expedience in reporting or from accounting convention (i.e. tax considerations, current practice, etc.). In a situation such as this the system may allocate a cost which does not embody the assumptions made in the justification of capital. A situation common in the experience of the author and respondents to the survey is corroborated by The National Association of Accountants [74] - In companies which allocate cost on the basis of plant or departmental overhead and direct hours, work tends to be channelled to the high cost computer controlled (CNC) machines. This arises in part as a consequence of the shorter cycle times and/or improved accuracy associated with such machines but is also the result of managers wishing to demonstrate the necessity of the investment. This approach may cause bottlenecks to be formed at these new facilities and hence an apparent case for justification of more capacity of this type, when in reality effective use of existing capacity may be more cost effective. The risk of capital investment which does not provide real cost benefits to the company is increased in this situation. Alternatively if a more realistic or even excessive assignment of overhead (e.g. too short a depreciation curve) is allocated to a specific CNC machine, users of the facility who were not responsible for its purchase may tend to route jobs away from it. If the investment was sound this should not be the case as reduced cycle times and improved quality should more than compensate for the increased operating cost rate (provided that the rate is realistic rather than excessive).

A more holistic and co-ordinated approach to investment justification is required rather than the "combative" and "intuitive" approach which appears to exist in many companies. More balanced approaches to investment analysis are discussed by Primrose [75], Kaplan and Atkinson [17] and New [72]. An individual manager should not be able (using a company's formal procedure) to show a satisfactory ROI where the project being considered is detrimental to the company as a whole.

One of the major issues in investing in AMT is the relatively long term nature of such undertakings and the associated difficulty in dealing with risk. Drury et al. [2] state that only 51% of organisations carry out sensitivity analysis, the remainder rely upon relatively arbitrary adjustments to payback period, discount rates and forecasts of cash flow and only 5% of companies used simulation techniques. The potential for more effective accommodation of risk on a practical basis is being made more feasible by developments in simulation software and innovative approaches to its use. This is discussed further in section 4.2.1.

There is clearly a need to change the attitude of production managers and engineers with respect to investment justification and to reconsider approaches to allocating costs to new acquisitions. If an item of plant is justified by a company's evaluation procedure (and the assumptions made in the process are subsequently proved to be correct) then the costing system should not indicate an adverse situation when the plant is used as planned. Equally if the assumptions made in the justification are not born out in the implementation and operation of the plant (e.g. proposed cycle times are not achieved) then the costing system should indicate an adverse performance with respect to cost. Until such time as realistic approaches to investment justification are introduced, including appropriate post implementation audit and assignment of overhead, production managers and engineers are unlikely to adopt more responsible attitudes to capital expenditure or have faith in cost assignment systems and associated performance measures. The following statement from Hamblin [76] is entirely appropriate, "Until productivity is measured properly, with figures that reflect real life, manufacturing cannot prove the worth of any investment".

2.7.4 The Continuing Role Of Management Accountants

The need for a new approach to performance measurement in companies wishing to embrace the new technologies associated with CIM, JIT and "world class manufacturing" is accepted widely [17] and [14]. Kaplan and Atkinson [17] suggest that a focus should be maintained on key success factors and claim that long term cost reduction and profit enhancement may be best achieved by continually improving short term manufacturing performance, not by achieving short term financial targets. Performance measures quoted by Kaplan and Atkinson are summarised in Table 6. Kaplan and Atkinson go on to suggest that "accountants and finance staff who articulate a narrow interpretation of their expertise and responsibility will be relegated to a minor role in their organisation. Companies will rely far less upon short term financial control measures". They suggest also that if management accountants do not provide or accommodate these new measures then they will be provided by others in the organisation "less capable of providing the reliability and integrity that managers have come to expect from accounting systems". This view is shared by Drury [14], who states "If accountants do not respond to the challenge and re-design the reporting system others will do so and production operations management will fill the controller role relinquished by the accountant".

MEASURE	IDEAL TARGET
Unit Cost	Cell cost per hour divided by maximum units produced per hour (under ideal conditions).
Cycle Time	Theoretical time through cell with no down time.
Delivery	100% on time - in line with actual demand.
Quality	Zero defects.
Linearity of Production	Zero deviation from absolute linearity - daily production equals monthly production goal divided by number of working days in month (i.e. no rush of output at end of month to satisfy period profit reporting).
Inventory Turns	Reciprocal of cycle time except for allowed inventory in WIP.

Table 6. Typical Performance Measures (Kaplan and Atkinson [17])

There is an urgent need for management accountants, production managers and engineers to work together in developing information systems and performance measures which include operational factors (essential for short term and medium term decision support) and cost factors (essential to ensure the compatibility of operational measures/targets with long run profitability). A danger is that the "pendulum" may swing too far towards the use of "operational" measures and that knowledge of the factors which drive actual cost, and hence influence profit, will be lost. Management accountants must work with production managers and engineers and work towards common business objectives rather than functional objectives.

2.8 SUMMARY AND CONCLUSIONS

The role of cost and management accounting may be described as that of supporting the determination, implementation and operation of strategies which will make the most effective use of a company's resources. For most companies the ultimate goal is maximisation of long run profitability. The review and analysis of published material and current practice provided in sections 2.0 to 2.7 depicts a diverse and fragmented situation with respect to the use of cost information as a basis for decision-support. Intuition, judgement, expediency, professional "good practice" and "operational" measures are seen frequently as a more relevant basis for decision-making by industrial personnel. In cases where cost orientated information is used by decision-makers, concepts and techniques are used frequently in an inappropriate manner and the results are mistrusted by the users.

A fundamental problem appears to lie with the two major traditional approaches to product costing i.e. absorption (full) costing and variable (marginal) costing. The basic structure of the two approaches is illustrated in Figure 12 (taken from Drury [71]). In both absorption and variable costing systems, non-manufacturing costs are allocated directly to the profit and loss account on a period basis. In companies with a high element of R & D, design and product support this may represent up to 30% of product cost. It is difficult to see any logic in companies not attempting to allocate these costs realistically to particular products/services or even to product types (current practice is normally to have relatively arbitrary assignment of such cost for the purpose of stock valuation.). With the current move towards higher levels of automation and IT and to increased emphasis on product development and support, traditional approaches appear to be even more suspect as a basis for decision-support. Where internal profit/performance reporting centres around a marginal ("contribution") approach and this is used as a basis for long term decision-making (i.e. product development, product mix and facilities development) the situation appears even more confused.

No evidence was found in the review and analysis to suggest that companies are confident in the ability of their cost accounting systems to determine accurately the cost of particular products. Companies in general appear to operate cost accounting systems which are understood by accountants alone and which provide little or no information in a form appropriate to product designers. The greatest concern with respect to the accuracy and relevance of cost information appears to come from the accounting profession itself - which is understandable given the alienation of many engineers and

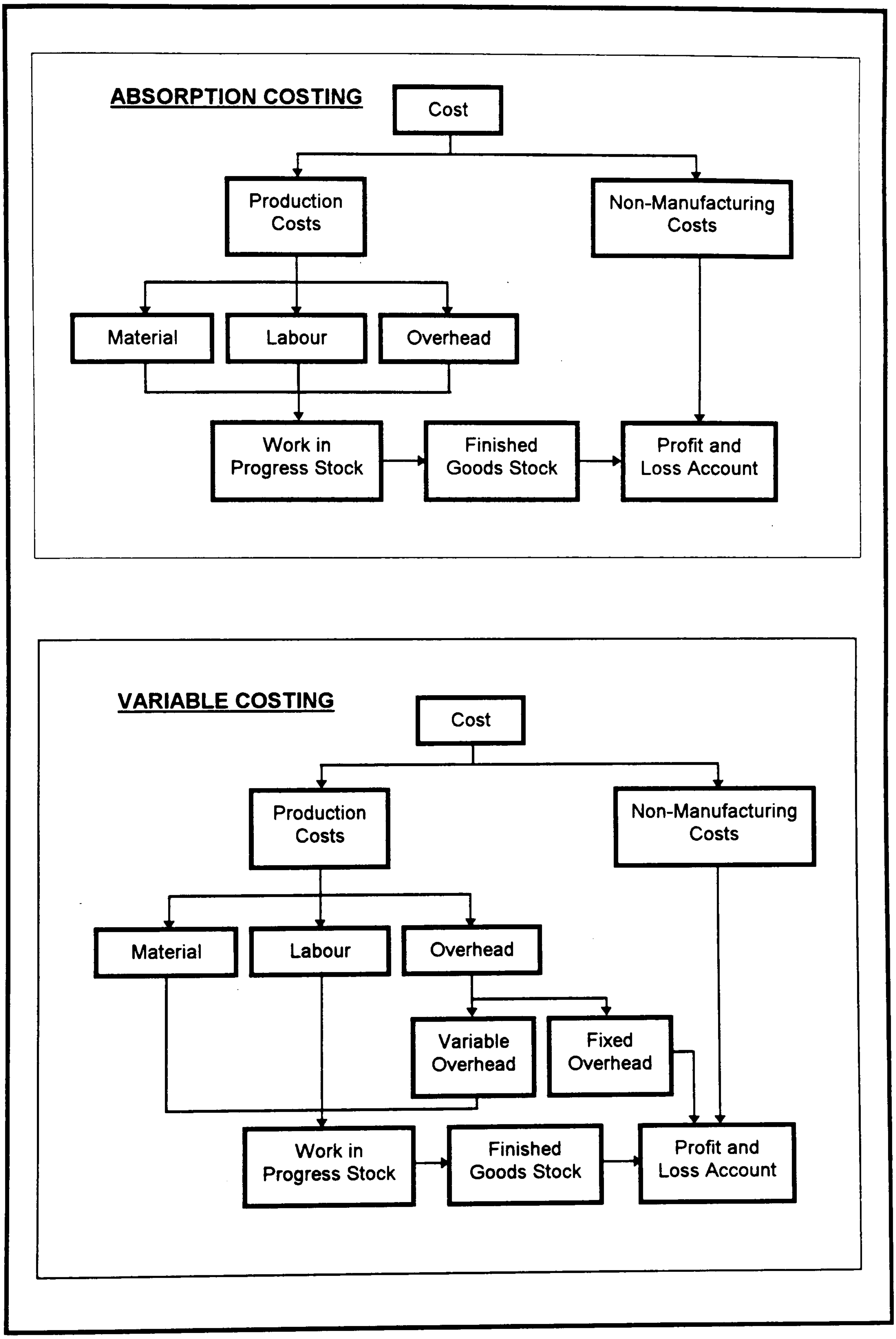

Figure 12 Traditional Approaches To Product Costing (taken from Drury [71])

operations managers with respect to accounting information. Many companies appear to be moving towards greater use of "operational" measures as a basis for decision-making, relegating cost information to the reports of period profit and loss.

Problems associated with the use of cost information are accentuated by organisational, behavioural and external factors as follows:

Organisational - Traditional hierarchical company structures with strong functional divisions inhibit the flow of appropriate information and the development of common objectives. This often leads to a tendency towards internal competition and does not motivate personnel to provide information in a form useful to other functions.

Behavioural - Engineers exhibit strong professional allegiance and loyalty. The business objectives of the company with respect to product development and product support may be overwhelmed by the quest for technical innovation and excellence. The engineer may seek to gain recognition from his/her peers at the expense of business considerations. However in defence of the engineer it must be said that companies do not appear to make serious efforts to supply them with information which would enable them to base their decisions more effectively on cost/profit criteria. The behaviour and the perceptions of engineers have been influenced (traditionally) by narrow, technically oriented education and strong functional divisions within companies.

Accountants to some extent share the criticism of professional rather than business loyalty. They also tend to have a rather narrow education (i.e. little consideration of the practical issues associated with manufacture) and tend to be preoccupied with the technical issue of financial reporting, at the expense of developing information systems which will increase the relevance and extend the influence of the information they provide.

Differences in the perception and understanding of cost and performance criteria across the levels and functions of many organisations mean that any attempt to provide an integrated approach to the pursuit of business objectives is hampered.

External Factors - Pressure on the accounting function with respect to period financial reporting and the squeezing of resources to provide such information leaves accountants with little time to develop the decision support aspect of their function.

Pressure on short term performance in many manufacturing organisations makes it difficult to justify investment in time and resource to develop and improve cost information systems.

The evidence provided in sections 2.0 to 2.7 provides strong evidence in support of the initial hypothesis i.e. that "Traditional approaches and practices with respect to the determination, communication and use of cost information do not provide a satisfactory basis for decision support in today's highly competitive and technologically advanced markets".

The barrier to development and operation of effective cost based decision support systems appears to lie in:

- The widespread use of outdated systems which were designed to meet stock valuation requirements.
- Company organisation structures based upon strong functional division.
- Narrow perspective of many engineers and accountants.
- Lack of an appropriate model to provide an effective platform for the integrated application of new concepts, techniques and IT.

3.0

"NEW" APPROACHES TO COST ACCOUNTING

Over recent years a considerable amount of research has been carried out by the management accounting profession, with respect to the development of cost accounting approaches appropriate to the needs of modern manufacturing organisations. Two approaches in particular have been the focus of sustained interest by researchers i.e. Activity Based Costing (ABC) and Throughput Accounting (TA). While there has been extensive publication with respect to the principles associated with ABC and TA, relatively little has been published with respect to the practical implications for decision-making in the areas of engineering and operations management. Several researchers [2], [7] and [15] have identified the need for research which will provide a framework for the effective implementation of these "new" approaches and in particular the need for collaboration between engineers and management accountants.

3.1 ACTIVITY BASED COSTING

3.1.1 Background

The major thrust towards the introduction of activity based costing (ABC) began in the late 1980s and was publicised and pioneered by Prof. Kaplan, Prof. Johnson and Prof. Cooper, of the Harvard Business School, together with several industrial collaborators. "Relevance Lost: The Rise and Fall of Management Accounting" [4] was published by

Kaplan and Cooper in 1987 and was followed by "Relevance Regained" [1] by Kaplan in 1988. Four linked publications under the general title "Activity Based Costing Systems" [77], [78], [79] and [80] were published by Cooper between 1988 and 1989 and set the scene for further work and publication by numerous researchers and practitioners. Central to the development of ABC was the support of Computer Aided Manufacturing - International (CAM-I), in the form of their Cost Management Systems Programme (CMS).

The concern expressed by Kaplan et. al. was in relation to the large number of companies which continued to rely upon traditional product costing systems which allocated overhead costs (which have increased significantly over recent years as a proportion of total product cost, due to increased levels of automation) to products on the basis of product volumes rather than upon more realistic criteria. The traditional approach to assignment of overhead cost is illustrated in Figure 13 (adapted from that presented by Tayles [7]).

The approach represented in Figure 13 assumes that products will always consume overhead resources in relation to their requirement for direct labour or machine hours. This is demonstrably not the case e.g. two products A and B each require 2 hours of machining effort in a company's machine shop, 1 hour of assembly time and 1 hour of testing. Component A is a standard product and has been produced in batches of 50, three times per year, for the last 2 years. Part B is a customised version of part A, requiring greater precision in manufacture and will be produced in a once off batch of 50. Part B requires special raw materials (in terms of Q.A. requirement), special components and revised tooling. Consider the way in which each component would attract cost using a conventional accounting system:

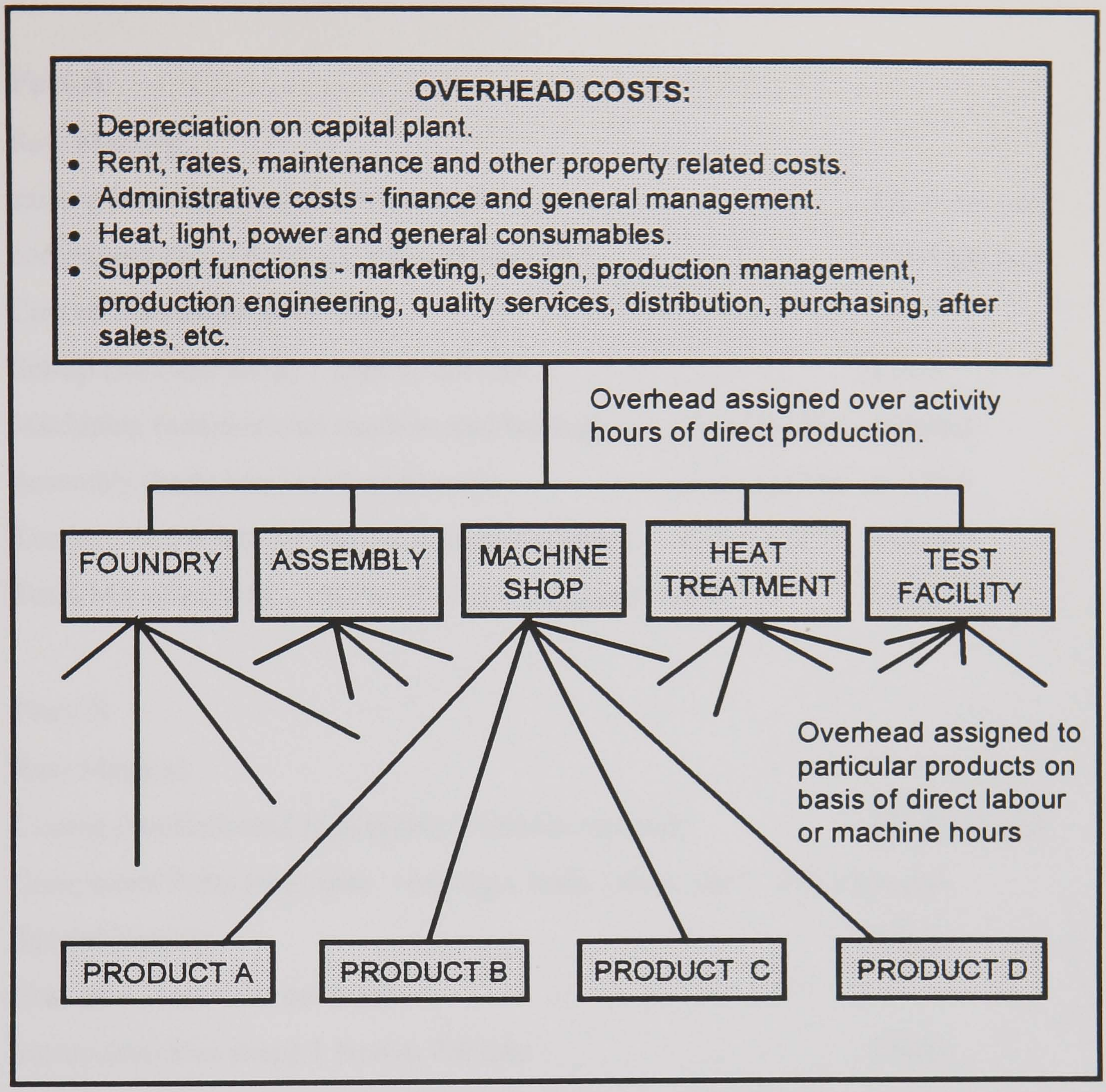

Figure 13 Traditional Approach To Assignment Of Overhead Costs (based upon Tales [7])

Assumptions

That the company assign cost upon the basis of direct hours and that the relevant labour rates and departmental overhead are as follows:

Machine Shop	labour	£10.0 per hour
	overhead	£26.0 per hour
Assembly Shop	labour	£10.0 per hour
	overhead	£14.0 per hour
Test Facility	labour	£10.0 per hour
	overhead	£15.0 per hour

Part A

Raw Material:		
casting (standard, low grade material)		£20.0 per part
component parts (bearings, seals, valves, etc.)		£22.0 per part
Cost of manufacture per batch:		
Set-up (machine shop) 1 hour at full rate		£36.0
Machining (conventional machine tool/tooling)	(50).(2).(36)	£3600.0
Assembly (basic hand tools and bench)	(50).(1).(24)	£1200.0
Testing (simple test for max. operating pressure)	(50).(1).(25)	£1250.0
Total Manufacturing Cost Per Part (excluding materials)		£121.72

Part B

Raw Material:		
Casting (sophisticated high quality traceable material)		£60.0 per part
Component Parts (high spec. - bearings, seals, valves, etc.)		£43.0 per part
Special Tooling		£500
Cost of manufacture per batch:		
Set-up (machine shop) 1 hour at full rate		£36.0
Machining (CNC machine with special tooling)	(50).(2).(36)	£3600.0
Assembly (precision press & special lubricants)	(50).(1).(24)	£1200.0
Testing (max. pressure and flow rate using special accredited equipment)	(50).(1).(25)	£1250.0
Total Manufacturing Cost Per Part (excluding materials and special tooling)		£121.72

The assignment of cost to products A and B by this traditional approach results in both products being assigned an identical cost of manufacture per product. Consideration in more detail of the particular manufacturing requirements for each product reveals significant ambiguity:

- The cost of work carried out in support activity associated with identifying and implementing the manufacturing process for each product (review of customer specification, design modifications, process planning, design and progressing of special tooling, identification of materials suppliers, quality assurance requirement, design of packaging, etc.) is assigned on a per product basis i.e. the support functions associated with these activities are regarded as part of the overhead. As the majority of this effort is once off (a relatively small amount of cost is associated normally with maintaining, storing and retrieving process plans, special tooling, etc. for repeat batches.) this means that product A (repeated batches of 50) will receive a disproportionally high assignment of support cost, compared with product B (once off batch of 50). The magnitude of this affect increases with the ratio of part A numbers over time to part B numbers over time.

- Part B requires the purchase and quality assurance of sophisticated and high quality material and components and hence demands more effort on the part of purchasing and Q.A. personnel than that associated with product A. While the higher cost of the material and component parts is assigned directly to product B, the higher cost of support is not.
- Part B is shown as requiring the purchase of special tooling. While the cost of purchasing the tooling (£500) is assigned directly to the batch, the cost of tooling design, selection and supervision of supplier and the provision of special instructions in process planning is not directly assigned. Again product B is assigned an unrealistically low cost in comparison with product A.
- Both batches being considered require the same amount of time for set up and processing in the machine shop and hence are assigned identical cost. Part B however is processed on a CNC machine tool (which is likely to make a much larger contribution to the depreciation element of the machine shop overhead burden than the conventional machine used for part A and to require a much greater level of support activity in terms of "part-programming", and maintenance). Again a disproportionally high assignment of cost is made to product A with respect to product B.
- The special facility and consumables required for part B at the assembly and the testing stages again result in disproportionally high assignment of cost to product A with respect to product B.

The above approach may provide cost assignment with sufficient accuracy to satisfy the requirements for stock valuation but clearly does not provide a satisfactory basis for operational and strategic decision-making. It might be expected therefore that companies would be moving towards the the adoption of costing systems which would allow more accurate assignment of cost as a basis for decision support in these areas. It is however significant that the survey by Drury et. al. [2] suggests that 26% of companies still use a single overhead rate for the factory and that only 31% use a separate overhead rate for each department. Academic accountants support the use of "machine hour rate" as a basis for the assignment of overhead in mechanised environments [1] and [7] but Drury [71] states that the majority of companies still recover overhead on the basis of direct hours. Kaplan [1] points out that while the use of machine hours as a basis for assignment of overhead provides an improvement over the use of direct labour, the problems associated with assignment based solely upon product volumes remains. The solution proposed by Kaplan [1] is the introduction of a new approach i.e. Activity Based Costing (ABC).

3.1.2 Principles of Activity Based Costing

The basic premise of ABC is that product manufacture comprises various activities and that the carrying out of these activities consumes resources and therefore cost. Thus if a company can identify the range of activities associated with the manufacture of its products, the resources/costs associated with those activities and the product characteristics ("cost drivers") which dictate the need for activities, then it becomes possible to assign cost consumed by activities in relation to particular products more realistically. The basic structure of ABC is illustrated in Figure 14 and is taken from Tayles [7].

Figure 15 illustrates the way in which an ABC approach might be applied to the example products, A and B, considered in section 3.1.1 and is based upon an approach presented by Innes and Mitchell [81]. The figure depicts that **part** of a fictitious ABC system which might relate, most significantly, to the manufacture of the two batches in question. The first difference to observe in the ABC approach is that the volume related overhead has been separated from the non-volume related. Direct production

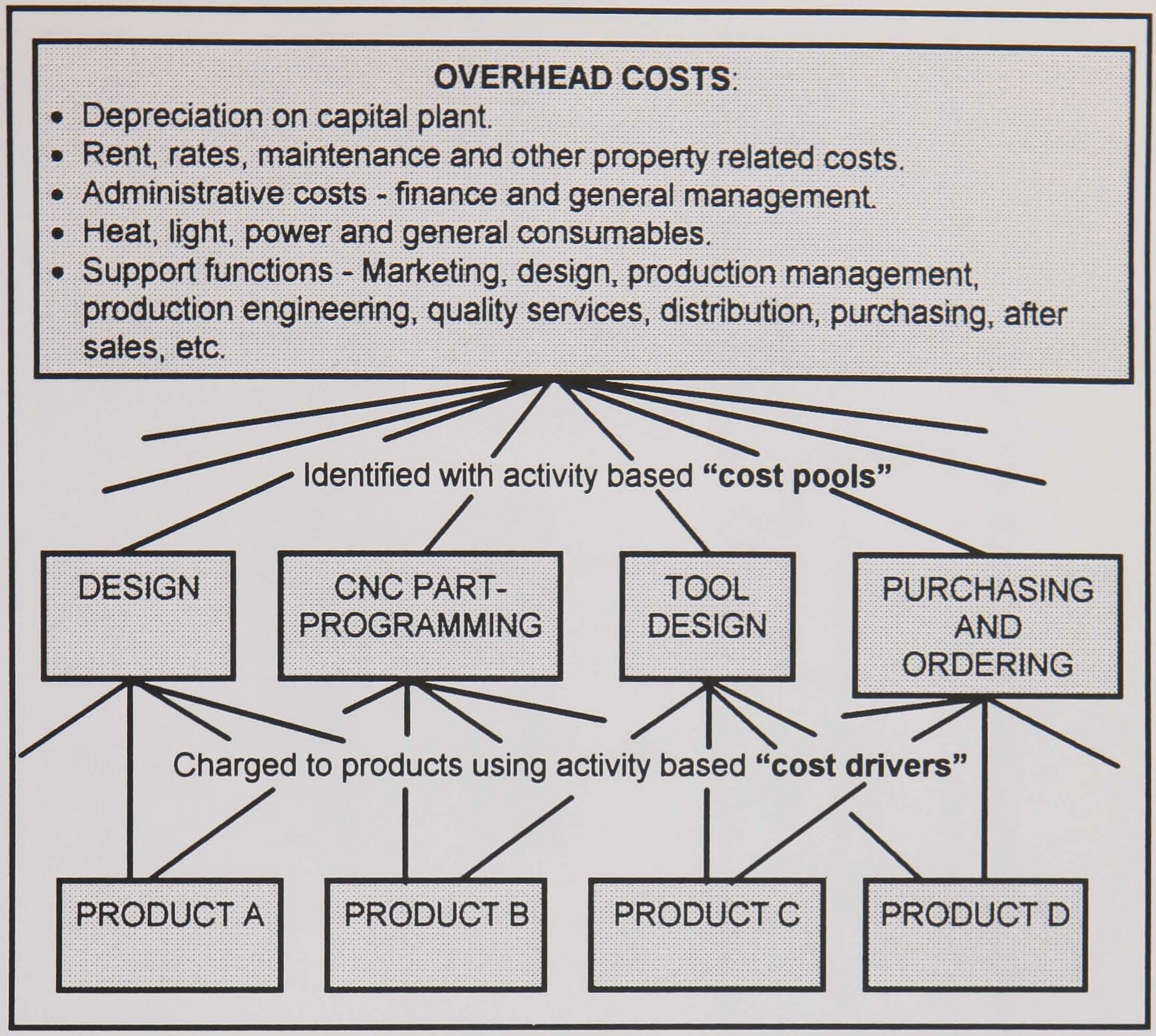

Figure 14 Basic Structure Of Activity Based Costing (based upon Tayles [7])

areas such as the machine shop continue to justify a significant assignment of overhead on the basis of product volumes but "support" activity associated with the machine shop and other "direct" areas is now assigned in part on the basis of activity rather than product volumes. The overhead assignment per direct hour associated with the direct production areas is therefore less than that used in the traditional approach, with the balance of support overhead being assigned to the various "cost pools" and the cost per unit of the "driver" associated with each activity being identified.

On a practical note it has been observed that many of the exemplar ABC cost structures proposed by researchers e.g. [7] and [81], identify "set up" as a non-volume related activity. Given that in a mechanised environment a major element of set up cost will be

	VOLUME RELATED					ACTIVITY RELATED			
	CNC M/C Tools £3m	Conventional M/C Tools £7.4m	Assembly £2.6m	Testing £1.4m		CNC Part Programming £10000	Tooling Design £60000	Selection and Accreditation of Suppliers for Traceable Material £20000	Inspection: Machined Parts £150000
	100000 M/C Hours	400000 M/C Hours	200000 Direct Lab. Hours	100000 Direct Lab. Hours		100 Programs	600 Sets of New Tooling	40 High Spec. Products	30000 Items
	£30 Per M/C Hour	£18 Per M/C Hour	£13 Per Direct Lab Hour	£14 Per Direct Lab Hour		£100 Per Program	£100 Per Set	£500 Per New High Spec. Product	£5 Per Item
Product A: repeat batch (50)	Not Applicable	(51)x(18) [inc. set up] £918	(50)x(13) £65	(50)x(14) £700		Not Applicable	Not Applicable: [standard tooling]	Not Applicable	Not Applicable: [no off M/C inspection]
Product B: one off batch (50)	(51)x(30) [inc. set up] £1630	Not Applicable	(50)x(13) £65	(50)x(14) £700		£100	£100	£500	(50)x(5) £250

Total Batch Cost Product A £1683
Total Batch Cost Product B £3051

Figure 15 Product Costing Using an ABC Approach.

associated with "lost" time on the productive facility and that the nature of the support activity necessary during set up is related to the status of the batch (i.e. repeat batch/first batch) and the complexity of the product, a modified approach may be more appropriate. Figure 15 shows the volume element of set up being assigned by including the machine set up time as part of direct hours and by including the non-volume element under more specific support activity headings e.g. CNC "part-programming". This serves to illustrate the expertise and care which is required in the development of ABC cost systems/structures for particular companies rather than to criticise previous models.

The second difference in cost structure is that a machine hour base has been used to differentiate between the cost associated with CNC machine tools and conventional machine tools. Thus the machining cost assigned to Product B is increased. Ambiguities in the areas of assembly and testing concerning the cost assigned to the two batches are maintained (continued use of the "direct" labour base) and this serves to illustrate the compromise which is inevitable in the practical application of ABC (and other costing approaches for that matter), between the accuracy of information provided by the system and the cost/complexity of providing it. Establishment and maintenance of this data in real manufacturing organisations, notwithstanding the requirements for system design, staff education and training, is a major source of cost and a potential barrier to the implementation of such systems. However it is possible that valuable insights into the cost structure of a company may result from "pilot" studies based upon some form of "activity sampling" rather than full scale implementation of ABC. Whatever the approach it is likely that the process of implementing or considering the implementation of ABC in a company will increase the level of awareness in the company with respect to the real cost of particular products and operations. The issue of justifying the implementation of ABC is discussed further in section 7.6.

Reference to Figure 15 shows the significant difference between the characteristics of the two batches being reflected in the manufacturing cost assigned to each batch.

Experienced engineers and managers now have a relatively objective measure of a difference they knew existed but had previously been unable to quantify.

3.1.3 Discussion

The nature of the ABC approach is such that it provides information about the way in which products consume resources/cost given a particular product mix and manufacturing system (where "manufacturing system" refers to a set of facilities for manufacture and the systems used to manage their operation.) rather than definitive product costs. As such an ABC system may provide important insights into the profitability of particular products and the costs associated with particular types of activity. It is however important to realise the limitations of ABC with respect to the making of discrete decisions on a day to day basis. e.g. Ceasing the manufacture of a product which has a negative contribution, based upon ABC data, will not necessarily improve the profitability of the company - particularly in the short term. This is due to the fact that the capacity released by the decision may not be capable of being transferred to the manufacture of a "profitable" product or of being eliminated in the short term (this issue is discussed further in sections 4.2.1 and 7.3.3). Hence ABC is of value as a basis for decision support with respect to medium and long term decision-making and to the periodic assessment of product profitability.

The information gained from a product and manufacturing system review based upon ABC may be applied in two ways:

1. Information relating to product cost and hence product profitability helps to identify products and product types for which increased demand should be encouraged and those which should be reduced in volume or eliminated. However as stated previously the situation is not as simple as would first appear; a decision to increase production of some products and reduce/eliminate the production of others must take into account also the overall affect on system capacity and system capability. The majority of productive capacity is not capable of linear increase/decrease, particularly in the short term. Hence ABC may be said to provide the direction for a comprehensive approach to medium/long term product planning rather than the complete answer.

2. Information about the cost of particular activities, in particular the more expensive activities associated with higher volume products, may be used to provide a focus for the development of improved manufacturing methods and the re-design of products. Again the situation is complicated by the interrelationships between product mix, and manufacturing system design and operation i.e. individual changes for one product may result in modification of the cost structure associated with another. The use of "cost drivers" as a means of providing product designers and manufacturing system engineers with cost awareness concerning their decisions has significant potential and has been introduced in some companies with considerable success [82].

If companies do use ABC on a periodic basis e.g. 12 months, to provide insight in the determination of product and manufacturing system policy, it is possible given the rapid progress of simulation techniques, that the affect of particular decision sets with respect to overall activity costs and product profitability may be forecast. This is discussed further in section 7.3.

ABC is not a panacea but does appear to have significant potential as part of an integrated model for decision support. Detailed consideration of the mechanics of ABC systems is however beyond the scope of this work, the main issue being to establish the extent to which the technique may lend itself to inclusion in a general model for cost based decision support. Comprehensive coverage of the principles and justification of ABC is provided in [71] and [81] and consideration of ABC system design together with extensive case material is provided in [82].

3.2 THROUGHPUT ACCOUNTING

3.2.1 Background

The term "throughput accounting" (TA) came to some prominence in the late 1980s following work and publication by a number of researchers, notably Galloway and

Waldron [11] and Shcmenner [12]. The use of throughput time as a basis for decision-making was embodied also in the "Optimised Production Technology" (OPT) approach developed and marketed by Goldratt [83] and [84]. These initiatives were motivated by the same misgivings concerning traditional approaches to accounting as were expressed by proponents of ABC (section 3.1.1). Both Goldratt and Galloway and Waldron have developed and marketed, with some success, computer based systems based upon the principles of their particular approaches to TA.

3.2.2 Principles of Throughput Accounting

Galloway and Waldron [11] set out three basic concepts as the foundation for TA:

1. "Manufacturing units are an integrated whole whose operating costs in the short term are largely pre-determined. It is more useful and infinitely simpler to consider the entire cost excluding material as fixed and to call this cost Total Factory Cost".

2. "For all businesses profit is a function of the time taken for manufacturing to respond to the needs of the market. This in turn means that profitability is inversely proportional to the level of inventory in the system, since the response time itself is a function of all inventory".

3. "The rate at which a product contributes money determines the relative product profitability and the rate at which the factory spends it determines absolute profitability".

Galloway and Waldron (and others in the TA field) emphasise the importance of key (or bottleneck) facilities in determining the throughput of the company and in providing various indices to form a basis for performance measurement and decision-making. The following is an example:

$$\text{Throughput Accounting Ratio} = \frac{\text{Return per Factory Hour}}{\text{Cost per Factory Hour}}$$

where:

$$\text{Return per Factory Hour} = \frac{\text{Sale Price - Material Cost}}{\text{Time on Key Resource}}$$

and

$$\text{Cost per Factory Hour} = \frac{\text{Total Factory Cost}}{\text{Total Time Available at Key Resource}}$$

Comparison of the profitability of particular products on the basis of the return per factory hour provided by their manufacture may give a totally different ranking than that given by a more traditional approach.

The emphasis on the "key resource" as a basis for TA means that it is unlikely to provide meaningful results for manufacturing facilities which are very general in their nature i.e. the key resource may change continuously with variations in product mix, process planning, etc. Galloway and Waldron suggest a move towards more "focused" approaches to manufacture based upon Group Technology and cellular manufacturing principles. As the trend in recent years has been towards the introduction of such systems it may be that TA will increase in relevance as a consequence. The problems associated with applying TA to the complex, multi-level bills of materials associated with GT. and cell based systems are addressed by Waldron and Galloway in [85].

3.2.2 Discussion

It may be argued that TA represents a more comprehensive approach to decision support than more traditional decision-relevant approaches,based upon often arbitrary notions of marginal cost. However reliance on an approach which assumes a relatively static situation with respect to cost structures and system capability is not a sound basis for decision-making in the medium to long term. It has been suggested [85] that the TA approach, being based upon analysis of key/bottleneck resources, provides clear identification of areas ripe for capital investment The use of TA as a basis for making decisions concerning capital investment may however promote the increase of capacity at a resource which is not efficient/effective and should therefore be reduced in the medium to long term, by decisions relating to product selection, product mix, product design, manufacturing system design and process planning.

The use of product costs based upon time required on the key facility, proposed by Waldron and Galloway [85], may well be of value in support of decision-making in the short run but appears to have found little support in wider application. TA therefore while providing the potential for maximising profitability in the short term may if used exclusively, encourage a complacent and narrow perspective for medium and long run planning and hence inhibit long run profitability.

The application of TA is discussed further in section 7.2 and detailed coverage of basic concepts and applications is provided by references. [11], [12], [85], [87] and [88].

4.0

REVIEW AND ANALYSIS OF THE CURRENT AND POTENTIAL ROLE OF INFORMATION TECHNOLOGY

Over the last decade the ability of companies to acquire, store, manipulate and exchange data has increased dramatically, in line with the rapid development and deployment of computers and computer networks. A move towards "open" systems is leading to an environment in which data may be shared/exchanged between functions and divisions at the company level and between customers and suppliers at the global level. Unstructured implementation of such systems may however lead to a proliferation of apparently meaningless data being presented to decision-makers, hindering rather than supporting the decision process. Data does not become useful as information until such time as it has been put into context and is presented in a format understandable and accessible to the decision-maker. There are therefore two major aspects to the effective implementation and operation of IT:

1. The development of appropriate data communication systems i.e. systems which are capable of receiving, storing and transmitting data across not only distance but also functional divisions.
2. "Filters", "interpreters" and analytical tools which facilitate the conversion of data into decision relevant information for particular decision-makers.

It is worth pointing out at this stage that effective implementation of IT at the company level is not likely to be achieved without the formulation of an appropriate information systems strategy. Parnaby [37] goes further and suggests that implementation of IT has little chance of success if it is overlaid on inappropriate organisation structures and ineffective business processes i.e. unstructured application of IT is a recipe for failure. More specific discussion concerning the need for structural change is provided by Waldron [86] who supports a move away from the rigid, centralised structure of "closed loop" Manufacturing Resource Planning (MRP2) to "distributed" support systems which make use of a central data base. The use of such systems allows teams of individuals (based upon functional and/or business groupings) to specify, develop and "own" their own information support systems while making use of and contributing to a central data base. The approach supported by Waldron is referred to as "Enterprise Requirements Planning" (ERP).

4.1 COMMUNICATION SYSTEMS

While detailed coverage of communication systems is outside the scope of this research, consideration of current and proposed developments with respect to data exchange systems, at a more general level, is essential to the development of an effective model for use in an AMT environment. The structural approach most likely to support an effective model is that associated with ERP and the practical implementation of such structures will rely to a considerable degree upon the availability of "open" systems for the exchange of data. Some of the more important/relevant developments concerning data structures and data exchange systems are discussed in sections 4.1.1 to 4.1.4. The more recent approaches develop the idea of a single product model for use by all functions within an organisation.

4.1.1 Standard For Exchange Of Product Data (STEP)

International standards for the exchange of graphical information have existed since 1981, with the adoption of IGES (Initial Graphic Exchange System) by the ANSI organisation. In more recent years the DXF (Data Exchange File) format, developed by Autodesk as a basis for data exchange between their highly popular CAD system AUTOCAD and other CAD/CAM and analysis software, has enjoyed widespread application. Both of these standards are however restricted to what is essentially graphical information and as such have limited potential with respect to the data exchange requirements for company wide, cross-functional application. With this in mind the IGES Organisation, in 1984, set up the Product Data Exchange Specification (PDES) and in the late 1980s the European Community set up, under the ESPRIT Programme, an initiative called Computer Aided Design Interfaces. The various initiatives have been drawn together by the ISO Organisation into a single unified approach called the "Standard For Exchange Of Product Data (STEP)" and a draft standard is currently being prepared. The STEP approach divides a product model into two elements:

1. "Application" models - drafting or electrical product modelling.
2. "Resource" models - finite element models, tolerances, form features, material, product structure, life cycle support, etc.

STEP in effect will provide a complete definition of the product so as to support automated approaches to process planning and CNC part-programming and the extension of the application to product cost estimation, material management, etc., would appear to be a relatively natural progression. STEP may well provide a basis (in the long term) for companies operating ERP systems. More detailed coverage of STEP is provided by [87] and [88].

4.1.2 Computer Aided Acquisition And Logic Support (CALS)

CALS is an initiative being undertaken by the US Department of Defence, with the support of companies such as Boeing and Rolls Royce. The main aim of CALS is to provide formats for use in the storage and exchange of computer based data associated with weapons systems. The principles are applicable however to the broad range of manufacturing activity. It is likely that CALS will incorporate the STEP system for product data exchange although much will depend upon the interaction between major vendors of CAD/CAM systems, MRP2 systems and the various standards institutions. In essence the CALS project shares many of the objectives associated with concurrent engineering, hence its attraction for "leading edge" companies such as Rolls Royce and Boeing. More detailed coverage of CALS is provided in [89].

4.1.3 Object Oriented Design (OOD)

The concept of a single product information model (PIM) which holds the complete life cycle information associated with a particular product has been made feasible by the development of data exchange systems such as STEP. Parallel with this runs the concept of Object Oriented Design. OOD is based upon the recently developed concept of Object Oriented Programming (OOP) [87].

A product information model (PIM) may exist as a list of entities in: a CAD system, an analysis system, a CAM system, a purchasing system etc., but without any dynamic link between these entities the data is simply part of a central data base, to be accessed by a variety of users. Object oriented design uses the principle of object oriented programming to specify the relationships between the entities which exist in the different elements which comprise the PIM. Thus when a design change is effected the implications for that change are reflected by automatic modification of all associated entities. e.g. a change in the diameter of the bearing seat of a shaft might trigger modification of the raw material specification for the shaft, the CNC part-program for its machining, the bearing size and the operational limits of the assembly. While these developments are at an embryonic stage and are confined predominantly to detailed design and component selection, the scope for extension into other areas of product management is considerable.

4.1.4 Open Systems Interconnection (OSI)

OSI is a reference model developed as part of an ISO initiative concerned primarily with encouraging vendors of hardware and software to adopt a standard protocol, so as to facilitate interconnection of multi-vendor, multi-application software with a minimum of effort. MAP (Manufacturing Automation Protocol) was developed to satisfy the requirement for communication between "intelligent" devices such as CNC machine tools, process controllers, shop floor data collection systems, engineering workstations, etc. TOP (Technical and Office Protocol) was initiated as a supplement to MAP and as the name implies is concerned with easing or eliminating problems of interconnection associated with multi-vendor, multi-application office systems.

Implementation of direct and in some cases "real time" communication between automated manufacturing facilities and the information systems used by decision-makers in various functional areas provides the potential for timely and effective decision-making. However this will apply only if the information provided is "visible", appropriate to the decision and is understood by the decision-maker. More detailed coverage of OSI is provide by Rembold et. al. [90].

4.2 ANALYTICAL TOOLS

Having discussed in general terms the role of communication systems in providing timely and accurate data it is now appropriate to consider the means by which the data will be processed/analysed so as to provide decision-relevant information. The precise requirements for data communication will be determined to a great extent by the form of analysis required by decision-makers - hence the need for an integrated information systems strategy. A wide range of analytical tools, both general and specialised, appropriate to the generation of cost information is available. Currently, however, the vast majority of cost information is provided by centralised, finance oriented accounting systems which are normally standard in their configuration. Relatively little cost information is supplied in a form tailored to the needs of engineers and operations managers (i.e. the value of "standard costing" systems and "variance analysis" to the decision-making process is rather dubious). The ERP approach with users being responsible for development of their own interface to an integrated company data base is potentially a route to far more effective systems. For the purpose of this research it is convenient to consider analytical tools/approaches as being of two types:

1. Generalised tools which may be applied to good effect both in the short term and the long term. For example: data base systems, spreadsheet systems, simulation systems, etc.
2. More specialised software developed as part of a longer term approach to providing cost based decision-support in an ERP structure. For example:

- Object oriented approaches to design, process planning, production planning, etc.
- Dynamic process planning and scheduling (as discussed in section 2.4.2)
- Software to support the integration of accounting approaches such as ABC and TA with product selection, product design, process planning, capital justification and structured approaches to project management (concepts, methodologies and software for structured project management are discussed in section 5.0)

A discussion of some of the potential applications associated with general analytical tools/software is provided in sections 4.2.1 to 4.2.2. These are applications based upon software which is widely available and therefore capable of implementation in the relatively short term.

4.2.1 Discrete Event Simulation (DES)

Discrete event simulation is a technique which can provide insight into the way in which a given system will respond to various inputs and occurrences by mimicking the behaviour of the actual system (to a greater or lesser degree depending upon the level of detail associated with the simulation model). The general approach to manufacturing system simulation is as follows:

- Identify the major elements (entities) associated with the system e.g. machines, buffers, labour, equipment, etc.
- Identify the logical relationships between the elements, with respect to the processing and progressing of parts through the system.
- Subject the model to a pattern of demand for products over a specific time period and monitor relevant operational parameters e.g. queue sizes, output, machine utilisation, etc.
- Refine the model by comparing simulated results with historical results (where this is possible).
- Subject the model to different patterns/levels of demand and thereby build up a picture of the way in which the real system might respond to different circumstances.

Information gained from manufacturing system simulation has been used typically to assess the efficiency of proposed manufacturing system configurations with respect to various product demand scenarios and also to assess the effect on existing manufacturing systems of changes in the pattern of demand for products. It is important to stress that simulation in itself does not identify "optimum" manufacturing systems, it simply provides information relating to the likely performance of given alternatives. Over the last decade the availability of powerful computer based packages for manufacturing system simulation (WITNESS, SIMON/CINEMA, PCMODEL, SIMFACTORY, etc.) has increased the scope for application from relatively small, greatly simplified models of systems to comprehensive models which are capable of close representation of the real thing. Detailed coverage of concepts, techniques and applications for DES is provided by Carrie [91].

Discrete event simulation of manufacturing systems is an exercise carried out traditionally by operations research specialists or more recently (with the advent of specialised simulation packages such as WITNESS) by manufacturing systems engineers. The insights and performance indices provided tend to be "operations" oriented rather than "business" oriented - reflecting perhaps the perspective of the modellers. This view of the application of DES is reinforced by reference to the standard reports provided by packages such as WITNESS (see Table 7).

MACHINE STATISTICS
Number of operations carried out in simulated period
% Idle (no work)
% Busy (working in cycle)
% Stopped ("blocked", broken down, set-up)
% Waiting (waiting labour for set-up, cycle or repair)
PART STATISTICS
Number entered
Number shipped
Number scrapped
Number assembled
Number rejected
WIP (count)
Average WIP (count)
Average time (average time parts spend in system)
BUFFER STATISTICS
Total parts in
Total parts out
Number of parts now in
Maximum number of parts in buffer
Average number of parts in buffer
Average time parts spend in buffer
LABOUR STATISTICS
Quantity of particular labour type
%Time idle
% Time busy
Average job time

Table 7 Examples of WITNESS standard reports.

As may be seen in Table 7 the standard information supplied by the package is concerned essentially with issues of capacity, utilisation and flow of materials. This provides measures of efficiency and with correct interpretation may provide insights into system effectiveness. Experimentation with the model using modified system configurations, modified operational logic (i.e. scheduling rules, job priorities, etc.) allows the modeller to exercise judgement in establishing the most appropriate system design and method of operation. System evaluation tends therefore to be carried out with no direct consideration of more "business" oriented performance measures (e.g. cash flow and period profitability associated with particular system configurations and operating scenarios). An approach which provided such indices would provide a more comprehensive base for decision support and could provide a focus for collaboration in decision-making between operations management functions and business functions (i.e. between manufacturing systems engineers, operations managers, accountants, marketing personnel, etc.)

The desirability of incorporating business oriented indices in manufacturing system simulation was raised by the author in 1992 [92] (Appendix 3.2) and an approach for developing such indices (using the simulation package WITNESS in conjunction with the spreadsheet software EXCEL) was developed by the author in 1993. Software to demonstrate practical implementation of the approach was developed as a final year undergraduate project, the student being given the task of modelling an appropriate example within WITNESS and creating the necessary interface between WITNESS and EXCEL. EXCEL was used as a means of analysing and presenting data from the WITNESS simulation so as to provide a set of supplementary "business" oriented indices. The range of indices provided by the software is limited but serves to demonstrate the value and practicality of the approach. An outline of the approach and the exemplar software follows in section 4.2.1.1 and a more detailed account is provided in the proposed publication included as Appendix 3.3.

4.2.1.1 Generation Of Business Oriented Performance Indices In Manufacturing System Simulation

Stage One

The first requirement is to identify the supplementary performance indices which are to be extracted from the simulation. The following are suggested as examples which may be of some value:

Work in progress:

Average value (all products/parts) over simulation period.

Average Value (by product/part type) over simulation period.

Graphical Representation of WIP -

Value over time (all products/parts) over simulated period.

Value over time (by product/part type) over simulated period.

Moving average over time (all products/parts) over simulated period.

Moving average over time (by product/part type) over simulated period.

N.B. Products/parts are assigned cost as they progress through the simulation, providing the potential to improve upon the relatively arbitrary valuation of stock applied in most current costing/reporting systems. However, it is clear that the approach depends upon the existence of a realistic coststructure for the activities covered by the simulation model. This issue is adressed in section 8.3, where an exemplar cost structure is proposed.

Sales Value and Profit:

Sales Value (all products/parts) over simulated period.

Sales Value (by product/part type) over simulated period.

Profit (all products/parts) over simulated period.

Profit (by product/part type) over simulated period.

N.B. Profit = (sales price - actual cost [derived from simulation]). This provides the potential for improving the visibility of profit as a direct factor in system design and operation.

Saleable Products/Parts:

% Saleable Products (all products/parts) over simulated period.

% Saleable Products (by product/part type) over simulated period.

N.B. Saleable products/parts are defined as products/parts having a due date within say 2 weeks or less of actual completion. The combination of this index with that of sales volume and profit provides the potential for assessing period profitability in terms of actual cash flows rather than the "paper" based profits which may be associated with producing to long term stock. This may be of value when used in conjunction with throughput accounting approaches.

Tardiness:

Average Tardiness (all products/parts) over period of simulation.

Average Tardiness (by product/part type) over period of simulation.

Maximum Tardiness (all products/parts) over simulation period.

Maximum Tardiness (by product/part type) over period of simulation.

N.B. Tardiness is defined as the difference between the date of completion of a product/part and the date of completion required to provide delivery on time when the former is later than the latter (i.e. a measure of delivery performance and customer satisfaction).

An overall "picture" of this new approach is provided in Figure 16.

Stage Two

A simplified representation of a typical manufacturing system was chosen as the basis for demonstrating the provision of one of the business oriented measures, i.e. the "dynamic" value of work in progress. The system configuration is shown in Figure 17. A "family" of parts was devised, together with process routes and processing times in the various "functional" areas of the system. Distributions of the demand for each part were specified and processing costs per unit time were established for each of the functional areas/departments. This information was used to develop a model within WITNESS, "action statements" (a method of initiating various functions and operations as particular

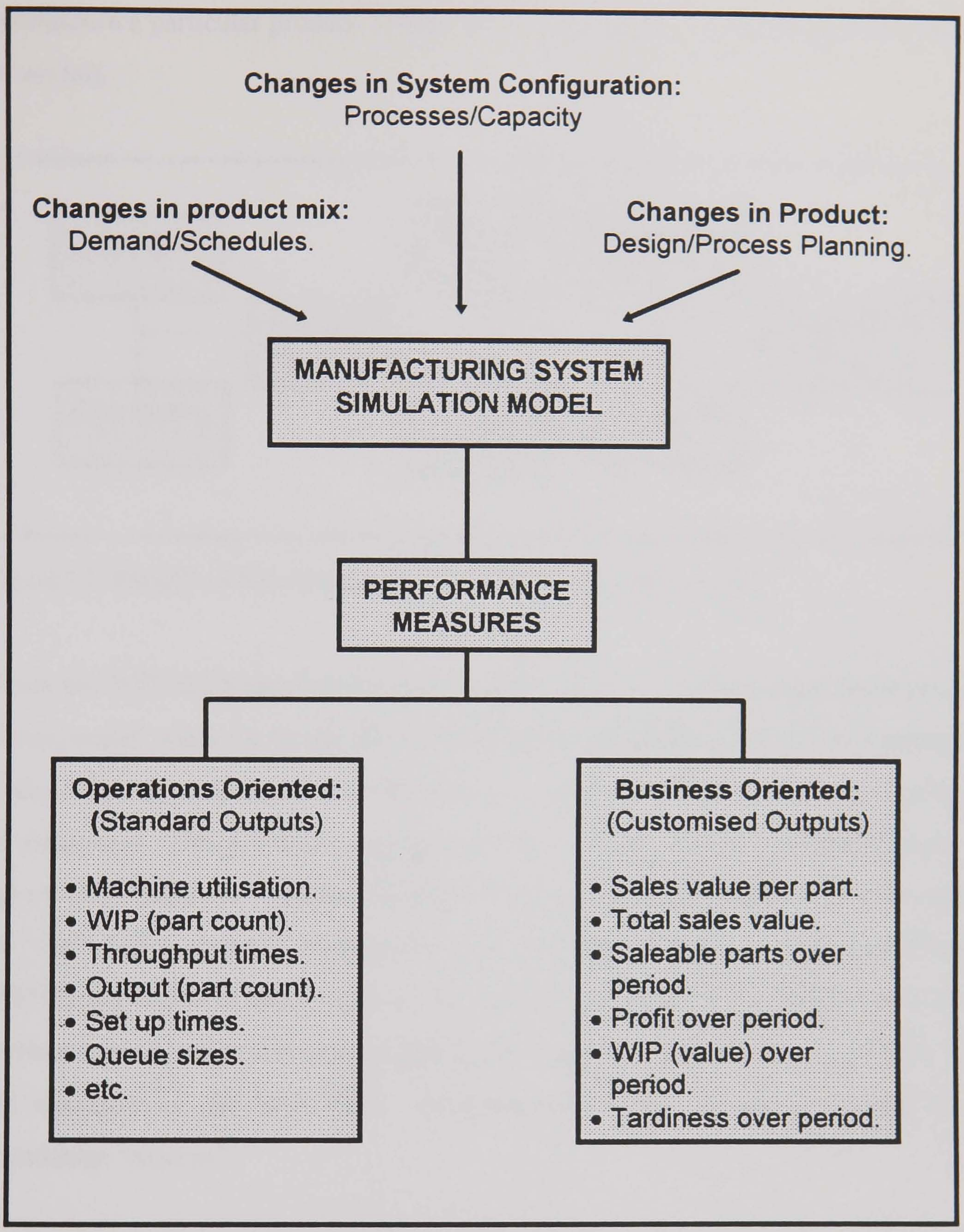

Figure 16 Overview Of Manufacturing System Simulation And Performance Analysis.

parts progress through the simulation) being used to assign cost to particular parts as they progress through the system. Thus the build up of a more realistic measure of the cumulative cost associated with a particular part at a particular point in time could be determined. This provides for greater accuracy than methods based upon average values for parts and provides an ability to take into account the actual process route used to manufacture a particular product (where alternative process routes are possible within the model).

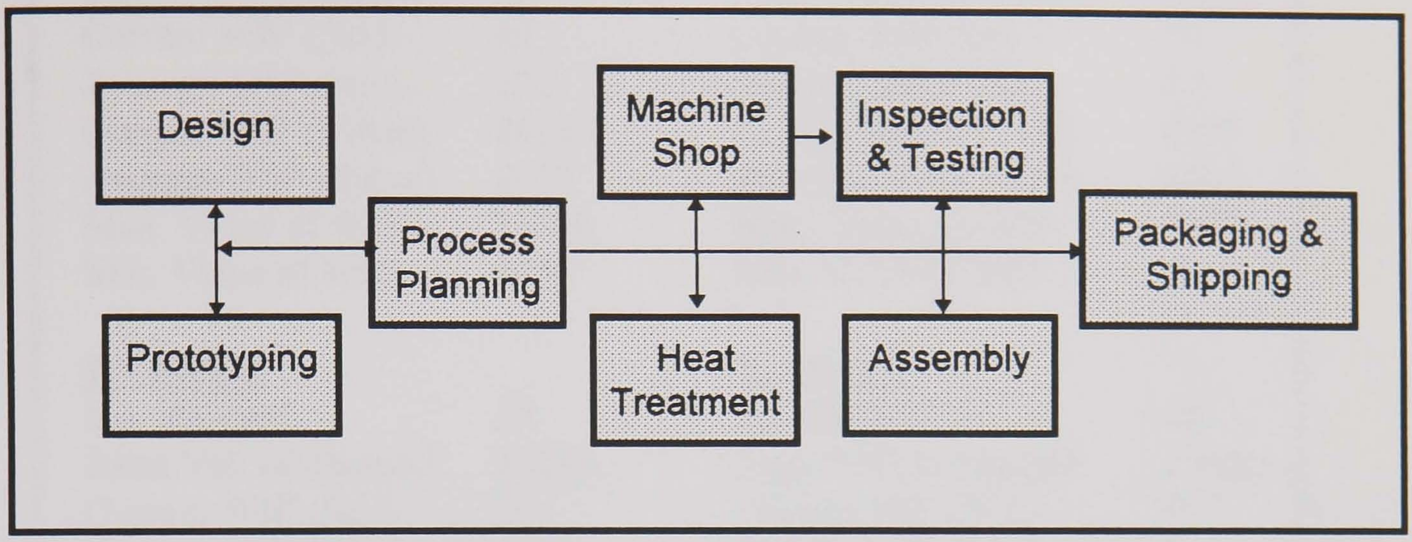

Figure 17 Simplified Representation Of A Manufacturing System.

Within the WITNESS simulation software exists the option to run a particular model in "experimental" mode i.e. to run the simulation for a specified number of time increments, to allow for the capture of status information at particular points in the overall period of the simulation. This procedure together with appropriate "action" statements makes the collection of "dynamic" information feasible and it was by this means that a measure of the "real" value of work in progress over time was achieved. The data from the WITNESS simulation was output to the EXCEL spreadsheet for analysis and for the development of customised reports (see Table 8 and Figures 18, 19). It is worth noting that operation of the WITNESS simulation run is set up and controlled via the spreadsheet "macros".

Figures 18 and 19 together with Table 8 demonstrate the potential for extracting business oriented performance measures from simulation models. The use of the spreadsheet (EXCEL) as a "front end" to the simulation software provides the potential for non-experts (with respect to simulation) to assess quickly and easily the business implications of particular patterns of demand and production schedules. Interfaces to the system model may be provided for decision support in various "functional" areas as appropriate and hence may form part of the ERP network.

Product A		**Product B**	
No. Shipped	95	No. Shipped	54
Sales Val. of Shipped	£9875	Sales Val. of Shipped	£2700
Current WIP (No.)	19	Current WIP (No.)	30
Average WIP (No.)	12.6	Average WIP (No.)	5.1
Current WIP (Value)	£1146	Current WIP (Value)	£800
Average WIP (Value)	£950	Average WIP (Value)	£100
Max. Value of WIP	£1090	Max. Value of WIP	£800
Min. Value of WIP	£108	Min. Value of WIP	£0
Product C		**Product D**	
No. Shipped	38	No. Shipped	15
Sales Val. of Shipped	£3230	Sales Val. of Shipped	£1050
Current WIP (No.)	20	Current WIP (No.)	0
Average WIP (No.)	3.4	Average WIP (No.)	2
Current WIP (Value)	£600	Current WIP (Value)	£0
Average WIP (Value)	£743	Average WIP (Value)	£20
Max. Value of WIP	£820	Max. Value of WIP	£300
Min. Value of WIP	£115	Min. Value of WIP	£115

Table 8 EXCEL Output From WITNESS Simulation Run.

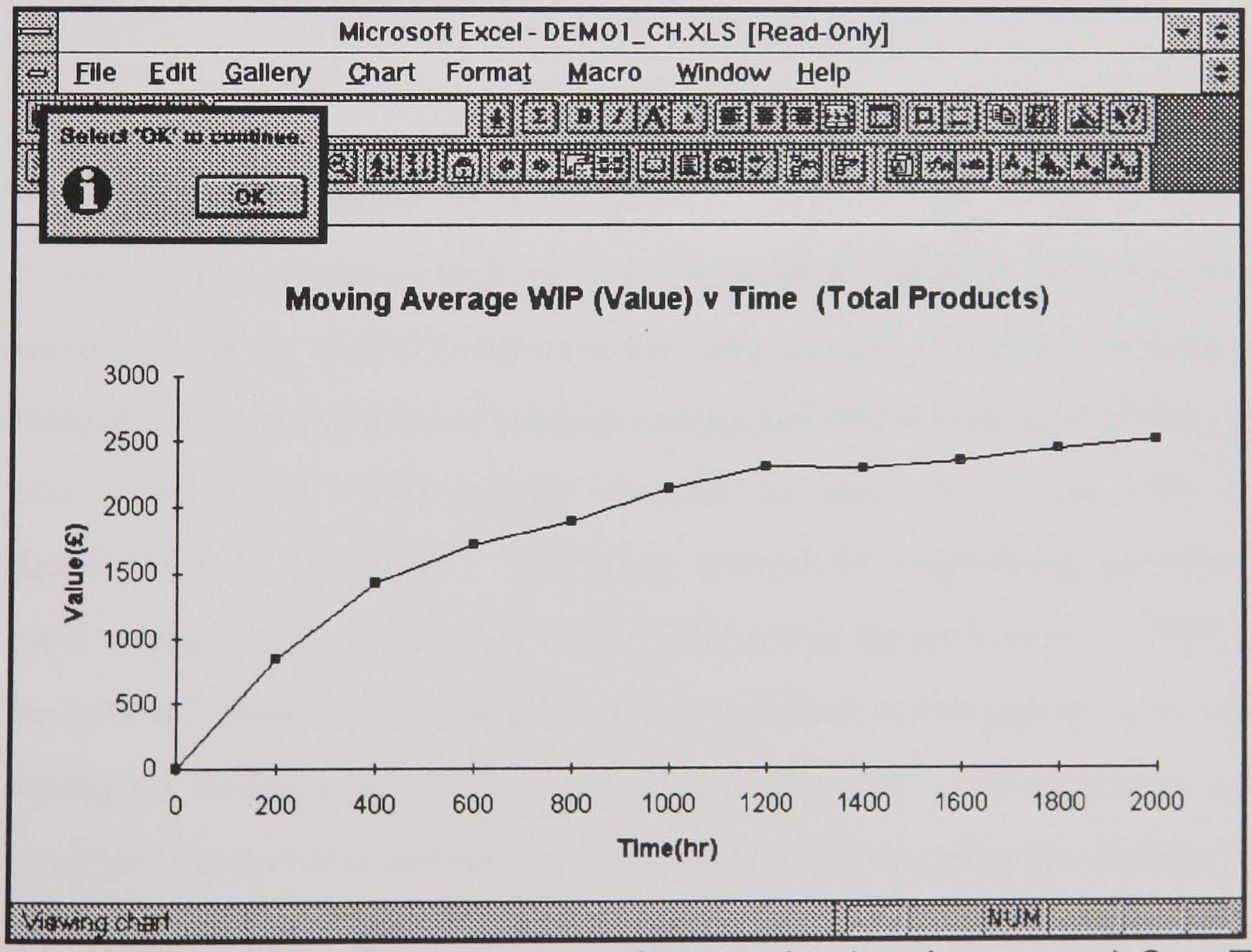

Figure 18. Graphical Representation of WIP Value (moving average) Over Time for All Products

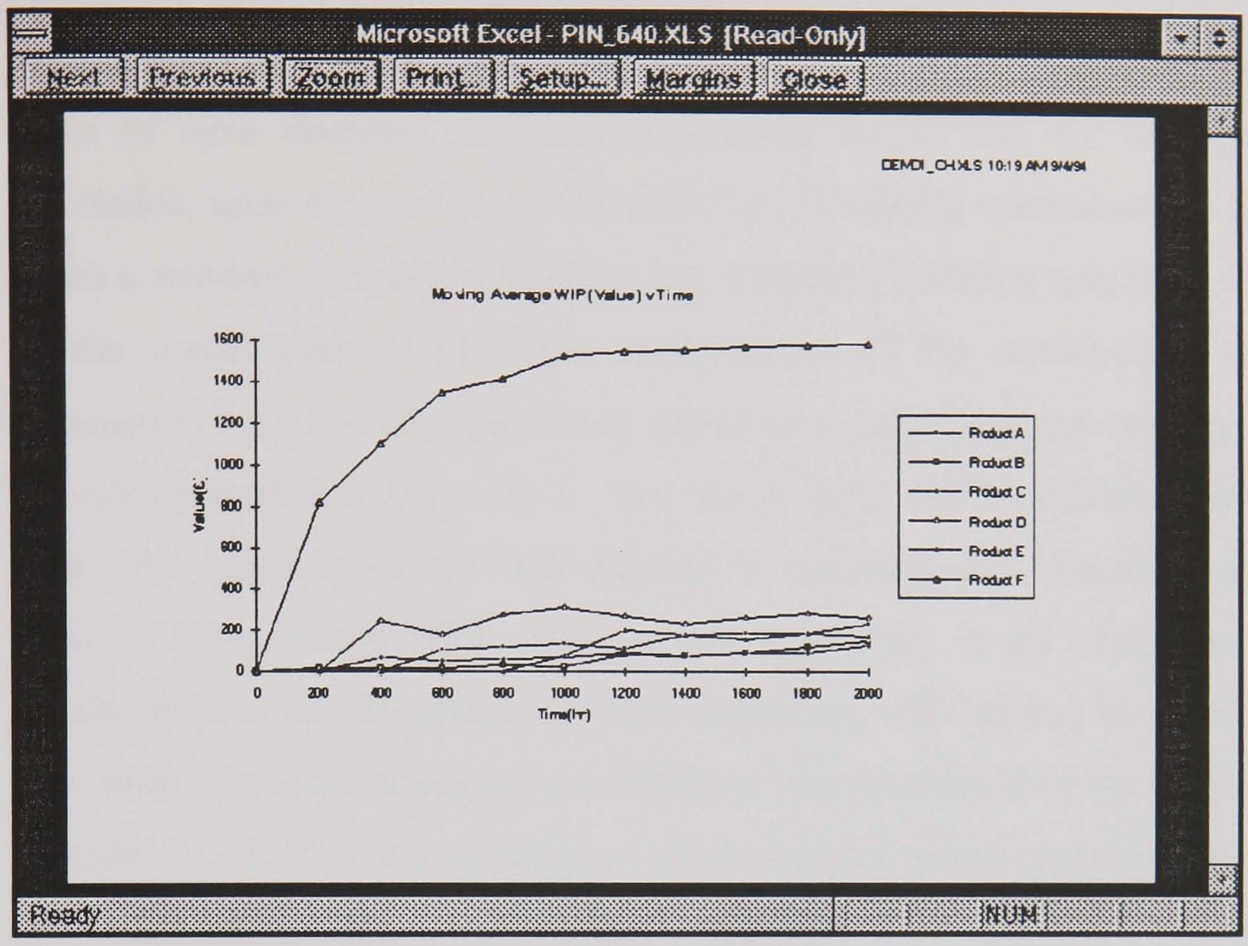

Figure 19. Graphical Representation of WIP Value (moving average) Over Time per Product.

4.2.2 Multiple Linear Regression

Application of regression techniques and in particular multiple linear regression (MLR) is commonplace in scientific/experimental analysis and in market analysis, but is used relatively little in the areas of product costing and manufacturing decision-support [2]. It was noted in 2.3.2 that valuable research has been carried out with respect to the development of "parametric" estimating systems for engineering products (notably the work carried out by Mileham et al [60] concerning the application of MLR to estimating the cost of injection moulded products), but this does not appear to be reflected in any significant measure of practical industrial application. The engineers and operations managers consulted in the survey were unaware of the potential offered by MLR and of the powerful and "user friendly" capability for MLR analysis provided by standard spreadsheet packages such as Microsoft Excel and Lotus 123.

MLR is in general terms a powerful technique which may be used to quantify the contribution of particular parameters with respect to some overall parameter e.g. the effect of table diameter, maximum component weight and the number of axes of orientation, upon the total cost of manufacture of welding manipulators. The ease with which a standard spreadsheet package may transform historical information with respect to the actual cost of particular combinations of the contributing parameters is demonstrated by the example Excel spreadsheet (based on the welding manipulator example) provided in Appendix 2. The use of these readily available packages is well within the capability of the vast majority of engineers and operations managers and provides the potential (N.B. MLR is not appropriate in all circumstances) for the development of useful systems for cost estimation, with relative ease and in relatively little time. In some situations the nature of the variables may be such that it is not possible to identify a combination of parameters which provides an appropriate correlation and in such cases alternative approaches are required. Where MLR does appear to provide satisfactory correlation it is appropriate to run the system as a "pilot" study, alongside existing approaches, for a suitable period of time. One of the major benefits to arise from the development and implementation of MLR based estimating systems by engineers and operations managers is the heightened awareness and understanding of "cost drivers" gained by those personnel.

MLR may be used at various levels, for example:

- Cost estimating systems for use by sales personnel in situations where estimates of product cost (in support of pricing decisions) must be made relatively quickly e.g. cost of welding manipulator (see Appendix 2).
- Product design - estimating the order of cost associated with particular combinations of product features (Appendix 2).
- Process planning/estimating the cost of alternative process routes and estimating the cost of support activity (e.g. estimation of time and cost of CNC part-programming for particular product groups, see Appendix 3.1).

- Estimating the cost of material supply. A MLR system for estimating the cost of "bought in" "rolled" rings has been developed successfully by one company as a consequence of this research .

Considerable care is required for the effective implementation of MLR, factors which need consideration in particular include:

- The cost accounting and reporting system employed by the company must assign cost with an appropriate degree of accuracy. If this is not the case then MLR and similar approaches simply add to the speed at which inappropriate estimates of product cost are produced. This is a very basic issue and is discussed further in sections 7.4, 8.3 and 8.7.
- The historical data may lose its relevance as the result of inflation. In such cases it may be possible to alleviate the problem by appropriate adjustment of the cost data, on a periodic basis.
- Changes in the technology and/or the manufacturing process associated with the manufacture of particular product groups may affect the relevance of the historical cost data.

As stated in 7.3.1 MLR may help in identification of the "cost drivers" appropriate for use in ABC systems, again helping staff to gain greater understanding and awareness of the cost implications of their actions. The industrial applications of MLR, to which reference has been made, were carried out by part-time students on the final year of their BEng (Hons) course. In each case the students claimed that the exercise had provided them with an increased awareness of cost issues (in particular "cost drivers") within their companies.

5.0

STRUCTURED "PROJECT" APPROACHES TO ORGANISATION AND CONTROL OF MANUFACTURING ACTIVITY

The performance of UK manufacturing companies is, according to a recent survey carried out by the PA Consulting Group [95], very poor. The PA survey revealed that in 40% of the responding companies more than half of the projects they undertook were not completed within the planned time scale or budget. Over half of the respondents knew of recent projects which had exceeded the planned budget or time scale by over 100%. Lack of information relating to "life cycle" costs (Neale and Holmes [96]) is an important contributing factor in this situation as are the simplistic approaches to investment analysis discussed in 2.7.3. Neale and Holmes refer also to a survey which suggests that only 34% of companies involved in engineering manufacture use any form of post-completion audit of projects. Hence projects are undertaken frequently with incomplete knowledge of the life cycle costs, simplistic evaluation of potential profitability and no objective feedback with respect to project performance.

Harrison [93] suggests that a project may be defined as "a discrete undertaking with finite objectives - often including time, cost and technical performance goals". He goes on to suggest that every manager deals with many such undertakings and that "projects" must therefore be of significant size, value and complexity, if they are to benefit from the application of formal project management (PM) concepts and techniques. Until relatively recent years the application of formal PM approaches was confined to major undertakings in the public sector, defence industries, construction industries and process industries and to other industrial undertakings involving major expenditure of capital. There is currently, however, a trend towards the use of PM concepts and techniques for a wider range of applications and for much smaller undertakings [93]. The increased relevance and use of PM approaches has been promoted by a number of factors:

- Industrial markets have become increasingly more competitive, with product life cycles being reduced and increased demands being made for customisation of products. Such trends increase the number of R&D projects which must be undertaken, together with the development of appropriate facilities for manufacture.
- The trend towards decentralised organisation structures in many industries [34] and the adoption of multi-disciplinery teams organised on the basis of business and/or product groupings e.g. team based approaches to concurrent engineering (see 2.3.2). PM systems focus on the planning and control of such multi-disciplinery activity.
- Developments in software for the support of PM have been dramatic over the last ten years. Powerful, user friendly systems are available at relatively low cost, with the more modern systems providing for integration with other support systems i.e. accounting systems, shop floor data collection systems, production planning systems, etc.

The degree to which it may be appropriate to apply PM concepts to the manufacture of products varies with the type of products being produced and the demand associated with those products. The following examples illustrate the point:

Example 1

The long term manufacture of a range of standard gear boxes will, over the life time of the product, consume resources in what might be described as "project" oriented activity at various points

- Initial design of the product.
- Design and implementation of the facilities and associated systems to manufacture the product.
- Design and implementation of systems to market and distribute the product.
- Periodic review and modification of the product design, product manufacture, marketing and distribution.

These "project" oriented activities may involve a variety of disciplines and may lend themselves to an approach which plans them, controls them and assigns cost to the product (or product range) using PM concepts and techniques. Assignment of the cost of these activities directly to the product/product range would, in the case of many organisations, represent a relatively radical innovation i.e. product development activity of this type involves support staff (product designers, process planners, marketing personnel, etc.) whose cost under traditional systems would be allocated on the basis of "overhead". This new approach might form the basis for a form of "life cycle costing", by using the concept of depreciation and assigning the cost of the initial support activity and the periodic support activity across the anticipated life of the product. This concept may be referred to as a "Product Life Cycle Cost Account (PLCCA)", with major elements of product support cost being collected automatically via PM based systems. The concept of PLCCA is discussed further in section 7.5.

The day to day planning and control associated with product manufacture would more appropriately be carried out by a production management approach. The assignment of these day to day production costs to products may be related more appropriately to product volumes (see exemplar structure for ABC in Figure 15. section 3.1.3).

Example 2

The manufacture of highly customised "capital" equipment for metal forming. For this type of product the manufacturing cycle is relatively long (months), the product is complex and the production costs are high. In these circumstances it may be that the majority of activity throughout the life cycle is project oriented i.e. multi-disciplinery and non-repetitive with a relatively small amount of activity concerned with the manufacture of standard component parts. For companies involved in the manufacture of this type of product the adoption of a PM oriented system may be the most appropriate approach to planning and controlling activities and for assigning and reporting the cost of manufacturing particular products.

5.1 STRUCTURED APPROACHES TO PROJECT MANAGEMENT

Harrison [93] suggests that structured PM provides "a common basis, language and dictionary for information consolidation and communication". He goes on to suggest that the coding systems associated with modern structured approaches may provide an integrating framework for information associated with activities such as: work definition, estimating, design and materials acquisition. Various approaches to structured PM have been developed over the years but the most relevant in terms of the current research is that associated with the adoption of work breakdown structures (WBS), organisation breakdown structures (OBS) and cost breakdown structures (CBS). Discussion of alternative approaches to structured PM may be provided by reference to Harrison [93] and Burke [94].

5.1.1 Work Breakdown Structures (WBS)

The WBS is a hierarchical structure which divides a project (at the lowest level of the hierarchy) into elements of work which are often referred to as "work packages". The WBS may be likened to the "bill of materials" for a product assembly, except that in the case of the WBS it is elements of work and work centres which are being considered rather than component parts and sub-assemblies. The lowest level of the WBS i.e. the "work package" represents an element of work which is small enough and sufficiently well defined to be allocated to a particular person or group, with clear identification of the person responsible for delivery of the work. A work package may be a single task, several tasks, or in some cases a sub-project. The basis for work structuring may vary from one project to another e.g. in some cases a structure based upon functional discipline may be appropriate and in others a structure based upon project stage/phase may be appropriate. Discussion of the latter issue is provided by Burke [94].

The current research addresses the area of engineering manufacture and with this in mind an exemplar WBS, based upon the requirements for introducing a new product, has been developed (the WBS is illustrated in Figure 20). Expansion of the WBS has been limited to the level one elements "design of gearbox" and "manufacturing facilities specification", so as to avoid unnecessary complication.

One of the most important and potentially useful aspects of the WBS is the ease with which a logical coding system may be developed. The basis of the coding system illustrated in Figure 20 is self-evident.

5.1.2 Organisation Breakdown Structure (OBS)

The OBS is similar to the WBS and relates to the organisation structure associated with the execution of the work defined in the WBS. It is in effect a detailed internal organisation chart for the project and employs a coding system similar to that of the WBS. A simplified OBS and coding system has been developed for the exemplar project introduced in 5.1.1. (see Figure 21). The lowest levels of the OBS are normally associated with the working groups, disciplines or in some cases individuals who will be responsible for carrying out the actual work. Groups may be of mixed or single discipline, depending upon the nature of the work involved. In the interest of avoiding unnecessary complication "Procurement", "Personnel" and "Works" have been shown as single level elements in the exemplar OBS. In practice this would not necessarily be the case (for the "Works" element in particular, which may in practice have a relatively complex structure of its own).

Harrison [93] makes the point that the OBS structure does not necessarily equate with the organisation structure of the company undertaking the project. However as organisations become "flatter" [34] and the adoption of project oriented organisation structures increases it is possible that the structures will increasingly combine.

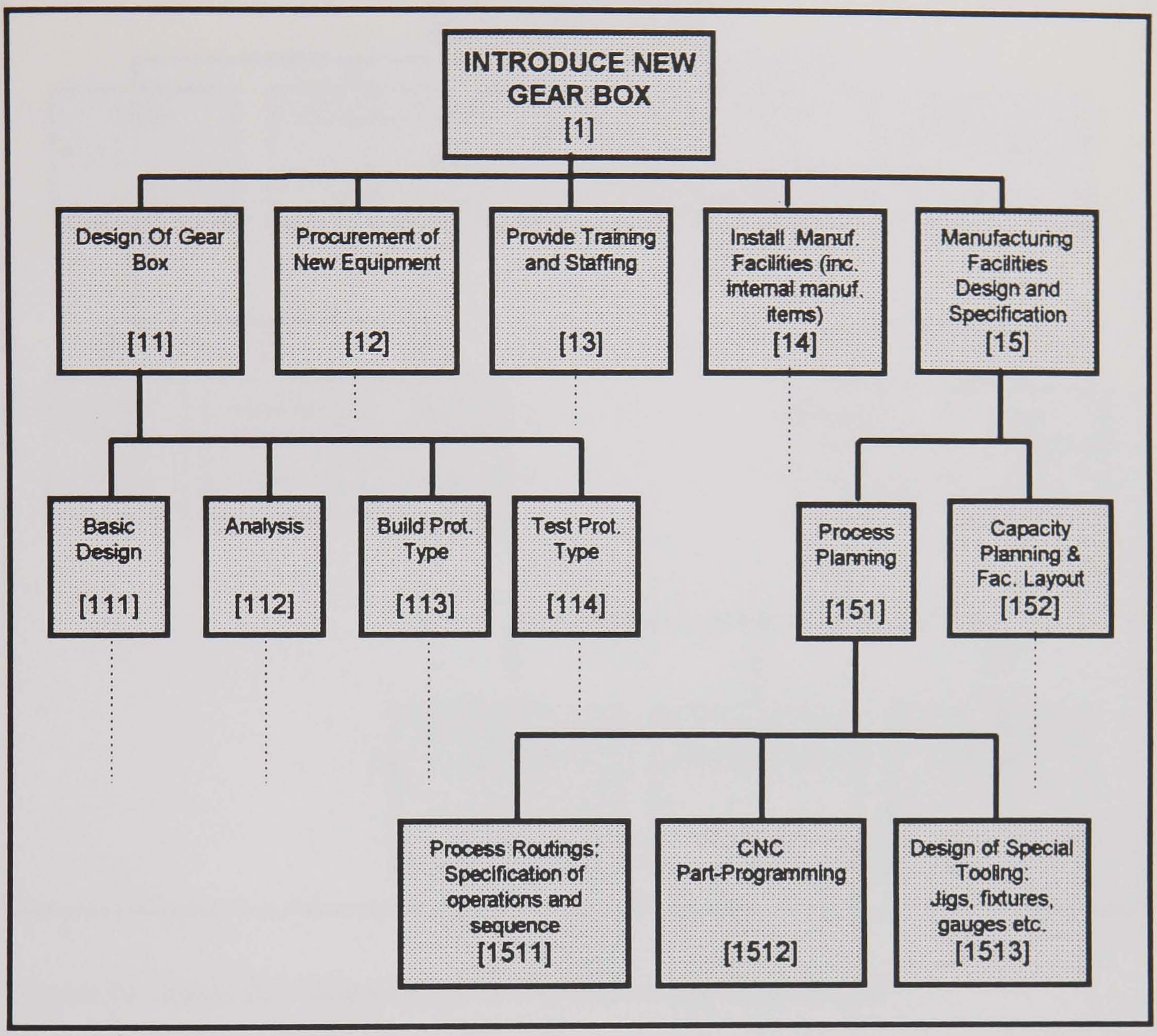

Figure 20 Simplified Work Breakdown Structure For Gear Box Project.

5.1.3 Two Dimensional Project Structures - The Cost Account

Having established the WBS and the OBS for a project it is possible to match the work packages contained in the lowest levels of the WBS with the work groups defined in the lowest levels of the OBS. Thus each work package in the project is assigned to a single work group, the work group having clearly defined responsibility for its execution. The work group acts also as a collection point for the costs incurred in completing the work package and with this in mind the combination of a particular work package with a particular work group is termed a "Cost Account". Cost accounts may be identified

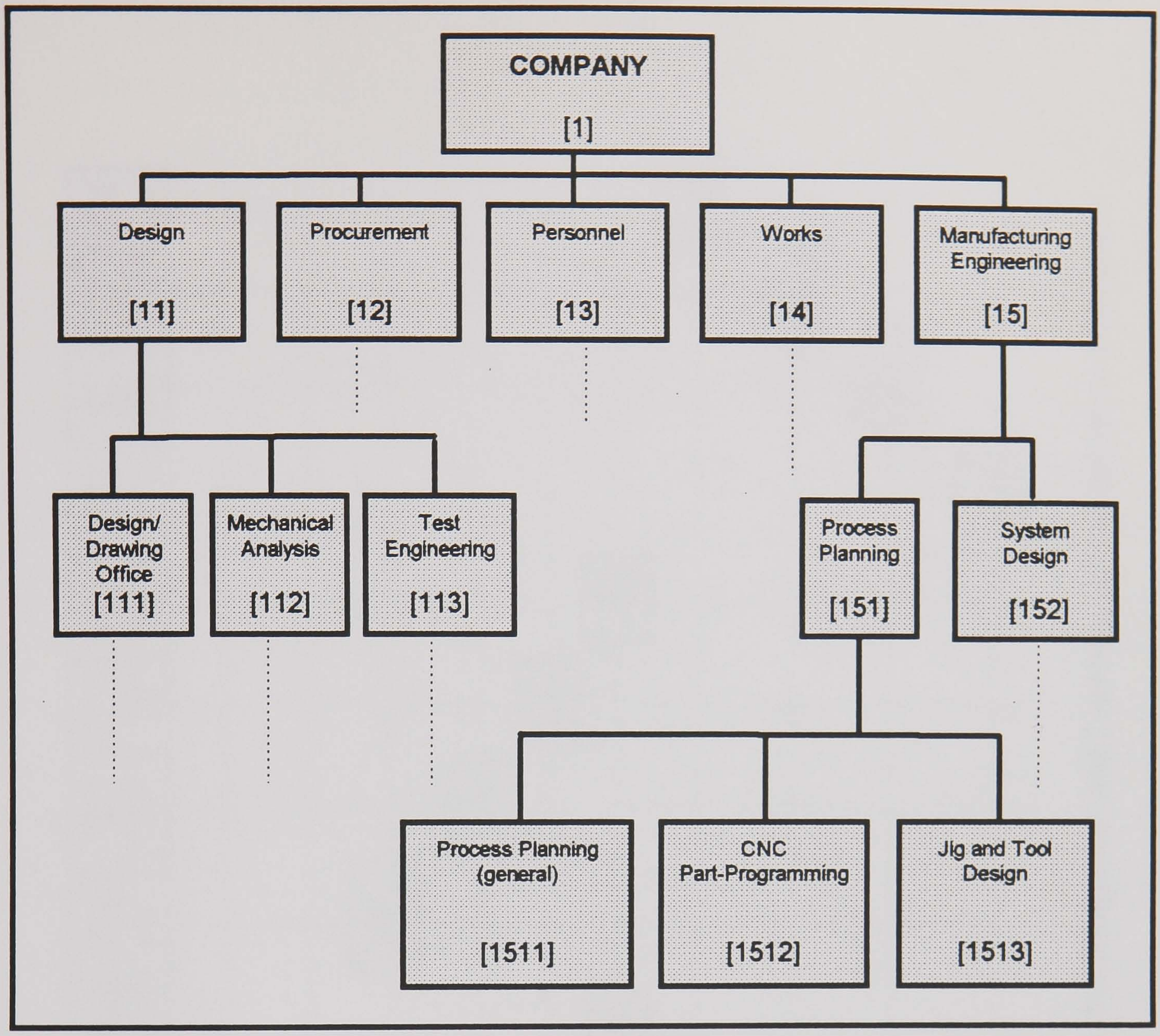

Figure 21 Simplified Organisation Structure For Gear Box Project.

clearly by a simple combination of the WBS code with the OBS code. The two dimensional project structure for the exemplar project is illustrated in Figure 22.

The cost account structure provides a clear and effective statement of responsibility for particular elements of work and logical centres for the collection of costs. Project responsibilities and costs may be consolidated at various levels of the structures to identify overall responsibility and overall project cost.

5.1.4 Cost Breakdown Structures (CBS)

Companies may wish to collect cost information under various headings within particular cost accounts. Such headings may include: capital costs, labour costs,

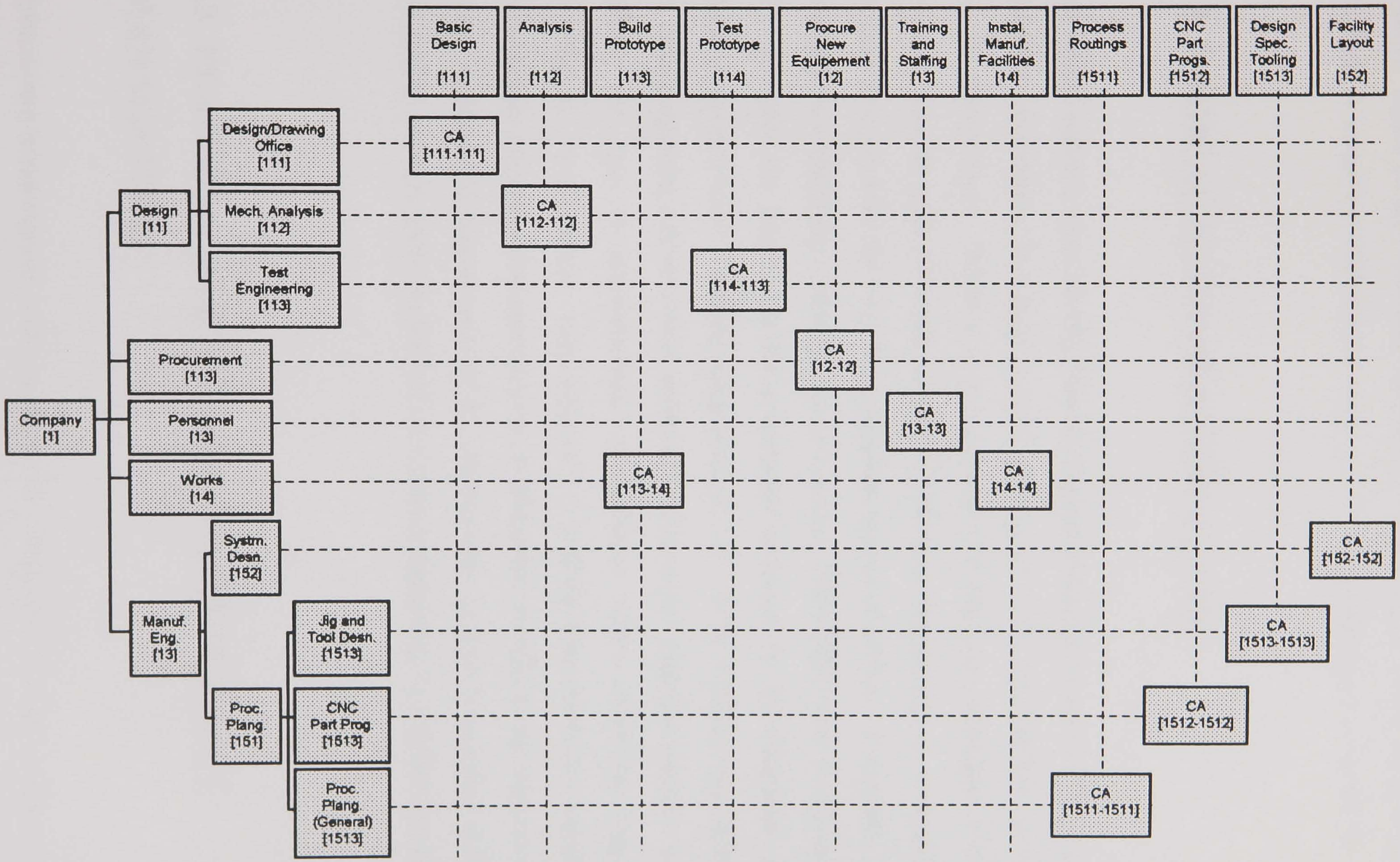

Figure 22 Two Dimensional WBS-OBS Structure For The Assignment And Reporting Of Cost (based on a structure presented by Harrison [93])

material costs and sub-contract costs. The provision of a third dimension to the project structure i.e. a cost breakdown structure makes the provision of such information possible. Again an approach to coding similar to that for the WBS and the OBS may be adopted. A simplified CBS for the exemplar project is illustrated in Figure 23.

5.2 LOGICAL NETWORK STRUCTURE

The logical network diagram identifies the logical relationships between the tasks which comprise the project. In a large project some or all of the tasks at the "project" level may be sub-projects. While it is not essential that the tasks identified in the logical network coincide with the work packages, maximum benefit will be obtained if this is the case as it provides the basis for a common system of coding. A common system of coding across the logical network (project tasks), WBS/OBS (cost accounts) and the CBS provides the foundation for a common language for the functions of project planning, project control and the assignment of cost. In the medium term differences in the coding systems and structures associated with project planning systems, accounting systems etc. may be accommodated by software which effectively translates the information. In the longer term, however, it is likely that maximum benefit will be derived from rationalisation and integration of support systems in the various functional areas. A simplified logical network for the exemplar project is provided in Figure 24. The logical network provides the basis for project scheduling and project management .

5.3 PERFORMANCE MEASURES FOR PROJECT MANAGEMENT

Performance measurement with respect to the "delivery" of major projects is given in terms of conformance to schedule and conformance to budget. This assumes that effective and appropriate project specification and project planning has taken place (i.e.

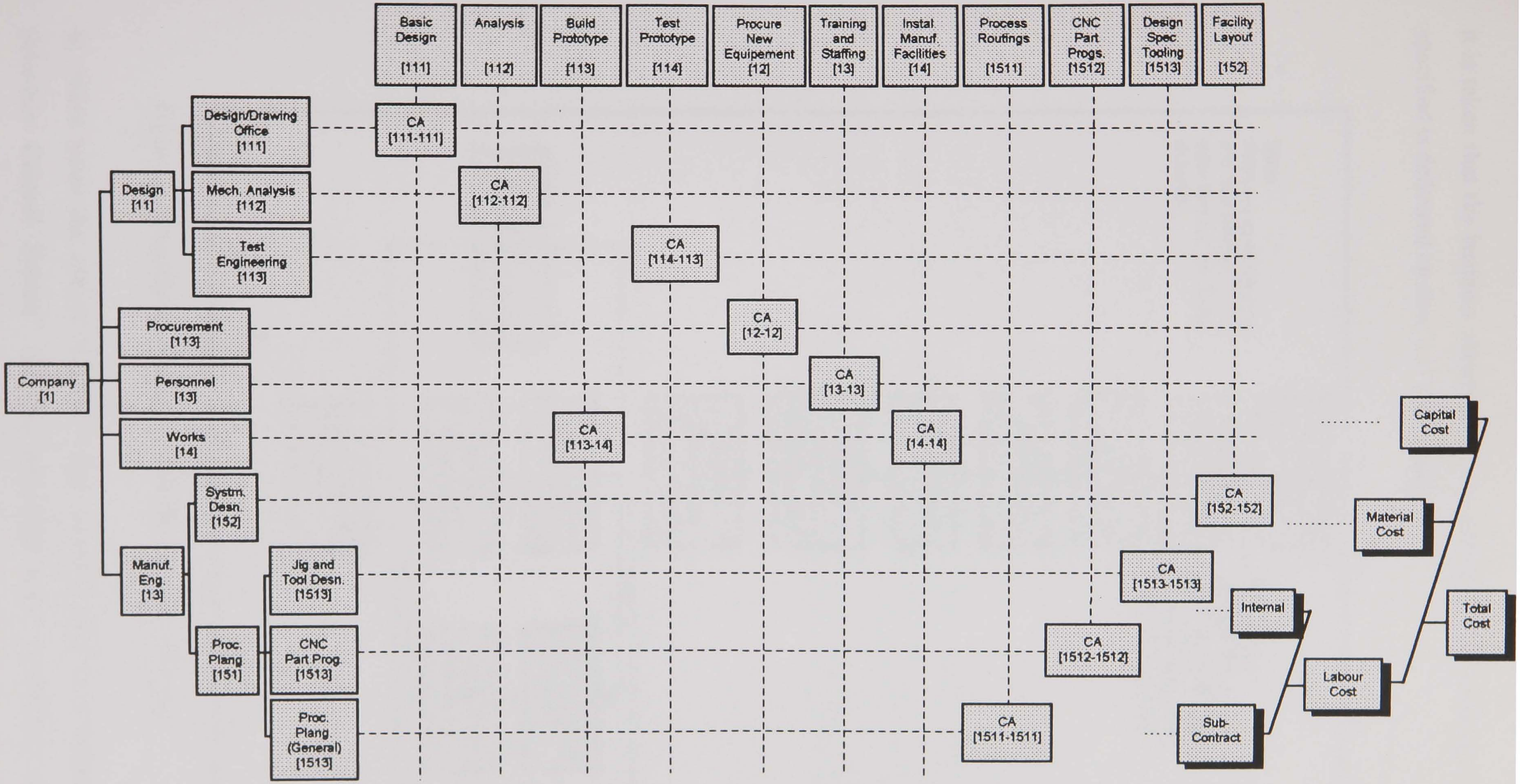

Figure 23 Three Dimensional WBS-OBS-CBS Structure For The Assignment And Reporting Of Cost (based on a structure presented by Harrison [93])

it is taken that the business objectives of the project will be achieved if the project as specified is delivered on time and within budget).

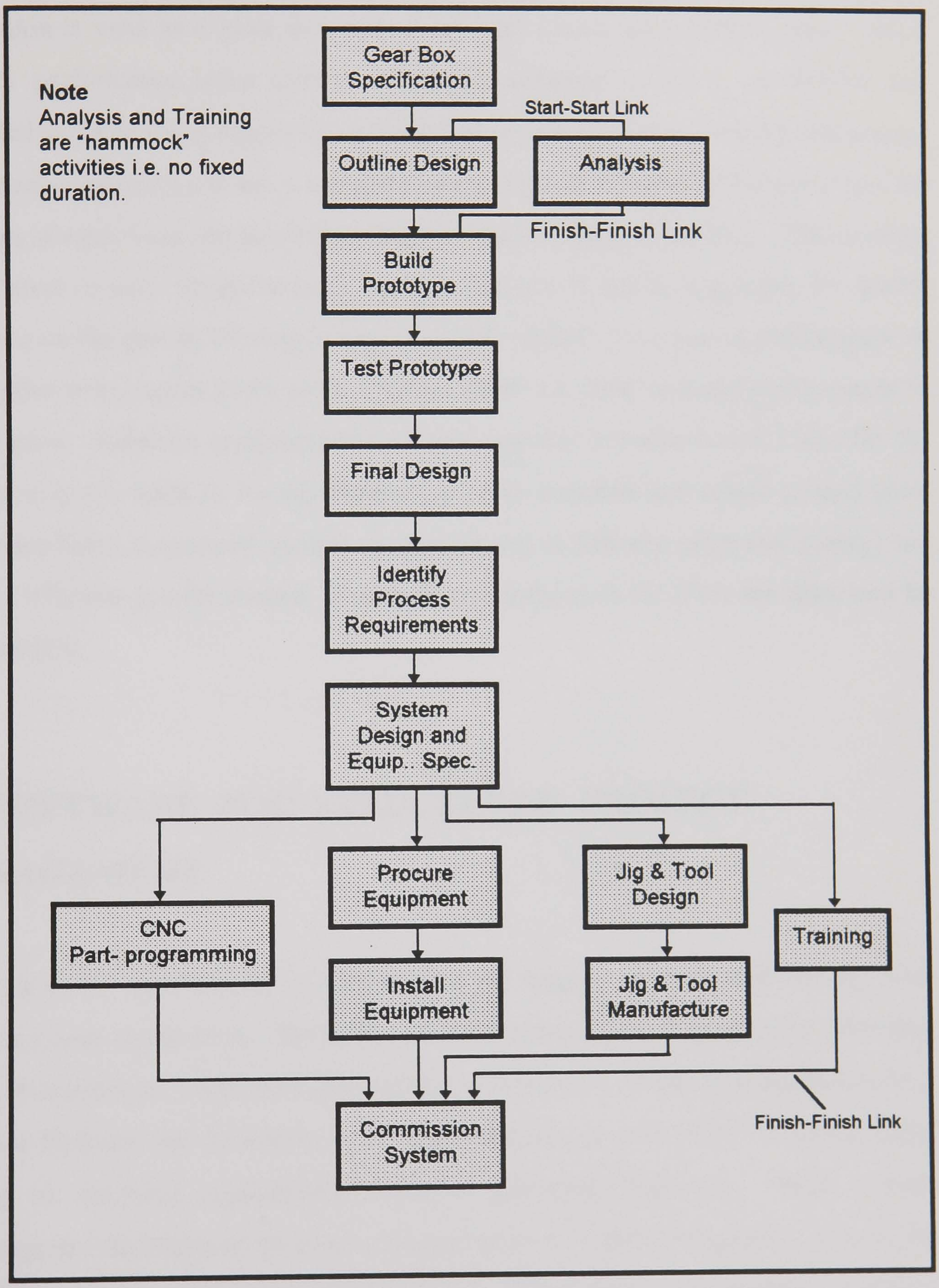

Figure 24 Simplified Logical Network For Gear Box Project

In recent years the use of "Earned Value Analysis" (EVA), a subset of the "Cost Schedule Control System" (CSCS), has been used increasingly as a basis for performance measurement with larger companies. CSCS was developed for the American defence industry in the 1960s but until relatively recently had little application outside that industry. EVA represents an interesting use of cost information in that cost information is used as a basis for establishing both a cost performance index and a schedule performance index (time). The basic concepts of EVA are defined and illustrated in Table 9 and Figure 25. Formal systems for project structuring and project performance reporting are being stipulated increasingly as a contractual requirement for suppliers of equipment and services to large industrial organisations [97]. The intention of the client in such situations is to promote the use of effective systems for quality assurance on the part of the supplier and to make "visible" the ongoing performance of the supplier with respect to the project "deliverables" i.e. time, cost and conformance to specification. Effective implementation of such systems provides benefits also for the supplier in that it leads to the development of more complete and robust project plans (and hence better considered quotations with respect to delivery, price and quality) and to more effective project control. Concepts and techniques for EVA are discussed by Harrison [93].

5.4 SOFTWARE FOR STRUCTURED PROJECT MANAGEMENT

As stated in 5.1 development of software for the support of structured PM has been significant over recent years. Relatively low cost systems (e.g. Superproject, Timeline, PMW, Primavera etc.) and more comprehensive systems for large scale operations (e.g. Artemis) facilitate the development of comprehensive project plans, including detail relating to: resource requirements, resource availability and cost. Such systems encourage the development of more complete project models and provide an accurate and effective means of identifying the timing and magnitude of the cash flows associated with particular project schedules. "What if" analysis with respect to project/schedule

BCWS Budgeted Cost of Work Scheduled to be complete by the date of the project review.

BCWP Budgeted Cost of Work Performed i.e. the work which has actually been completed by the date of the project review. This requires the exercise of judgement with respect to activities which are partially complete.

ACWP Actual Cost of Work Performed up to the date of the review. The inertia present in the majority of company cost accounting systems, together with the problem of assessing the cost of partially completed activities means that the exercise of judgement may again be required.

Cost Variance = BCWP - ACWP

Schedule Variance = BCWP - BCWS

Cost Performance Index **(CPI)** $= \frac{BCWP}{ACWP}$

Schedule Performance Index **(SPI)** $= \frac{BCWP}{BCWS}$

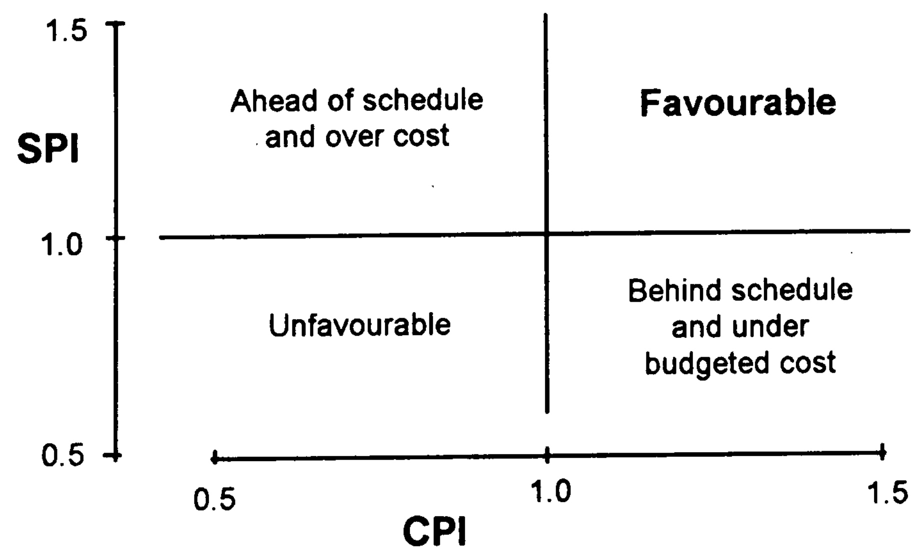

Table 9 Definitions For Earned Value Analysis (based upon Burke [94])

alternatives may be carried out and the facility for providing "filtered" reports enables clear communication of project responsibilities to appropriate groups.

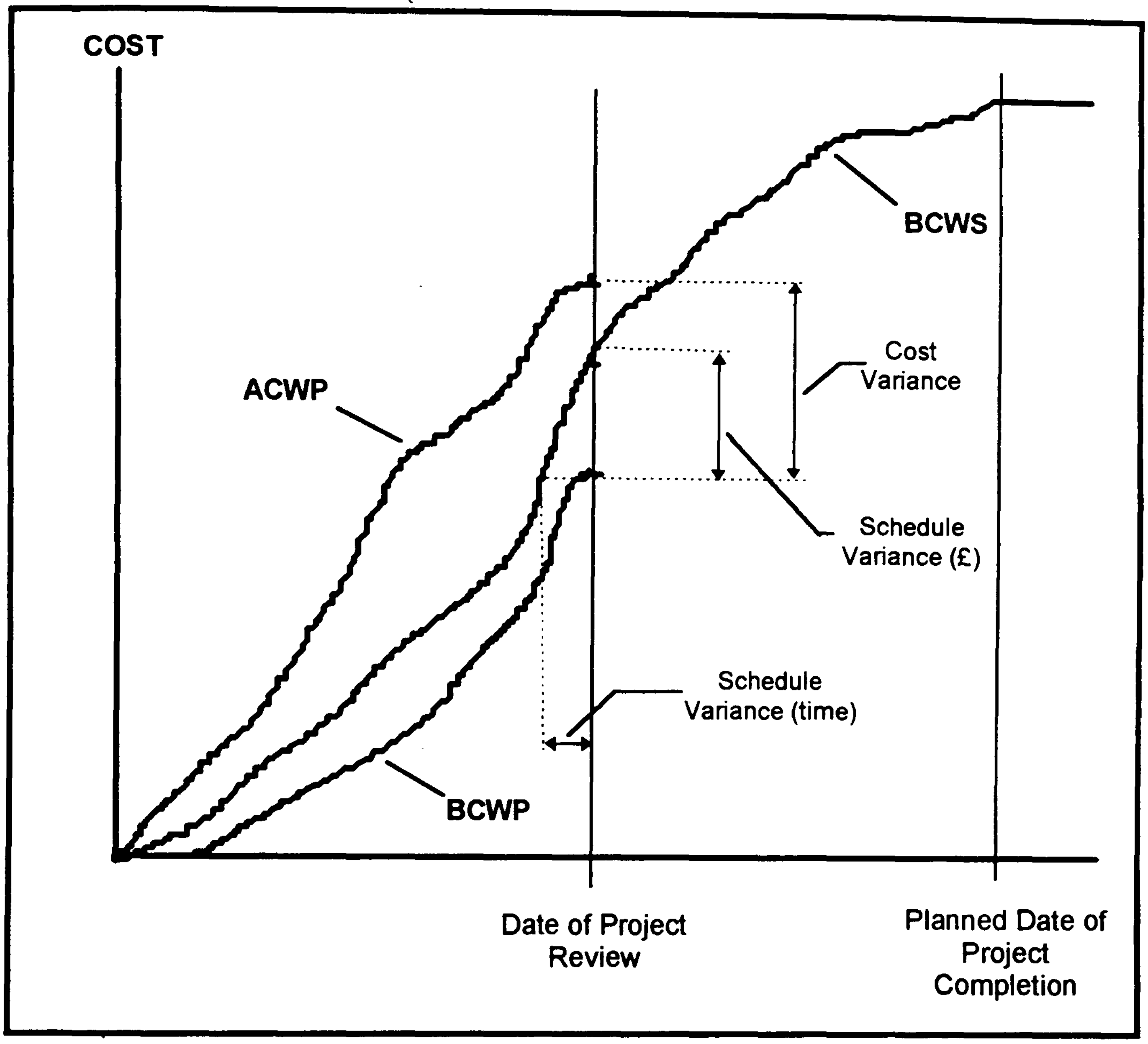

Figure 25 Graphical Representation Of Earned Value Analysis (based upon Burke [94])

The majority of modern software systems for PM provide for the specification of WBS and provide for relatively "open" communication with other software systems e.g. accounting systems and production planning systems. The development of "open" systems provides for the exchange and integration of cost information between accounting systems and PM systems provided that the overall structure of the company's product/work coding system is compatible. The initial failure of the CSCS system to gain widespread application (section 5.0) as a means of cost assignment and control was the result in part of its incompatibility with the existing cost accounting systems [98]. Changes in the approach to: cost accounting e.g. decentralised cost structures based upon particular products or business activity and to company organisation structures e.g. project oriented structures, combined with the introduction of "distributed" information systems (e.g. ERP as discussed in 4.1) mean that the integration of planning, accounting and control systems may be achieved in the near future. Commercial systems for supporting the implementation of WBS/OBS/CBS structures and EVA are beginning to appear (e.g. Artemis I/CSCS) and this is a trend which is likely to continue. The integration of these project oriented approaches to activity planning, activity costing and project control may provide the basis for radical change in the way that manufacturing organisations manage and in particular assign the cost of support activity. The idea of using PM concepts and techniques to assign more accurately/appropriately the cost of support activity is discussed further in section 7.5.

6.0

SUPPLEMENTARY HYPOTHESIS

As a consequence of the review and analysis provided in chapters 2, 3, 4, and 5 it was decided that an appropriate model for the use of cost information might be provided by combining/integrating several of the concepts/approaches discussed in those chapters. A supplementary hypothesis was formulated to provide a focus for the development of the model and is as follows:

Integration of the concepts, principles and techniques associated with activity based costing, throughput accounting, structured project management and concurrent engineering provides an appropriate foundation for the effective use of cost information in AMT environments. Implementation of such a model may act as a focus for providing organisation structures and manufacturing strategies appropriate to the competitive challenges of the 21st century.

7.0
DEVELOPMENT OF THE MODEL

Having established the hypothesis stated in 6.0, a primary aim is the validation of that hypothesis. It is important to realise however that while the model must be robust from a theoretical aspect, it must also be capable of practical implementation. The model in its entirety must provide a framework for the integrated (and in some cases novel) application of concepts, techniques, approaches and software in the support of cost oriented decision-making. It is however unlikely that particular manufacturing organisations will have the ability or be prepared to commit the resources necessary to support a "step" implementation of such a model. With this in mind it is essential that the model is constructed so as to facilitate phased implementation appropriate to the needs and capabilities of particular organisations. Particular organisations may in fact take the view that certain elements of the model have direct relevance to their operations but that other elements do not. For example a company may accept the relevance of ABC as a basis for medium to long term decision-making with respect to product development but not accept the relevance, or see any potential benefit in the application of techniques for structured project management. Hence the structure and presentation of the model must be such that the individual elements and the potential benefits associated with them are defined clearly and that the supporting structure for their implementation and integration is defined as a separate issue.

It is not the aim of this research to provide a panacea for all manufacturing organisations (impractical given the diversity of manufacturing industry and its environment) but to provide a logical framework which may help organisations to understand the contribution which may be made by the integrated application of modern approaches to the provision and use of cost information and to identify and implement systems relevant to their particular circumstances.

7.1 Specification Of The Model

Having identified the general aims associated with the development of the model it is possible now to provide a clear specification of what must be provided. The model must:

- Provide for sufficiently accurate assignment of cost to the manufacture of particular products.
- Provide the basis for decision relevant cost information across functional divisions.
- Provide high "visibility" of the cost implications of particular decisions, across the organisation.
- Provide the basis for performance measures which are compatible with the achievement of corporate rather than merely local objectives.
- Support decision-making across the full range of planning "horizons" i.e. from short term to long term.
- Be capable of phased implementation and/or partial implementation, appropriate to the needs of particular companies.
- Be capable of responding/adapting to changes in cost structures resulting from change in the economic/market environment and change associated with new technology.

It is of great importance also that the costs/resources required to develop, implement and operate the model are considered, together with a strategy for its implementation.

7.2 Outline Structure For The Model

The outline structure illustrated in Figure 26 identifies the major areas of decision-making which are addressed by the research and shows those areas to be linked to a common "core" of cost information based upon ABC principles and throughput accounting principles.

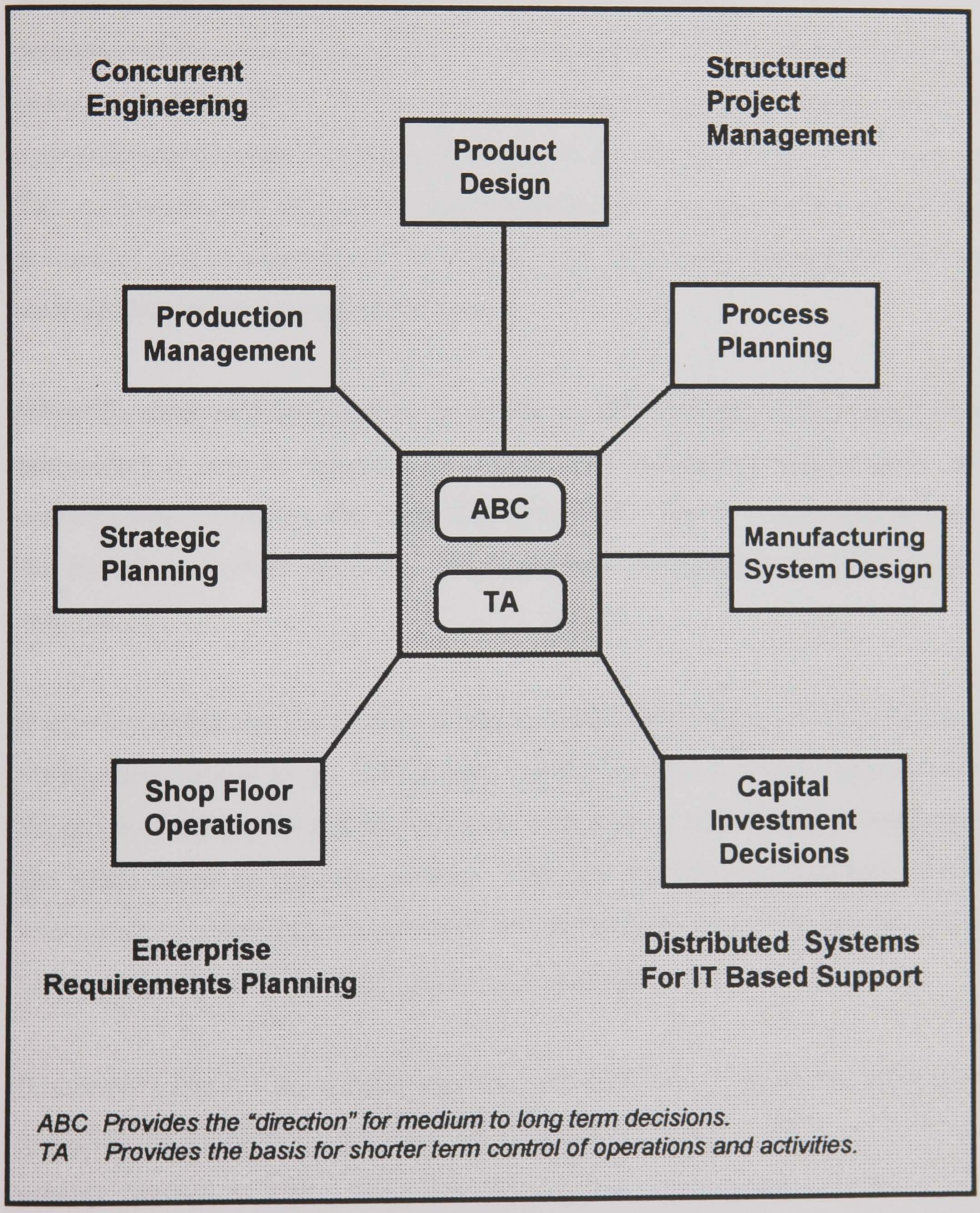

Figure 26 Outline Structure Of A Model For Cost Oriented Decision Support

As suggested in Sections 3.1.2 and 3.2.2, ABC principles are appropriate as a basis for medium to long term decision-making, providing a "direction" for such decisions and throughput accounting/OPT approaches provide the basis for short to medium term decision-making and day to day control of operations. The framework for providing an integrated and standardised means of accessing and using the data in the various decision-making areas is provided by the application of appropriate principles and techniques drawn from concurrent engineering, structured project management, enterprise requirements planning and distributed systems for IT based decision-support. This outline structure satisfies the specification by allowing for discrete consideration of the use of cost information in the various areas of decision-making and for separate consideration of the integrating framework.

While the terms used in Figure 26, to identify the different areas of decision-making, are self-evident it may be beneficial to outline the contributions made by the different elements which comprise the integrating framework. Figure 27 provides an outline of the framework and its operation. More detailed discussion is provided in following sections.

It is worth noting that the function of management accounting is not identified as one of the decision-making areas. This is logical as the function of management accounting is the provision of systems and information to support cost oriented decision-making across the whole range of company activity. Thus the management accounting function is responsible for the design, co-ordination and operation of the costing systems and for the maintenance of a common data base for cost information.

In section 7.3 to 7.5 the detailed structure and operation of the model is described and explained by considering particular decision-making areas. While in each case the primary concern is with a particular decision area, considerable overlap is inevitable given the nature of the model. Emphasis is given to the activity of product design as the primary and integrating activity in concurrent engineering [62].

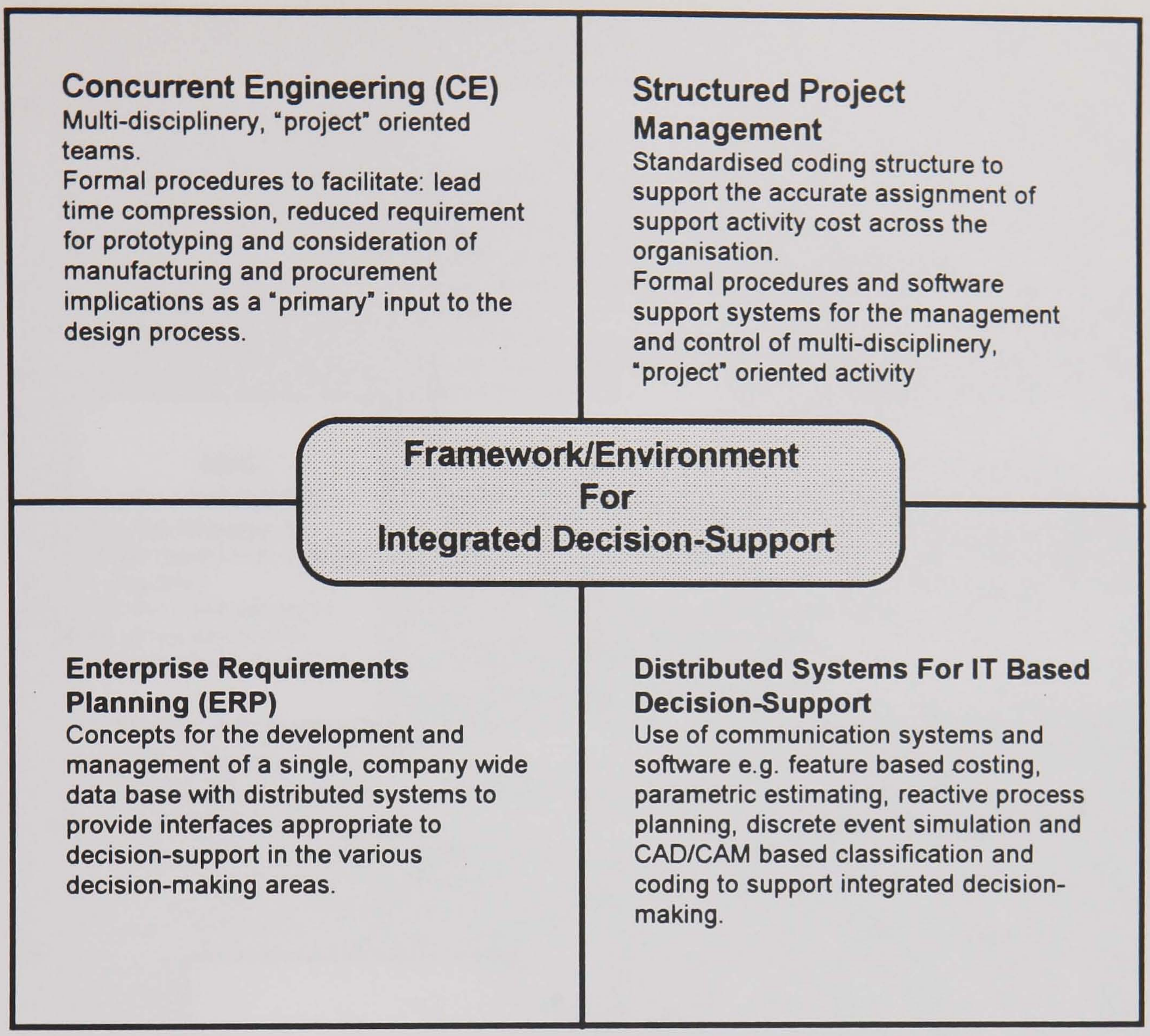

Figure 27 Framework/Environment For Integrated Decision-Support

7.3 Operation Of The Model

Figure 28 illustrates the way in which decision-making in the area of product design is supported and integrated by the model. A "direction" for medium to long term decision-making is provided by a periodic review based upon ABC, short to medium term decisions are based on TA principles (e.g. OPT approach).

7.3.1 Periodic Review Of Activities And Products (ABC)

Periodic review of an organisation's operations and products using an ABC approach is potentially the major source of cost oriented information for decision support in the area

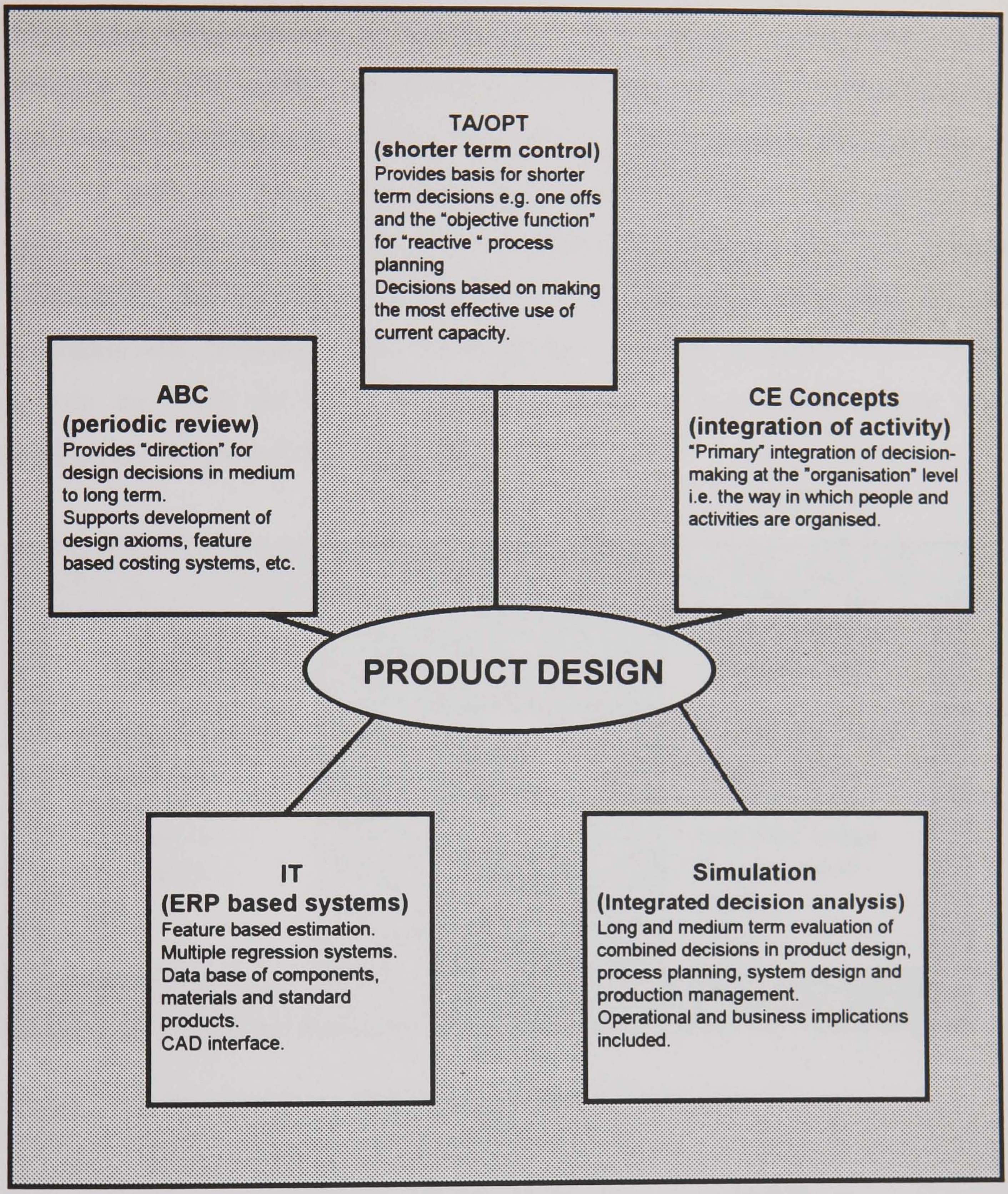

Figure 28 Decision Structure For Product Design.

of product design. The periodic review provides updated information with respect to the cost of the various activities carried out within the organisation and provides also an opportunity to reconsider the cost drivers associated with those activities. Of particular relevance are those activities whose consumption is determined largely by product characteristics specified at the product design stage e.g. choice of material, geometric shape, dimensional tolerance, surface finish, etc. Information with respect to the cost of particular activities and the cost drivers associated with them may be used directly by experienced/knowledgeable product designers (i.e. those capable of visualising the effect of particular design decisions upon the demand for particular activities) in carrying out effective "design for economic manufacture" for new products. Alternatively the information provided may be used to develop/refine the rules associated with axiomatic approaches to design (discussed in section 2.3.2) so as to provide the basis for effective decision-making by less knowledgeable and/or experienced design staff (see Figure 29).

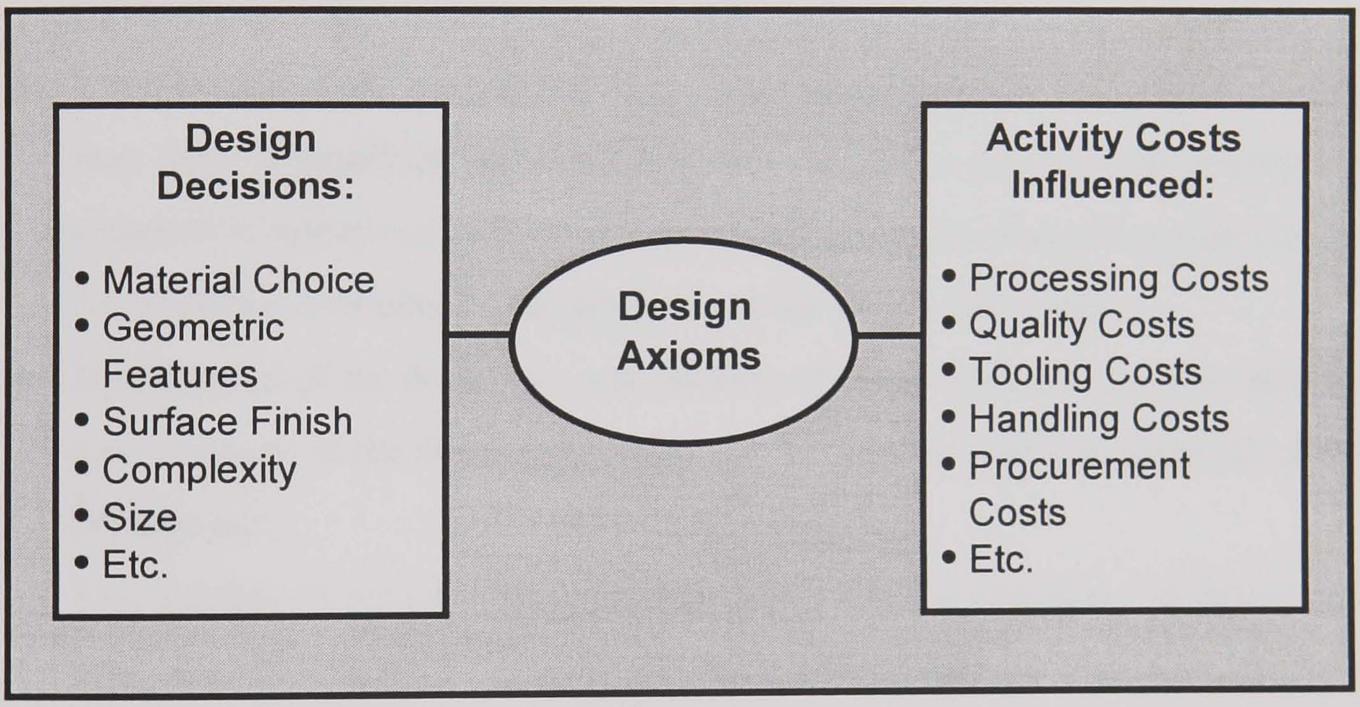

Figure 29 Design Decisions, Design Axioms And Activity Cost.

"Parametric" approaches such as multiple linear regression (MLR is discussed in 4.2.2 and in Appendix 3.1) may be used to estimate the cost of design decisions (e.g. The affect of material: type, size and shape upon the cost of forged components) and may help to impart an awareness of major "cost drivers" to product designers. MLR may be used also to help in identifying cost drivers for more general activity in support of periodic review of operations, based upon ABC. The accuracy of MLR relies to a some extent upon the volume of historical data available, satisfactory levels of accuracy may however be achieved by means of "activity sampling".

In circumstances where the periodic review identifies products with low or negative profitability it may be considered appropriate to carry out a review of the product design, along lines directed by the updated knowledge of activity costs and cost drivers. If re-design fails to identify an appropriately "profitable" new design for the product then the position of the product in the overall product mix must be considered (in some circumstances this may result in elimination of the product or a reduction in its contribution to the product mix). These issues are complex in that a number of factors must be taken into account:

- The product may have some strategic value e.g. may be associated with a valued customer or may be a key product in maintaining the reputation of the company in the market place.
- Modification of the position of the product with respect to the overall product mix may have a significant (and possibly adverse) affect on the cost structure of the company's operations (due to changes in the utilisation of resources associated with the activities consumed by the product), in the short term at least.
- Modification of the design/process planning of the product may have an affect on the cost structure of the company's operations for reasons similar to those for changes in product mix.
- The changes in resource requirements dictated by modifications to product design may be such that some or all of any increased requirement for particular resources may not be capable of being provided in the short term.

Companies may decide therefore to persist, in the short term, with the manufacture of products which appear to be "unprofitable", with the intention of identifying appropriate replacement products or achieving an appropriate restructure of resources in the medium to long term. It may be that the decisions implemented will be a suitable compromise between the "direction" provided by a periodic review of cost structures based upon ABC principles and shorter term considerations based upon available capacity, throughput accounting principles and/or an OPT approach. A possible advantage of a company taking the radical step of eliminating or reducing the quantity of apparently "unprofitable" components in the short run is the stark "visibility" given to productive capacity (resources) associated currently with the manufacture of those products. The latter approach may be compared with the arbitrary reduction of stock level to make more visible the inefficiencies associated with production organisation and scheduling (i.e. in pursuit of JIT).

It is clear that effective design for economic manufacture requires co-ordination across functional divisions, in particular the functions of product design and process planning. The primary mechanism for achieving such integration in decision-making may be provided by the adoption of CE principles and in particular the concept of multi-disciplinery "project oriented" product teams. Further potential for evaluating the combined effect of decisions relating to product design, process planning, system design and system operation (production management) may be provided by the use of manufacturing system simulation for decision support in both the short term and the long term. The availability of a simulation model of a particular manufacturing system, which contains information relating to available capacity and the cost associated with the operation of particular resources (and hence activities), together with information relating to product process routes, product demand, scheduling rules and product prices may provide an assessment of the **potential effect** of:

- Changes in product design(and hence product process routes).
- Changes in product mix.
- Modifications to manufacturing system configuration.
- Modifications to product priorities, scheduling and procurement.

Assessment of the potential effect of particular decision combinations may be achieved by running the simulation model over an appropriate simulation period e.g. several months for long term decisions such as system re-configuration and product design (i.e. products with relatively long term demand) and several days for decisions relating to product priorities and scheduling decisions. The simulation model may provide information concerning both operational and business oriented aspects see Appendix 3.3). Simulation of the operation of the manufacturing system may after appropriate interpretation (period requirements for resources and resource utilisation levels for relatively fixed resources) provide information concerning the activity cost structure which may result if particular decisions relating to product design, etc. are implemented.

7.3.2 Short Term Factors In Product Design

As stated in 7.3 short to medium term decision-making may appropriately be based upon the principles of TA/OPT. One-off or short run products may be designed therefore with a view to making the most effective use of current resources and may not therefore be strictly in line with the "direction" provided by periodic ABC analysis and/or general axioms for design.

Effective manufacture of products with relatively long term demand may be facilitated by an approach which bases the product design upon the "direction" provided by ABC but which provides also the "flexibility" of design described in section 2.4.2. Flexible product designs may allow TA/OPT based systems to make the most effective use of available resources by varying the detail design of the product within allowed limits. The algorithms developed by Palmer [64] and [65] to support "reactive" process planning may be operated with an "objective function" based upon an appropriate TA/OPT criterion and could be incorporated in a simulation model of a system and used also in real time scheduling.

Product designers require information concerning the cost and availability of components and materials and the regime of CE dictates that these issues of procurement are considered as a primary input to the design process rather than at merely the detail stage. This may be achieved by the provision of a central data base (along the lines of ERP) which is accessed and interpreted by an appropriate interface. It is quite feasible that the use of a CAD system at the conceptual design stage could (if an appropriate system of feature based costing or index of manufacturabilty was employed) provide an appropriate assessment of a particular design solution based upon the combination of features comprising the design. It is feasible also that a system for product classification and coding could, automatically, code the product design concept (on the basis of the combination of features) and retrieve/display any similar products. If support systems for product design/process planning are to provide an estimation of the cost associated with alternative designs/process plans it is essential that the cost information used (e.g. machine hour rate) is sufficiently accurate; this issue is addressed in section 7.4.

Following the initial adoption of a design approach based upon periodic review (ABC) the order of change suggested may be significant. Subsequent reviews however may be expected to suggest progressively less dramatic change as the profile of the company's products, product designs and product mix becomes more compatible with its basic business and resources. It may be suggested in fact that the introduction of periodic review could be an effective means of supporting the "business process re-engineering" ([99] and [100]) being carried out currently by many manufacturing organisations.

The activities of product design and process planning are in the context of this model linked inextricably i.e. effective decision-making with respect to product design is linked directly to decisions/implications for process planning. It has been stated also that "flexible" design may provide the basis for "optimising" process plans, enabling the most effective use of available capacity in the short term.

7.3.3 Long Term Issues

In the longer term process planning must be linked to the issue of manufacturing system design and development rather than to simply making the best use of existing capacity and capability. In this context the information provided by the periodic review based on ABC is of value. The process plans and (as described in 7.3) the design of high cost and/or apparently unprofitable products may be reviewed with the aim of providing a more effective design/process planning combination. With products having relatively long term demand it may be appropriate to review the manufacturing resources utilised by the activities necessary for manufacture of the products. In effect this will tend to be a review of high cost and/or high volume activities with the objective of reducing cost by means of introducing change in the manufacturing system. Such change may involve re-configuration of existing equipment and/or the acquisition of new facilities. The potential effect of proposed changes may be assessed by means of the simulation approaches described in sections 4.2.1 and 7.3 and in Appendix 3.3. The decision area of manufacturing system design is linked closely with the areas of strategic decision-making and capital investment justification. The latter issue is discussed further in 7.4.

At the strategic level a significant level of support may be provided by the use of appropriate simulation models as discussed in section 4.2.1 and in Appendix 3.3. The potential affect of alternative policies with respect to product mix, product pricing, scheduling and procurement may be determined by "business" oriented simulation. In shorter term "operational" decision-making shop floor operations must be carried out so as to make the most appropriate use of current capacity and capability, given current product/customer priorities. The concept of "reactive" process scheduling based upon "flexible" process plans and "flexible" product design may be appropriate in these circumstances, using TA/OPT principles to provide an "objective" function (section 2.4.2). Short term decisions also require the availability of easily understood information with respect to the cost of alternative processes/activities and the cost associated with sub-contracting.

7.4 Investment Analysis And The Assignment Of Overhead

Capital investment is a major factor in determining the long run cost structure of manufacturing organisations which employ AMT. While the importance of strategic issues associated with investment in AMT must be emphasised [101] it is essential also that the financial criteria used to justify investment are sufficiently accurate and appropriate and that the likely affect of the investment upon the company's cost structure is identified. The unstructured approaches to investment justification described in Section 2.7.3 are identified with the tendency of engineers and operations managers to specify the equipment they perceive as being needed to cure apparent "bottlenecks" or to improve the level of technology employed in the production process, without any detailed reference to wider implications or alternatives. There is a claim frequently that proposed investment in AMT is strategic and that this negates the need to show any direct improvement in the profitability of the company's operations. Neale and Holmes

[96] suggest that engineers and operations managers involved with investment justification tend to know relatively little about the life cycle costs associated with proposed plant and this ignorance is reflected in the quality investment decisions.

The exemplar structure for an activity based costing system illustrated in 3.1.3, Figure 15, shows that a considerable proportion of cost is associated "directly" with the operation of capital plant and is therefore taken to be related largely to product volumes. Therefore if systems for assigning the cost of "direct" manufacturing activity to particular products for the purpose of quantifying:

- The implications of alternatives in product design e.g. feature based estimating systems.
- The costs associated with alternative process routes.
- The decision to sub-contract activities or to acquire "in house" capability
- As a basis for product pricing decisions.
- As a basis for more accurate valuation of stock.

are required it is necessary to assign, appropriately, the cost of capital plant. This is of relevance increasingly given the continuous movement towards more capital intensive manufacturing operations (discussed in 1.1.5).

The cost information associated with capital investment justification is provided normally by the costing system operated by the particular company concerned. As stated previously the purchase of capital plant has an affect upon the level of cost associated with the company's operations and the costing system employed should reflect the influence of past investment if it is to have any value as a basis for investment justification. As stated in 2.7.3 this requirement is rarely if ever the case in practice; companies tend to operate relatively arbitrary systems for investment justification (with a tendency to emphasise the short term) and tend to employ costing structures/systems which are not linked effectively with the process of capital justification. Thus, the very basis of financial justification of capital investment is flawed within many organisations. Practice with respect to investment justification tends to be flawed also by the "combative" approach adopted by many engineers and operations managers and by their lack of understanding of and faith in their companies procedures for capital justification.

It would appear sensible to move towards a more integrated approach to investment justification and product costing, where changes in one are reflected more directly in the other. A logical first step might be to use the discounting period associated with a company's investment criteria (assuming some form of DCF is utilised) as a basis for assigning an appropriate level of depreciation to new plant. Such an approach would enable the affect of the investment in new plant to be reflected more accurately in the assignment of cost to particular products. In the case of existing products an appropriate reduction in cost and/or increase in revenue might be expected and in the case of new products an appropriate target cost should be achieved. Monitoring of the actual costs of particular products following implementation of the investment may form part of the post completion audit recommended strongly by Neale and Holmes [96].

Consideration must be given also to the effect of capital investment upon the cost structure of support activity. The envisaged changes should be taken into account when establishing the anticipated cash flows for proposed investment projects and may be compared with the actual cost of those activities following implementation, as part of the post completion audit.

The approach outlined above may help in ensuring that the wider issues associated with capital investment (e.g. support costs associated with highly automated plant) are taken into account fully at the proposal stage and that a formal mechanism for audit/review of capital expenditure is built into the system. The more realistic assignment of depreciation provides the basis for more realistic definition of machine hour rate, which combined with a realistic cost structure for support activity provides effective support for decisions relating to product design, product pricing, valuation of stock and sub-contracting. A revised structure for investment analysis and product costing is illustrated in Figure 30.

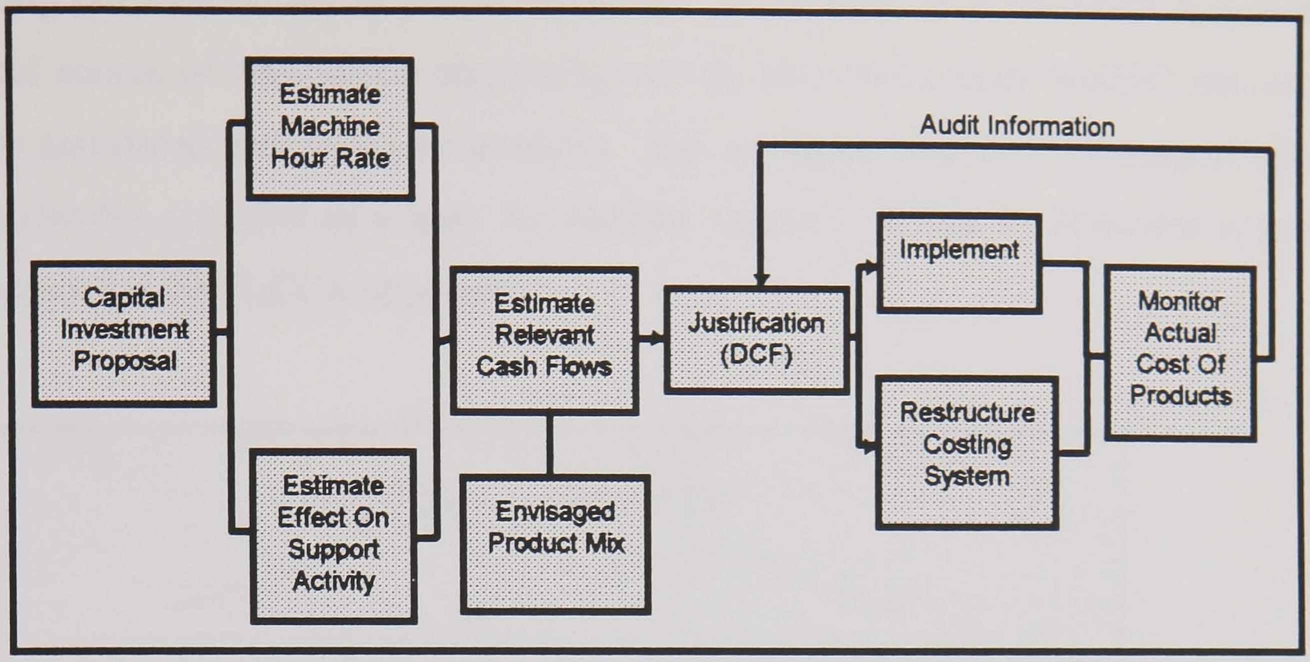

Figure 30 Link Between Investment Analysis And Product Costing.

7.5 Product Life Cycle Cost Account (PLCCA)

In sections 5.2 and 5.5 it was suggested that the adoption of "project" oriented company organisation structures and "distributed" information systems (e.g. ERP) might be combined with concepts and software for the support of "structured" project management in providing a radically new approach for assigning the cost of support activity. The use of such an approach would facilitate the development of a standard coding system (based upon the WBS/OBS/CBS structures discussed in 5.2) for the planning and control of support activity and for the assignment of support activity cost to particular products/product types. With this approach it would be possible to assign the cost of support activity to what may be described as a **"Product Life Cycle Cost Account (PLCCA)"** over the whole life cycle of a product or product range. Thus the support activity costs associated with particular products through initial design, prototyping and introduction to re-design and retirement may be provided on an automatic and continuous basis. As stated in section 5.2 it would be necessary to make some assumptions concerning the life of the product/product range and an appropriate model of support cost depreciation if this approach was to be used as a basis for product costing (an area worthy of further research). At the basic level the PLCCA provides a useful source of information concerning activity costs and makes "visible" the support costs associated with particular products. This increased "visibility" of support cost has considerable potential as a basis for decision support. Figure 31 illustrates a possible structure for the PLCCA approach.

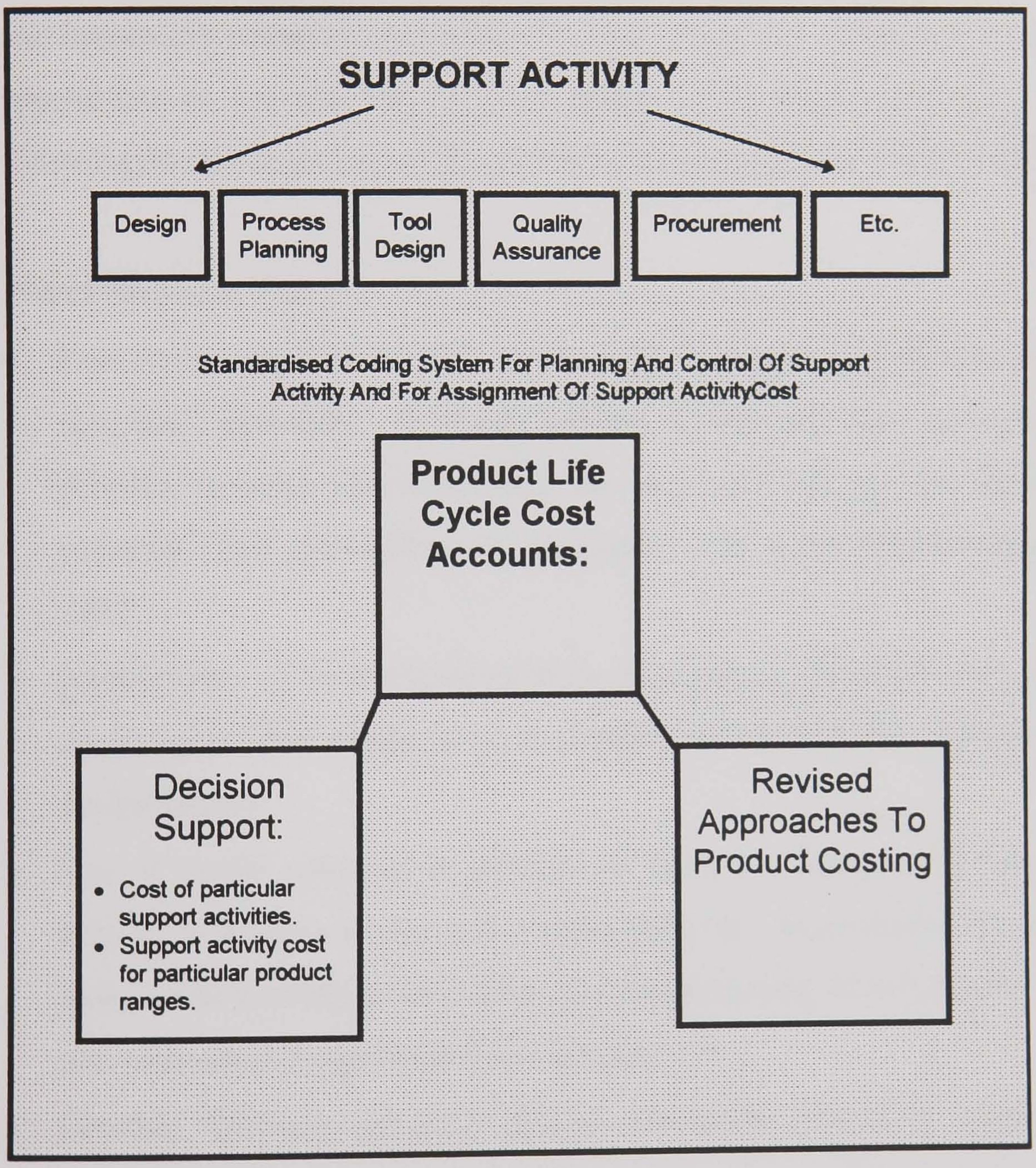

Figure 31 Structure For Product Life Cycle Cost Account

7.6 Issues Of Implementation

As stated in 7.0 it is unlikely that particular organisations would wish to undertake a "step" implementation of all the concepts and techniques associated with the model. The aim has been to define a logical framework for effective implementation and integration of "new" approaches to cost based decision support and so help organisations to select and implement elements appropriate to their operations. With this in mind it is clearly appropriate to consider the issue of phasing in implementation of the model. The following illustrates an outline programme of implementation which may be appropriate:

Short/Medium Term:

- Pilot implementation of ABC across a limited range of products, using an "activity sampling" approach. This will provide a relatively low cost assessment of the potential benefits associated with the approach and provide an insight into the potential costs and difficulties associated with comprehensive implementation of ABC.
- Identification of the implications of the information gained from the pilot review with respect to product design, process planning and product mix. Development of simple design axioms.
- Use of simple software to provide the basis for automated estimation of cost in support of product design and process planning. In particular the use of MLR as a basis for promoting an awareness and understanding of major cost "drivers" on the part of product designers and process planners.
- Develop "business oriented" system simulation models in support of decision-making.
- Education of engineers and operations managers with respect to the costing systems employed by the company.
- Introduce realistic approaches to the justification of capital expenditure and to the assignment of realistic costs (depreciation in particular) to the operation of new plant.

Longer Term:

- Introduction of a formal system for the review of operations and products using ABC.
- Introduce formal systems for using the knowledge derived from the periodic review process e.g. feature based costing linked to CAD.
- Introduce project oriented organisation structures where appropriate together with systems and software to provide automated assignment of cost to support activity.
- Introduce cost information systems based upon TA/OPT to support short term decision-making. e.g. day to day scheduling decisions.

Successful implementation of the model in full or in part is dependent upon understanding and acceptance by those who will utilise it. Woodgate [102] suggests that the flexibility required for effective operation of complex systems (e.g. MRP11) is provided by the people who use the system rather than the system itself and with this in mind it is essential that implementation of the cost information model is accompanied (or preceded) by education of the staff involved. The programme of implementation should be based upon consultation and discussion across the functional boundaries and the specification and development of systems should, where possible, be carried out by those who will use it.

8.0
EXEMPLAR APPLICATION OF THE CONCEPTUAL MODEL

It was determined that there was a need for an exemplar, to identify the way in which the major elements of the conceptual model might be applied in a real manufacturing organisation.

8.1 INTRODUCTION

As stated in the research objectives (1.2.2), the purpose of the conceptual model is to "act as a logical framework for helping organisations to understand the contribution which may be made by the integrated application of modern approaches to the provision and use of cost information and to implement systems relevant to their particular circumstances". It is intended that the model discussed in 7.0 and **illustrated** by means of this exemplar application, will form the basis for a further programme of research, concerned with its practical application in a suitable manufacturing organisation.

The exemplar application takes the form of a case study based upon the products and operations of PFK Engineering, a manufacturer of gears and gear related products. While the material used in the case study is essentially fictitious, it is based upon the products and operations of one of the collaborating organisations. The objective of the exemplar is to illustrate a methodology for implementation of the model, in a practical situation and to consider the range of decision-making which could be supported.

The development of a comprehensive and detailed data base of product, process and business data, together with the simulation models, support cost structures and ABC structures described in the model, would represent a major research project in its own right and is outside the scope of this work. The exemplar contains therefore sufficient detail to illustrate the way in which the various elements of the model may operate and interact, without developing the elements at the "detail" level. The potential for further work associated with industrial implementation, evaluation and development of the conceptual model is discussed in sections 9.0 and 10.0.

8.2 BACKGROUND

8.2.1 The Company

PFK is a progressive and successful company and is involved in the manufacture of: geared reduction units, gear boxes for special applications, geared motor units and "loose" gears of various types. The company has a well established reputation for its extensive experience and capability with respect to the design of gears and gear related products and for high standards of product performance and reliability. The company's performance with respect to price and delivery in recent years has been of some concern and several initiatives have been undertaken (e.g. introduction of cell based manufacturing systems and schemes for the reduction of set up time) as a means of addressing these problems. While the company's performance with respect to product lead time and delivery has improved, there remains some concern with respect to their ability to identify, with sufficient confidence, the costs associated with particular products/product types. This is an important issue given that one of the company's strategic objectives is to expand their range of products and activities and to become less dependent upon what appears to be a shrinking market for military products.

With the above in mind PFK have, over the last two years, implemented a system for product costing and decision-support, utilising the conceptual model introduced in section 7.0. In following sections the structure of the new system will be described and the way in which it is being used as a basis for decision-support will be explained.

8.2.2 Company Products

The products which comprise PFK's current business are summarised as follows:
(N.B. The data presented is fictitious and is not representative of any of the collaborating organisations.)

Geared Reduction Units (26% of turnover)

Standard reduction units, used primarily by suppliers of equipment to a wide range of manufacturing industries. The range covers reduction ratios from 1.3:1 to 600: 1 and output torque capacity up to 100000 Nm as standard. The range is built around 10 standard units which may be customised to provide the precise requirements for a particular customer. Customisation (approximately 55% of units) is associated primarily with modifications to the reduction ratio, gear box mountings and the input and output shaft connections. This appears to be a declining market and competition is strong. Information relating to the price structure for geared reduction units is given in Table 10.

Product Code	Standard Price (£)	Non-Standard Ratio Extra Cost (£)	Non-Standard Mounting Extra Cost (£)	Non- Standard Connection Extra Cost (£)
GRUS-20	103	30	20	15
GRUS-90	135	30	20	20
GRUS-140	197	48	28	20
GRUS-200	256	60	38	29
GRUS-260	306	78	45	33
GRUS-370	394	86	45	33
GRUS-490	498	119	50	40
GRUS-600	620	145	63	55
GRUS-710	780	169	63	55
GRUS-820	939	184	80	55

Table 10. Geared Reduction Units

Geared Motors (19% of turnover)

Geared motors are integrated products comprising a motor (bought in under a collaborative arrangement with a major manufacturer of electric motors) and a reduction gear box. The major customers for this range of products tend to be associated with the process industries, with major applications being found in conveyor systems and other systems for materials handling and processing. Some customisation takes place (approximately 25% of products) and is associated primarily with the provision of non-standard output shaft connectors. This is an expanding market with strong competition. The standard geared motor is based upon electric motors capable of delivering up to 10000 Nm and operating at a nominal speed of 1500 RPM. Reduction ratios of between 1.5:1 and 25:1 are available as standard. Information concerning the price structure for geared units is provided in Table 11.

Standard Geared Motor	Price (£)	Non-Standard Coupling Extra Cost (£)
GMUS-2KW		
1.5-5	73	25
5-9	80	25
9-15	93	25
15-25	109	25
GMUS-5KW		
1.5-5	81	30
*5-9	93	30
*9-15	115	30
15-25	128	30
GMUS-15KW		
1.5-5	135	38
*5-9	141	38
*9-15	163	38
15-25	183	38
GMUS-25KW		
1.5-5	180	47
*5-9	202	47
*9-15	228	47
15-25	250	47
GMUS-40KW		

1.5-5	230	59
*5-9	256	59
*9-15	281	59
15-25	315	59
GMUS-60KW		
1.5-5	340	73
5-9	361	73
9-15	390	73
15-25	430	73

* Manufactured and assembled in GT cells

Table 11 Geared Motors

Special Gear Boxes (39% of turnover)

Gear boxes for specialised applications, including: military vehicles, agricultural equipment and, more recently, racing cars. This business ranges from long running contracts e.g. military vehicles, to one-off specials (approximately 20%) e.g. racing cars. This is the most complex range of products and has traditionally been regarded as the "core" of the business. Approximately 50% of this business is on the basis of long term contracts, the remainder being associated with one-off or small batch products. Some of the more important products are as follows:

TMU200 - Gear box and transmission unit for all terrain military vehicle. A long standing contract which has run for 10 years and has 2 more years to run.

TMU130 - Gear box and transmission for self propelled missile "launcher". Has run for five years and has four years left to run.

TMU115A - Gear box and transmission for armoured personnel carrier. Has run for one year and has two years left to run.

TMU12 - Gear box and transmission supplied to manufacturer of heavy duty "dumper" trucks. Has run for two years and has 2 years to run.

TMU92 - Gear box and transmission unit for special purpose vehicles for civil engineering projects. A basic design which is customised for particular applications in line with customer requirements. The range was introduced two years ago and there is no formal contract, due to the highly customised nature of the business.

Loose Gears (16% of turnover)

The company has extensive expertise and facilities for the design, manufacture and testing of high performance gears of all types. Loose gears are supplied to a wide range of equipment manufacturers and to the spares market. The company tend to regard this business as "secondary" in that it serves to fill "spare" capacity. The demand for loose gears is relatively high and the company limits the amount of business taken on in this area by varying quoted prices and lead times as appropriate. The range of gears produced is wide and includes: spur gears, bevel gears, worm and wheel arrangements, helical gears, spiral bevel gears and hypoid bevel gears.

8.2.3 Company Facilities

In parallel with the implementation of the new approach to product costing and decision-support the company has over the last two years re-structured its facilities for manufacture. An outline of the company's new facility is shown in Figure 32. While the majority of the capacity is laid out by "process", two machining cells and one assembly cell have been introduced (using GT principles). The two machining cells accommodate shafts and gears for the most popular sizes from the geared motor range and a number of long standing "special gear boxes". The assembly cell is centred around the assembly of five of the most popular sizes of geared motor.

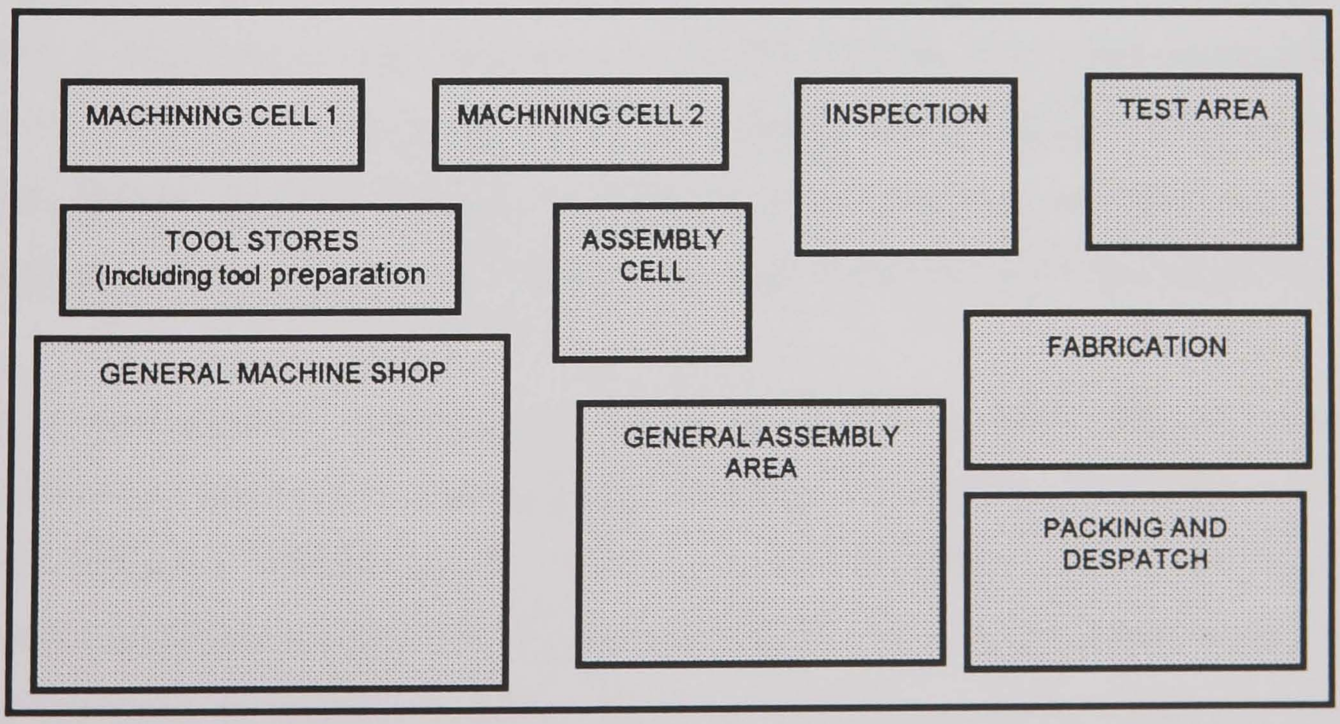

Figure 32. Outline Of New Manufacturing Facility For PFK Engineering

Design and development of PFK's new manufacturing facilities was supported by the development of discrete event simulation models of each of the major system elements. The models were developed so as to provide the capability of being linked together, to provide a model for overall system operation. It was decided that the simulation models would be developed further so as to provide a basis for decision-support on an ongoing operational basis. The development and use of the simulation models is discussed further in section 8.4.3.

8.3 REVISED APPROACH TO PRODUCT COSTING

8.3.1 Outline

For the purpose of the exemplar, three areas of manufacturing activity will be considered: machining, fabrication and assembly. The company's original approach with respect to these areas of activity was based upon direct labour hours with each hour attracting an assignment of overhead. Three overhead rates were specified i.e. one for each area. The assignment of overhead (which included support activity in the areas of: design, process planning, CNC part-programming, tool design and product testing) was based upon precedent rather than upon any detailed analysis. It is worth noting that the use of a single overhead for the activity of machining resulted in there being no "rate" differentiation between products utilising resource intensive machines e.g. CNC machining centres and products requiring very basic resources e.g. radial arm drilling.

The revised approach which has been assumed for PFK is based upon the structure introduced in section 3.1.2 and illustrated in Figure 15 (section 3.1.2) i.e. a structure which utilises a combination of "volume" related assignment of cost and "activity" related assignment of cost. The structure assumed for the company differs slightly from that illustrated in Figure 15 (section 3.1.2), in that an additional mechanism for the assignment of cost has been introduced i.e. direct assignment of some support costs by means of a system for "structured" project management (a detailed explanation is provided in section 8.3.3).

Thus the new structure assumed for PFK assigns cost in three ways:

1. Direct manufacturing operations e.g. machining, are assigned cost on the basis of product volumes i.e. on the basis of machine hours consumed.
2. Support operations which are assigned under the system for "structured" project management e.g. CNC part-programming, have their cost assigned directly to products/product ranges.
3. The cost of support activity which does not lend itself to direct assignment via the "structured" project management system e.g. pre-kitting, is assigned on the basis of appropriate cost "drivers".

It would be inappropriate to attempt the development of a complete and detailed cost structure for the areas covered by the exemplar, i.e. those shown in Figure 32. In outline, however, a split between "volume" related cost and "support" related cost, as illustrated in Figure 33, has been assumed.

8.3.2 Volume Related Costs

A more detailed structure for the volume related costs assumed for the machine shop is illustrated in Figure 34. An explanation of these volume related costs (using CNC turning as an example) is appropriate:

Given that the CNC turning centres (machines) are relatively similar in terms of size, capability and sophistication it was considered appropriate for them to be grouped as a cost centre and hence to generate a standard cost per machine hour for CNC turning across the whole range of CNC turning activity. If depreciation and other volume related costs had been more significant for one machine (or a sub-group of machines) it may have been appropriate to consider more than one category of CNC turning.

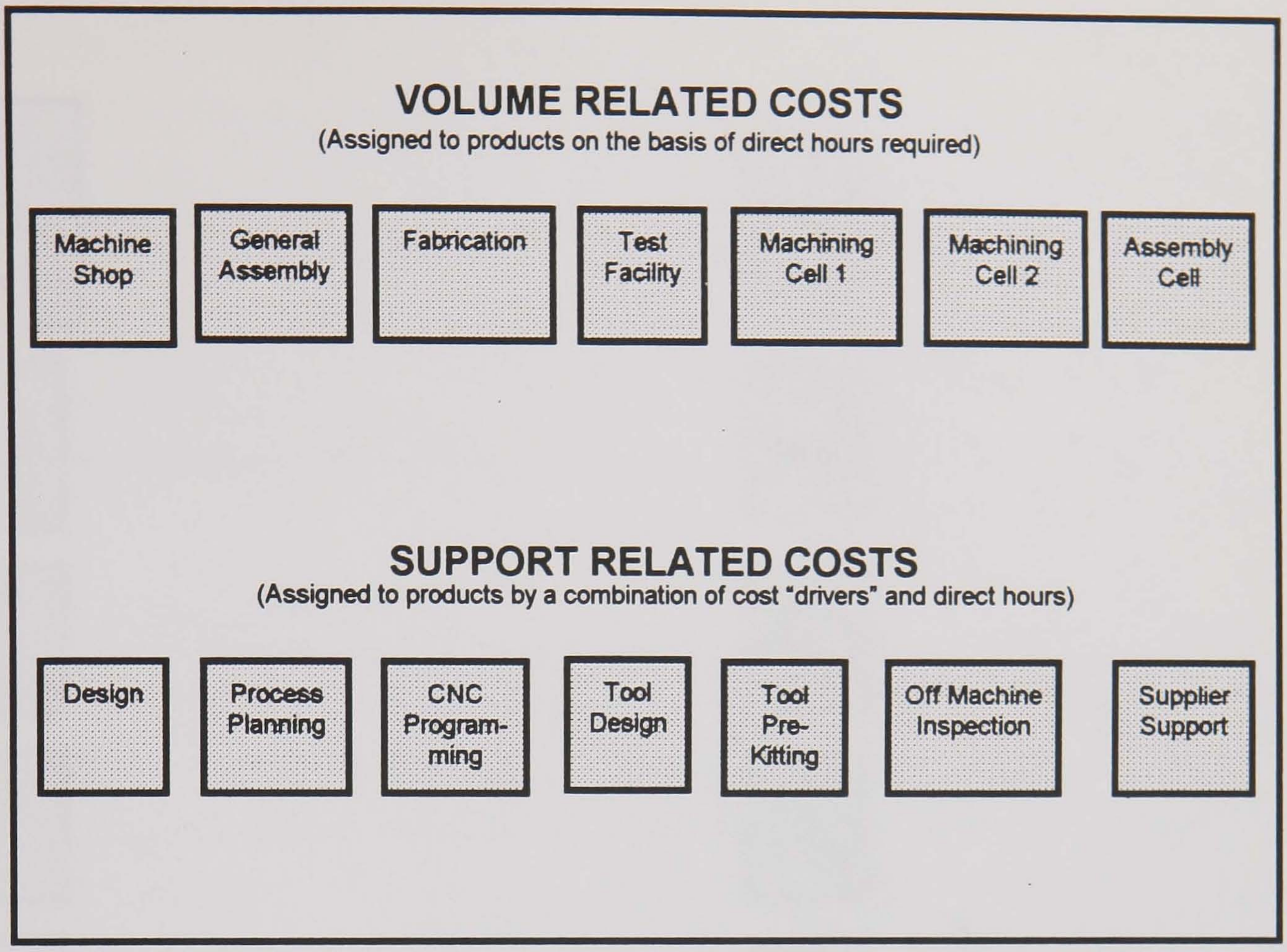

Figure 33 The Split Between Volume Related Cost And Support Related Cost

Depreciation

This is an aggregated figure, based upon a discounted value for annual depreciation for each of the eight machines in the CNC group. The method of depreciation is based upon a realistic assumption with respect to the useful operating life of the machine tools and a discount factor which reflects a realistic cost for the capital employed. The company believe that depreciation should assign the capital cost of machine tools to the products produced by those machine tools. Thus the concept of depreciation as being a means of providing for the replacement of a machine tool was regarded as inappropriate for the purpose of decision-making. PFK believe that this new approach will provide a more direct link between the justification of capital expenditure on machine tools and subsequent identification of the actual returns/cost benefits provided by the expenditure. Replacement of capital plant is considered as an issue of investment and manufacturing strategy rather than one of depreciation It is therefore the case that the depreciation figure used may well be different to that used for financial accounting purposes; taxation issues and strategic issues may dictate a policy for depreciation which is apparently at odds with the assumptions associated with investment justification and the assignment of

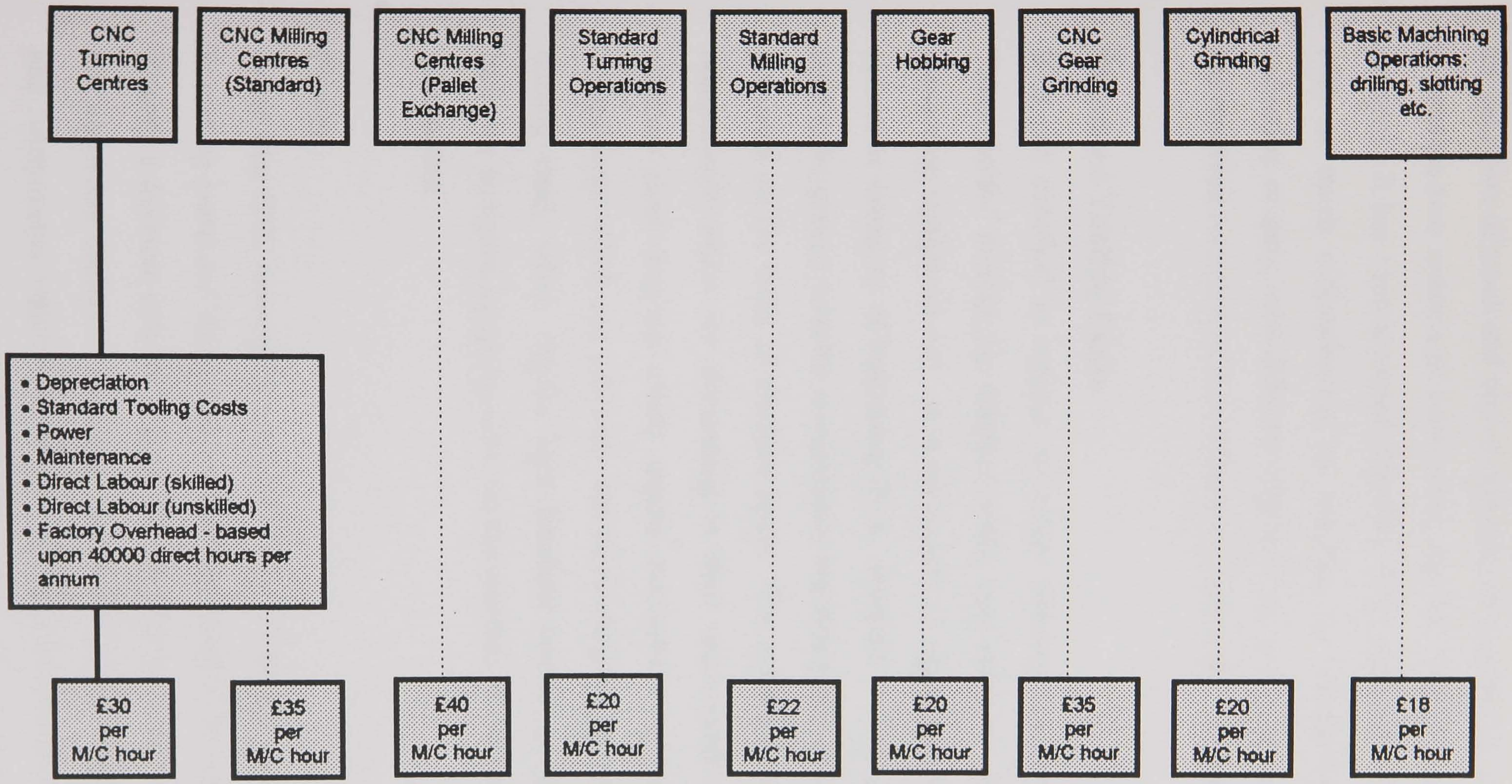

Figure 34 Structure Of Volume Related Costs For Machine Shop

cost to products as a basis for decision-support. This factor along with the requirement for valuation of stock and period reporting of profitability means that it may be necessary to operate two systems of accounting, one for financial reporting and one for decision-support. It has been assumed that PFK Engineering decided to operate a dual system, with as much rationalisation as possible i.e. standard/common procedures for the collection of data, with different interfaces for analysing and reporting. In practice this has involved retention of the company's original systems for period financial reporting.

Standard Tooling Costs

It is not practical to attempt to assign precisely to particular products the cost of "consumable" tooling e.g. standard: drills, taps, reamers, cutting inserts, fixtures, gauges, measuring equipment etc. It is reasonable to aggregate the cost of such tooling for a particular category of machining (N.B. standard tooling costs for CNC machine tools tend to be greater than for conventional machine tools) over a period and assign them to products on the basis of machine hours. This approach does not differentiate between components which are demanding in their requirement for consumable tooling e.g. stainless steel forgings which require extensive roughing operations as opposed to components which are relatively less demanding e.g. pre-machined components in free cutting steel, which require light finishing operations only. The compromise was however accepted as appropriate, on the grounds of the cost versus benefit of additional information.

Power

Given that CNC turning centres tend to spend a greater proportion of their available time in cutting metal and that metal removal rates tend to be higher, it was felt appropriate to identify a different rate for each of the machining categories. The approach taken does not make any distinction between components which require large amounts of roughing and components which require only finishing operations but was considered to be an acceptable compromise, again on the basis of the cost versus benefit of additional information.

Maintenance

Maintenance support in terms of the need for spares, service contracts and call outs is far more significant for CNC machines than for conventional machines. Again PFK have decided to adopt an approach which aggregates the cost of maintenance across the eight machines and provides an allocation per machine hour (N.B. this approach is subject to lack of precision caused by variations in activity level and the random nature of breakdowns). With the latter points in mind some companies have regarded maintenance as a support activity and striven for more direct assignment of its cost. Major maintenance, refurbishing or modification of capital plant is allocated to what is termed a "machine life cycle cost account" rather than being classed as a simple "period" expense. Thus it may be that the depreciation associated with a particular machine tool is increased (or reinstated in the case of a machine which was depreciated fully) following major refurbishment i.e. the cost of the refurbishment would be discounted over what is estimated to be the machines remaining operational life.

Direct Labour (Skilled)

The company's policy is to employ highly skilled operators for their CNC machine tools and to give them responsibility for setting up between batches and for the majority of inspection (in some circumstances more specialised inspection is provided as a support activity). The employment cost for a skilled CNC operator is £8.50 per hour.

Direct Labour (Unskilled)

The CNC turning facility has one general labourer allocated to duties such as swarf removal, lifting and cleaning. The employment cost for a general labourer is currently £6.0 per hour.

Factory Overhead

Assignment of a "general factory overhead" (rent, rates, building costs, administration, etc.) is made to each of the major areas on the basis of the number of direct personnel, floor space, class of building structure and value of capital plant. While this approach does not represent a departure from the conventional approach to the assignment of "general" overhead, the exercise of taking a "fresh" and objective look at the problem resulted in what the company believe to be a more realistic assignment to the various areas . The assignment of this general overhead applies to both volume related cost centres and to activity (support) cost centres. The precision with which the assignment is made is influenced by the accuracy with which activity levels are predicted.

An approach similar to that described above is adopted for each of the volume related cost centres and to the support activity centres as appropriate. Volume related cost is assigned to products on the basis of direct machine or labour hours, this is not necessarily the case for activity (support) related cost. The issue of assigning activity (support) cost is discussed in section 8.3.3.

As a result of the complexity of the products which pass through the machine shop and the relatively small batch sizes, set up time is significant. In the past the procedure was to "book" the actual time taken to set up for a batch and to cost the time at the general rate for the machine shop. This approach is dubious in that a relatively standard product which is following a relatively complex/unusual product may be penalised. To address this problem it was decided to assign set up cost on the basis of an appropriate cost driver, based upon: component size, complexity, required accuracy and method of location. It is worth noting that the use of a cost "driver" means that there may be a discrepancy between the total time/cost actually incurred for set up over a period of time and that assigned to products. This was considered as acceptable as the assignment in relation to particular products is more realistic and therefore more suitable as a basis for decision-support (N.B. period cost of sales is collected in the "traditional" way for the purposes of financial reporting). This latter point demonstrates the general case that while "balancing" of the accounts used for financial reporting purposes over a particular period is essential, it is not essential (although it is desirable) that the overall cost reported by the ABC system for decision-support equates precisely to the overall cost which has actually been incurred.

8.3.3 Support Related Costs

It has been assumed that the company decided to adopt a "structured" project management approach to the provision of support effort, where possible. To this end they have implemented systems and software to control and co-ordinate support from the areas of: design, process planning, CNC part-programming and tool design. A system of coding has been introduced, using a cost breakdown structure similar to that described in 5.1.4, to assign the cost of support effort, in the areas described above, to particular products. In the other "support" areas i.e. tool pre-kitting, inspection (off machine) and supplier support, it was considered impractical to use "direct" assignment of cost to particular products. This led to the determination of appropriate cost "drivers" for these activities. Figure 35 illustrates in outline the approach taken to the assignment of support activity cost.

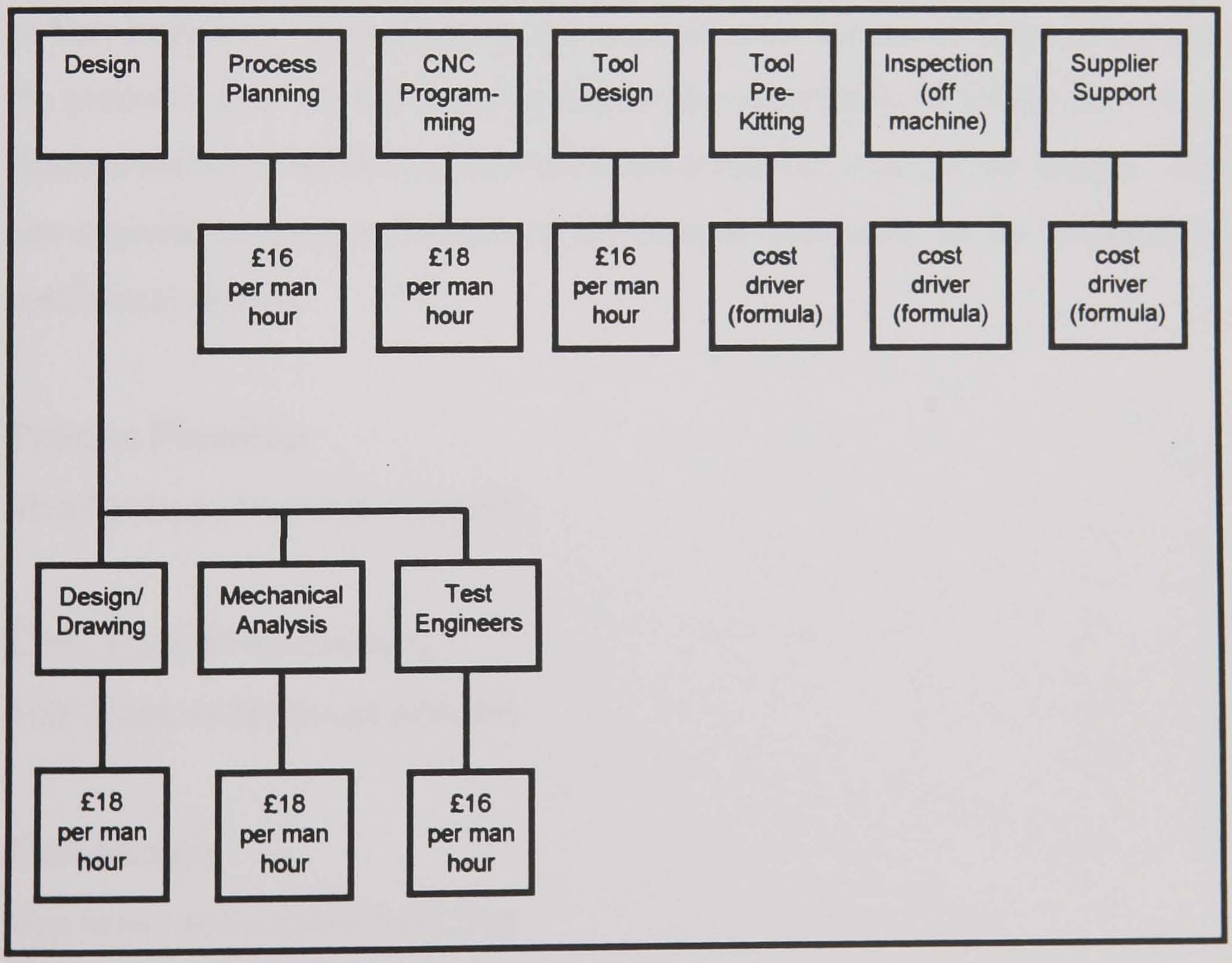

Figure 35 Structure Of Support Related Costs

More detail is provided as follows:

Design

Design activity was identified as comprising three elements:

1. Design/Drawing - Man hours are "booked" to particular products/product ranges by means of the software for structured project management. In the case of a one-off batch the full cost of design/drawing is assigned to that batch. In the case of design/drawing activity associated with a continuing product or product range the cost is assigned to particular products in line with a revised prediction of future product volumes. The company have expressed interest in using the concept of "product life cycle cost accounts" as described in section 7.5 and plan to carry out a pilot implementation at some point in the future.

2. Mechanical Analysis - Man hours booked to particular products/product ranges in a manner similar to that for design/drawing.

3. Test Engineers - Test engineers are responsible for the specification of test procedures for products as and when required and for the supervision of testing on new products. Routine testing is handled by the technicians associated with the test facility. The cost of test engineer support is assigned on the basis of man hours, as for design/drawing and mechanical analysis.

Process Planning

Man hours, as for design activities.

CNC Part-Programming

Man hours, as for design activities.

Tool Design

Man hours as for design activities.

Tool Pre-Kitting

Tool pre-kitting involves the collection, "building up" and "pre-setting" (where appropriate) of all the tools, fixtures and gauges necessary to manufacture a particular batch of products. The introduction of pre-kitting arose out of the initiative to cut down the machining time lost as a result of setting up requirements between batches. The operator of the machine tool is provided with a complete "kit" comprising all the equipment necessary to set up the machine for the next batch. The pre-kitting is carried out by skilled personnel in the tool stores area, in parallel with their other more general responsibilities for issuing and receiving tooling. Thus the time devoted to pre-kitting tends to be fragmented. With this in mind, it was decided to assume that assignment of the cost of pre-kitting is effected by means of an appropriate cost "driver". It has been assumed that a survey was carried out in the tool stores area (using the technique of "activity sampling") and revealed that the major influences on pre-kitting effort were: the number of items to be assembled in a kit, the number of tools to be built up and the number of tools to be pre-set. In this type of situation the use of multiple linear regression (discussed in section 4.22, Appendix 2 and Appendix 3.1) may be of value in quantifying the effect of the various cost "drivers". It is assumed that the company have applied these techniques and have determined an acceptable formula by which to assign the cost of pre-kitting to particular products/batches of products.

Inspection (Off Machine)

Off machine inspection is carried out on products which are:

- unusual in their demand for accuracy e.g. some aspects of geometric tolerancing.
- complex in terms of the shape and/or orientation of critical features.
- specified as requiring formal certification by "approved" inspectors.

The pattern of work associated with off machine inspectors is such that that their effort tends to be fragmented. With this in mind it was decided to employ a cost driver for the assignment of off machine inspection activity. An approach similar to that for tool pre-kitting has been assumed and a cost driver based upon size, a "complexity" factor and the number of products off, has been assumed to be found satisfactory.

Supplier Support

The day to day activity of dealing with supplies is included in the general overhead for administration. Certain materials however require special effort in sourcing and control e.g. products which have an unusual material specification (composition, heat treatment, etc.). In such circumstances additional activity is involved. It was considered impractical to assign this cost on a direct basis and therefore the determination of an appropriate cost driver has been assumed. The cost driver is based upon the material specification, in terms of the requirements for: destructive testing, non-destructive testing, material traceability and supplier accreditation.

The revised cost structure assumed for PFK provides:

A. The ability to carry out, with an acceptable level of accuracy, a periodic review of the profitability associated with particular products and product ranges. This may be used to support decisions concerning product mix, product development and company strategy.

B. A more realistic assessment of the cost of particular activities - both volume related and non-volume related. This may be used to support decisions with respect to product design, process planning, scheduling and investment in new plant. This information could be used by PFK in the development of "business oriented" simulation models, along the lines described in sections 4.2.1, 4.2.1.1 and in Appendix 3.3. Cost information relating to support activity in those areas covered by the software system for structured project management, enables the production of "cost profiles" for planned support activity, with a greatly improved level of accuracy.

The use of a structured project management approach, together with the revised cost structure, has been assumed to provide the company with greater insight into the factors which drive cost in areas such as product design and process planning. This knowledge may be used to provide a more accurate basis for estimating the support costs associated with potential business (a factor which tended to be ignored in the past).

8.4 OVERALL OPERATION OF THE NEW APPROACH/SYSTEM FOR DECISION-SUPPORT

Before considering the information which may be provided by the revised approach, in detail, it will be helpful to describe briefly the company's plans for its overall operation.

8.4.1 Revised Structure For Product Costing

As explained in section 8.3, product costing is fed by:

- A more comprehensive and accurate structure for "volume" related manufacturing costs - assigned on the basis of direct machine or labour hours.
- A structure for the assignment of support cost in the areas of: design, process planning, tool design, test engineering and CNC part-programming - assigned on the basis of direct labour hours. The planning and control of support activity in these areas and the assignment of support costs to particular products/product ranges being achieved with the aid of software for structured project management.
- A structure for the assignment of support cost in the areas of tool pre-kitting, inspection (off machine) and supplier support - assigned on the basis of appropriate cost "drivers".

8.4.2 Structure Of The Overall System

The overall system for decision support may be described therefore as comprising essentially three main elements:

A. Product costing - incorporating a more realistic approach to the assignment of both volume and non-volume related costs.

B. A structured project management system as a basis for planning and controlling support activity and assigning its cost to particular products/product ranges.

C. A suite of linked, discrete event simulation models incorporating business oriented performance indices. The simulation models being designed to assess the potential of alternative decisions, on the basis of parameters such as period profitability (effectively an application of throughput accounting principles).

8.4.3 Links Between The System Elements

The revised structure for product costing provides the basis for a periodic (annual in the case of PFK Engineering) review of the profitability associated with particular products/product ranges and the cost associated with the various manufacturing and support activities.

In identifying those products which are contributing most towards the company's profitability and conversely those which are contributing least (perhaps even loss-making), the review suggests a **direction** for modification to the product mix i.e. greater concentration upon more profitable products and reduction (or even elimination) of less profitable products. The decision is however not a simple one; other factors must be taken in to consideration, in particular the associated marketing and capacity implications.

Some of the more important marketing considerations would be:

- Lack of demand for increased volumes of the more profitable products.
- Pressure on market price associated with increased volumes of apparently more profitable products.
- Some of the less profitable (or loss making) products may be associated with customers who provide a major source of profit to the company by virtue of the range of products they purchase.
- Some products may be less profitable as a direct result of marketing strategy e.g. a new product being introduced into an existing and highly competitive market.

While detailed consideration of marketing issues is beyond the scope of this work, the issue of capacity is central i.e. proposed changes to product mix may not be feasible in terms of the capacity constraints associated with the company's resources for manufacturing (including support activity) and/or the change in product mix (and hence the pattern of utilisation of capacity) may have an affect upon the cost structure itself.

An example of the latter situation would be loss of activity, as a result of changes in the product mix, in a particular area of manufacture e.g. a 25% reduction in CNC gear grinding. The capital plant and associated support for the CNC gear grinding process must be maintained (N.B. there are two CNC gear grinders, working currently at 90% capacity) and therefore the volume related cost associated with them is effectively increased. The approach taken by PFK is to use the periodic review of product profitability, together with consideration of relevant marketing factors to provide the basis ("direction") for identifying "promising" policies with respect to product mix and to evaluate alternative policies by means of discrete event simulation. As stated in 8.4.1 the simulation models which comprise the overall model incorporate business oriented performance measures as described in sections 4.2.1, 4.2.1.1 and in Appendix 3.3. The "costing" of products within the simulation is based upon the actual process route employed in the simulation (N.B. some potential for alternative process routes for particular products may exist and the actual process route employed will depend upon the product mix, available capacity and the scheduling approach employed in the simulation model). It was stated in 8.4.3 that changes in product mix which result in lower levels of activity in particular manufacturing areas may be regarded effectively as changing the cost structure. This problem is accommodated in the simulation models by means of assigning a cost to unused capacity (i.e. the "fixed" element associated with the capacity). Thus the model provides a realistic picture of the **overall** cost associated with the adoption of a particular policy, over a particular period. It is worth noting that any capacity which is consistently "under-utilised", will be considered in the longer term with respect to facilities design and development. When run over the medium term (up to six months) the simulations provide information relating to:

- Output - has the volume requirement for products, over the simulated period, been met? It may be appropriate in, the case of PFK, to assume that the schedule associated with the products required over the period, is provided in the form of schedules produced by the company's MRP system. (It is worth noting at this stage, that an approach which links a simple MRP simulation in EXCEL, with a simulation model of the associated manufacturing system in WITNESS, has been developed by the author. The approach provides an automatic link between the generation of schedules from an MRP system and evaluation of their potential effect, using discrete event simulation.)

- Period cost of manufacture - by total and by product.
- Period profitability (saleable products e.g. products which may be invoiced within one month of production) - by total and by product.
- Delivery performance (tardiness) - by total and by product.
- WIP levels (volume and value) over the period - by total and by product.

The above approach allows the company to identify an appropriate use of capacity given short to medium term demand and the objective of maximising period profitability, in line with the concept of throughput accounting. Given this approach it is likely that the product mix will include (at least in the short to medium term) some of the products with low or negative profitability.

In the medium to long term, periodic review of product profitability and the cost associated with particular activities may be used as a basis for;

- Identifying new products and product development.
- Identifying effective approaches to the design of products.
- Development of manufacturing capacity/capability (e.g. investment in new plant so as to reduce the cost of an essential activity which is currently regarded as high cost).

The structured project management system used to plan, control and assign the cost of support activity is used to assess the capacity implications and the cost of support activity associated with alternative policies. This information makes possible identification of the total period costs and the feasibility of alternative policies.

Figure 36 illustrates, in outline, the links between the various elements of the system.

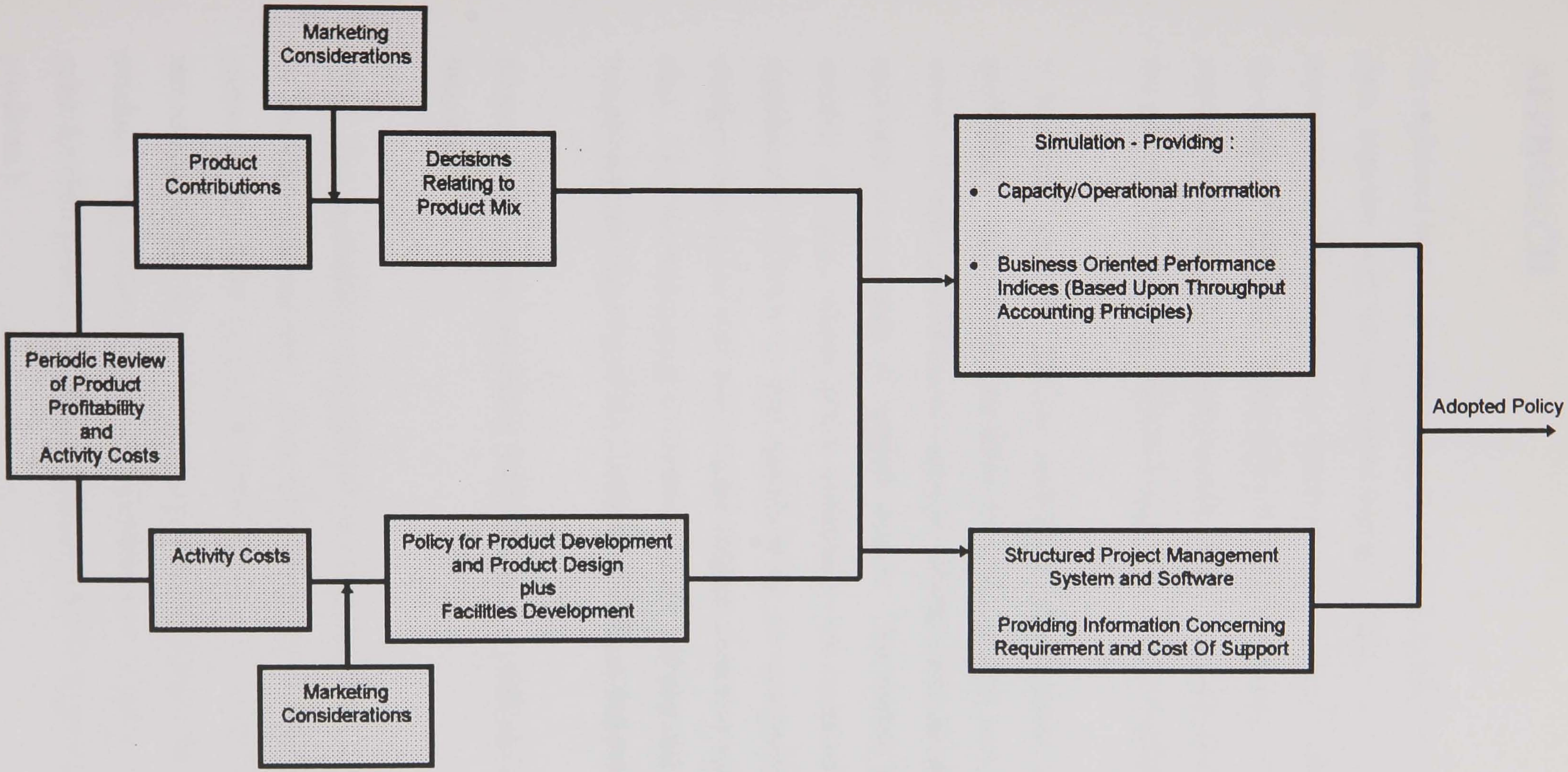

Figure 36 Overall Structure Of Decision Support For PFK Engineering.

8.5 DETAILED INFORMATION PROVIDED BY THE NEW APPROACH

As explained in 8.1, development of a detailed database of product, process and business data, together with the simulation models, support cost structures and ABC structures necessary to demonstrate the model, in the context of the "PFK" exemplar, is beyond the scope of this thesis. What follows is an **illustration** of the type of information which may be provided, following a practical implementation of the model. The way in which the information might be used as a basis for decision-support is described in section 8.6.

It has been assumed that the company's initial review of product/activity costs and profitability was carried out three months ago and was based upon the first twelve months of operation of the revised cost structure and the structured project management approach to provision of support activity. The review revealed a surprisingly large number of cases where actual profitability (as measured by the new systems) was significantly different to that perceived by the company. The review did however confirm their belief that more recent military contracts were less profitable than in the past. They were surprised to observe that the military and special gear box business did not provide the majority of the company's profit, as had previously been assumed.

Some of the more significant information provided by the review is summarised as follows:

(N.B. The profitability associated with particular products is expressed as a % of sales, to facilitate comparisons. It is accepted however that the turnover associated with particular products is also of relevance e.g. a relatively low selling price may be introduced as part of a marketing strategy to increase the sales volume for a particular product. PFK however have, with the exception of loose gears, tended to follow market price for their products in an attempt to be price competitive across the full range of their products.).

Product Code	Profitability (%) Standard Product (new syst.)	(old syst.)	Profitability (%) Customised Product (new syst.)	(old syst.)
GRUS-20	17	(16)	8	(16)
GRUS-90	18	(20)	9	(15)
GRUS-140	16	(18)	7	(16)
GRUS-200	20	(21)	18	(19)
GRUS-260	25	(20)	20	(21)
GRUS-370	24	(20)	20	(18)
GRUS-490	23	(21)	16	(23)
GRUS-600	23	(20)	12	(19)
GRUS-710	19	(18)	12	(17)
GRUS-820	19	(20)	13	(18)

Table 12 Profitability Of Geared Reduction Units

Standard Geared Motor	Profitability (%) Standard Product (new syst.)	(old syst.)	Profitability (%) Customised Product (new syst.)	(old Syst.)
GMUS-2KW				
1.5-5	13	(16)	12	(15)
5-9	15	(18)	14	(17)
9-15	16	(19)	14	(18)
15-25	15	(17)	15	(16)
GMUS-5KW				
1.5-5	15	(19)	11	(16)
*5-9	30	(22)	23	(20)
*9-15	33	(21)	21	(20)
15-25	18	(20)	16	(18)
GMUS-15KW				
1.5-5	17	(20)	15	(15)
*5-9	38	(23)	27	(19)
*9-15	37	(25)	28	(21)
15-25	19	(21)	18	(19)
GMUS-25KW				
1.5-5	18	(19)	16	(17)
*5-9	32	(22)	22	(19)
*9-15	32	(20)	21	(20)
15-25	18	(21)	17	(19)
GMUS-40KW				
1.5-5	20	(21)	19	(20)
*5-9	35	(20)	23	(22)
*9-15	36	(22)	20	(23

15-25	18	(20)	15	(20)
GMUS-60KW				
1.5-5	18	(21)	17	(19)
5-9	17	(19)	15	(17)
9-15	17	(20)	16	(16)
15-25	15	(18)	12	(14)

Table 13 Profitability Of Geared Motors

Profitability Of Special Gear Boxes

The profitability of some of the more important, longer term products is listed below:

	(new syst.)	(old syst.)
TMU200 - Gear box and transmission unit for all terrain military vehicle.	27%	24%
TMU130 - Gear box and transmission for self propelled missile launcher.	9%	17%
TMU115A - Gear box and transmission for armoured personnel carrier	4%	18%
TMU12 - Gear box and transmission for heavy duty "dumper" truck.	23%	20%
TMU92 - Gear box and transmission for special purpose vehicles for civil engineering projects.	5%	21%

The profitability associated with "one-off specials" was in general satisfactory, at approximately 18% overall. The "old" cost structure reported overall profitability of approximately 24%.

Loose Gears

Average profitability for the loose gears business, across all gear types and sizes is 26% (as measured by the new structure), with the larger sizes of precision worm and wheel arrangements and spiral bevel gears having profitability between 29% and 51%. The "old" cost structure had reported average profitability of the order 18%. The significant contribution to company profits of business which had been regarded as simply filling capacity, came as a considerable surprise to the management of PFK.

Activities

The revised cost structure for the Machine Shop and related support activity made visible the significant difference which exists between the cost of activities such as CNC milling (£35 per hour, plus associated support costs for programming, pre-kitting and tool design) and conventional milling at £22 per hour. In the past, practice on the part of process planners and production planners has been to route the majority of products through the CNC machines where possible, so as to maintain high levels of utilisation on these expensive capital purchases. This has had a tendency to create artificial bottlenecks at these machines and create the impression that further capital purchases of such plant were essential, simply on the grounds of capacity. Priority on CNC machines has tended to be given to what the company saw as its core products e.g. special gear boxes rather than to products which would lead to the most profitable use of such sophisticated and expensive capacity e.g. relatively simple components for special gear box contracts being given priority over complex products associated with the loose gears business. Prior to the introduction of the new cost structure it was not possible for process planners and production planners to carry out any form of cost oriented decision-making - it is now possible for them to identify with reasonable accuracy the cost of alternative process routes.

8.6 COMPANY INTERPRETATION OF RESULTS

As stated in 8.4.3 the cost information provided by the review must be combined with marketing and operational considerations, in order to identify promising alternatives in policy. The company judge their current situation to be as follows:

Geared Reduction Units

The level of profitability associated with the range is acceptable, with the exception of customised versions of the three smallest units, given the high level of competition in what is believed to be a declining market. The three smaller units account for only 15% of geared reduction unit sales, with approximately 30% of orders being customised. For the short term the decision is to attempt to move demand away from customised versions of the three smaller units, by means of marketing effort.

Geared Motors

The geared motors machined and assembled in the GT cells (identified by * in Table 12) account for 50% of the turnover for geared motors. The level of competition in this market is high, suggesting that the good level of profitability associated with the products manufactured in the GT cells is due to the lower costs associated with cellular manufacture. As the market for geared motors is expanding the company have decided, in the medium to long term, to develop the facilities for cellular manufacture across more of the geared motor range. In the short term, marketing effort will be directed towards maximising sales of the more profitable motors while maintaining the base for expanding the sales of other motors.

Special Gear Boxes

The profitability of products TMU200 (all terrain military vehicle) and TMU12 (heavy duty dumper truck) is satisfactory. While the profitability of TMU130 (missile launcher) is poor it is regarded as acceptable given the current climate in the military market. Products TMU115A (personnel carrier) and TMU92 (special vehicles for civil eng.) are not acceptable in terms of their profitability and have been singled out for more detailed review.

TMU115A - This is the most recent of the company's long term military contracts and was "won" on the basis of a closed tendering process. The nature of the design, which was not carried out by PFK, is such that a high proportion of the machining demands the use of expensive plant e.g. CNC gear grinding and a high element of off machine inspection is required. At the time of tendering the company's costing system did not differentiate between classes of machining and the cost of off machine inspection was allocated (as an overhead) across all products, including those which did not require it.

The company had originally anticipated profitability of the order 18-20%. As the contract has two years to run and the design is fixed there is little that can be done in the short to medium term. The experience will be taken into account in future tenders for military and other contracts.

TMU92 - This product range has a high requirement for customisation and is produced in relatively short batches. Prior to the introduction of the new cost structure this was perceived as a highly profitable range of products. Under the revised system however the product range attracts a relatively high level of support cost in the form of design (customisation), process planning and CNC part-programming and appears to provide a very low level of profitability. As a result of the company's perception that this was a highly profitable range these products have in the past been promoted heavily by the marketing function and have been given a high level of priority with respect to the limited capacity for high precision/specialised machining processes.

Due to the high level of customisation there is no formal contract for the supply/price of these products and the company have therefore decided to increase the price of the products progressively over the next 12 to 18 months, accepting that this may reduce the level of demand. Naturally this will be linked to the company's ability to attract, if necessary, other more profitable business.

Loose Gears

The visibility given to the good level of profitability associated with this part of the business and in particular that associated with precision worm and wheel arrangements and spiral bevel gears has caused the company to re-think its strategy. While to some extent the high level of profitability may be associated with PFK's policy of using the loose gear business to fill "spare" capacity (using price as a control) the marketing function believe that there is a "rich" market for high precision/special loose gears. Given the problems with the TMU92 (gear boxes and transmissions for special vehicles for civil eng.) and the need to diversify away from a reliance on military business, the company have decided to adopt a more positive attitude to the manufacture of loose gears. In the short to medium term they will target marketing effort in the areas of greatest profitability i.e. precision worm and wheel arrangements and spiral bevel gears, (N.B. In the past PFK have made no effort to promote this element of the business). In the longer term they plan to increase the business to 25% of turnover, with the emphasis on the high precision/special products which provide the greatest profitability.

Thus it may be said that the review of product profitability has provided a promising **direction** for change to product mix in the short to medium term. The company have considered the market potential for such changes to the product mix and have identified what they believe is achievable in a "marketing sense". It remains now to assess the feasibility of implementing such a policy, in terms of capacity (manufacturing and support) and the level of overall profitability which could be expected to be delivered.

8.7 SIMULATION

As stated in 8.5, development of the simulation models which would be required to demonstrate practical application of the model, in the context of the exemplar, is beyond the scope of this work. What follows is again an illustration of the way in which appropriate simulation models might be employed (It is worth noting at this point that a practical approach has been developed and demonstrated, as part of this programme of research, with respect to the generation of business oriented performance measures from discrete event simulation models - Appendix 3.3).

The company has been assumed to evaluate the potential affect of the proposed changes over a simulation period of three months. Delivery schedules being produced with the aid of the company's MRP system and translated into "part files", appropriate for input to the WITNESS simulation model. Some refinement of the policy for product mix, prior to input to the simulation model, may be made, following consideration of "rough cut" capacity implications, within the MRP system. It has been assumed that the initial simulation was based primarily upon the following changes to product mix:

- 10% increase in the volume of loose gear work and in particular a 16% increase in the volume of work associated with high precision worm and wheel arrangements and spiral bevel gears. This represented a major increase in the latter category of loose gear work and a small reduction in the amount of "standard" loose gear work.
- 20% reduction in the volume of work associated with TMU92 (gear box and transmissions for special purpose civil eng. vehicles).
- 4% reduction in the volume of work associated with the less profitable members of the geared motor range and a 2% increase in volumes for the more profitable motors.
- The volume and type of one-off products was assumed to be unchanged and to comprise products with similar capacity and process requirements to those produced over the last year.

The simulation has been assumed to reveal capacity problems which could not be resolved by modifying the MRP schedules or by experimenting with local scheduling rules e.g. batch size. In particular, bottlenecks with respect to CNC gear grinding and CNC milling (pallet exchange machines), resulted in poor utilisation in some of the conventional machining areas and in some assembly operations and there was a shortfall with respect to the scheduled requirement for "high profit" loose gears. This situation triggered a review of the process planning of the products using these facilities and resulted in the provision of alternative process routes for some products e.g. some products originally routed through the CNC (pallet exchange) machines were provided alternative routes via conventional milling facilities. Variations of product mix and product routing were experimented with until an acceptable combination of period profitability (based upon the throughput accounting principles incorporated in the simulation model) and delivery/customer service was achieved. Again it must be stressed that the period review of profitability helps (in conjunction with consideration of marketing issues) to identify promising changes to the product mix, which may then be evaluated by means of simulation. Simulation does not provide optimum solutions - it supports the decision-making process by quantifying the potential of discrete alternatives and helps therefore to identify good/acceptable policies. The capacity implications and the cost of support activity which would be associated with the determined policy are established via the software for structured project management. Problems in relation to the capacity or cost of the support activity may necessitate change in the policy for product mix and further simulation.

This use of simulation to provide a basis for establishing the most effective use of capacity in the medium term was determined to be the most important application by the company. PFK plan to use simulation also as a means of evaluating the potential effect of introducing new plant and new products in the long term. It is planned also to build direct links between the MRP system and the simulation model so as to provide more realistic short term capacity planning, in the implementation of medium term policy.

A complication associated with the introduction of alternative process routes is that the costs assigned to particular products may vary with the particular process route employed. The company have decided that product profitability will be defined in terms of the "preferred" process route and that any difference between actual cost and cost associated with the preferred route will be used as a "trigger" to consideration of investment in new plant.

8.8 IMPLICATIONS FOR DESIGN AND PROCESS PLANNING

Product designers and process planners may now be provided with access to the new costing structure, by means of appropriate interfaces e.g. cost estimation based upon "feature analysis". Costing of alternative process routes may now be an integrated feature of the computer based system for process planning. Information relating to the cost of activities and the "drivers" associated with those activities is now available to designers and process planners and influences their decision-making.

8.9 SUMMARY AND CONCLUSIONS

At the strategic level there is increased confidence in the company's ability to develop medium and long term policies for: product mix, product development and capital expenditure, appropriate to their objective of expansion and diversification into more profitable markets.

At the operational level the company has greatly increased confidence in the accuracy of estimates used to support decisions in the areas of: product design, process planning, product pricing and investment.

This exemplar has provided an insight into the potential benefits of a revised approach to the use of cost information. It is accepted that implementation of the model in a practical industrial situation will be a major undertaking and will raise many new problems e.g. integration of financial reporting, integration of software systems and training. The issue of further development is addressed in section 10.0.

9.0 CONCLUSIONS

A comprehensive review and analysis of the way in which cost information is used as a basis for decision-support in AMT environments has been carried out, emphasising in particular the areas of product design, process planning and manufacturing systems. The work provides substantial support for the hypothesis that "Traditional approaches and practices with respect to the determination, communication and use of cost information, do not provide a satisfactory basis for decision-support in today's highly competitive and technologically advanced markets". Analysis of the information provided by the review reveals that the underlying causes of this unsatisfactory situation include:

- The widespread use of cost accounting systems which were designed to meet stock valuation requirements for financial reporting systems.
- Emphasis, on the part of the accounting function, on the provision of financial reports concerning period profitability and cash flow, at the expense frequently of providing cost information appropriate for decision-support in the areas of product design, process planning and manufacturing systems engineering.
- Narrow perspective of engineers with respect to consideration of cost issues. This is the result largely of narrow, technically orientated education and training which tends to promote an emphasis upon technical innovation and excellence, at the expense of "business" considerations. Functional barriers result frequently in isolation of the functions of product design and process planning from cost information systems and accountants.

- External pressure on companies (shareholders etc.) to achieve short term objectives with respect to profitability - hence the apparently disproportionate amount of time spent on financial reporting as opposed to decision-support.
- Lack of an appropriate model to provide an effective platform for the integrated application of new concepts, new techniques and IT.
- Lack of awareness and understanding of new concepts and approaches for the provision of decision-relevant cost information.

A credible conceptual model has been developed in line with the objective set out in 1.2.2. While the model taken as a whole represents a relatively radical departure from traditional approaches to the use of cost information, its structure is such that the various elements are capable of being implemented on a selective/phased basis.

The major contributions to knowledge provided by the work are as follows:

- Identification of the factors responsible for the inappropriate use of cost information in the areas of product design, process planning, manufacturing systems design and operations management.
- Identification of the relevance and the implications of "new" concepts and approaches for cost accounting, organisation structure and the use of IT, for practical decision-making.
- Development of a conceptual model for the integrated application of appropriate concepts, approaches and techniques to support organisations in the effective implementation of cost oriented decision support.

At a more detailed level innovative approaches have been developed for :

- The use of discrete event simulation of manufacturing systems, as a means of generating "business" oriented measures of performance, in support of integrated approaches to decision-making.
- The use of "structured" project management techniques and activity based costing principles to provide the basis for an integrated approach to the assignment of support activity costs.

A major challenge associated with the work was that of maintaining the breadth of view, across the engineering, accounting and operations management functions, necessary to develop a model capable of providing a focus for the integration of modern approaches and techniques (see section 1.2.2). The required breadth of view was maintained and is reflected in the scope of the conceptual model.

An important objective of the research was concerned with the identification of further work at the "detail" level, to support development and implementation of the concepts, techniques and approaches comprising the model. Several specific projects have been identified and are discussed in 10.0.

The objectives set out in 1.2 have been satisfied and a conceptual model has been provided to aid companies in identifying and implementing modern approaches to the use of cost information. The model provides a "platform" for continued research at a more detailed level.

10.0

RECOMMENDATIONS FOR FURTHER WORK

The scope for development of the model at the detail level and for its practical implementation is considerable. It is envisaged that research/development projects will be initiated in some or all of the areas listed below and it is encouraging to note that interest in collaboration has been expressed by two manufacturing organisations.

- Linking of activity based costing to computer aided design.
- Integration of long and medium term decision-making with respect to: investment analysis, manufacturing system design, product design, product mix, etc. by means of discrete event simulation, incorporating automatic "business" oriented analysis.
- Development of cost criteria to support "reactive" process planning.
- Linking of activity based costing principles to organisation structures and software for "structured" project management, to provide integrated approaches to assigning and controlling the cost of support activity.
- Development of revised approaches to product costing based on the idea of the "product life cycle cost account"

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APPENDICES

APPENDIX 1

1.1 Information Requirements For Interviews And Questionnaire

1.2 Questionnaire.

APPENDIX 1.1

Questionnaire - Structure

- Respondents Name.
- Job Title.
- How many with same job title.
- To whom does respondent report.
- Responsibility for other staff.
- How long in current job.
- Previous jobs and training.
- Respondents description of job.
- What are seen as major functions/responsibilities.
- What objectives does respondent have in mind today.
- What objectives have been pursued over the last six to twelve months.
- What are the major decisions taken in the course of a working day.
- People communicated with on a regular basis.
- What are the major information flows in/out.
- How does the respondent measure his/her performance.
- How does the respondent's superior measure the respondent's performance.
- Are any decisions based primarily on consideration of cost - if so where is the information acquired and how is it used.
- Does the respondent consciously make what he/she feels are poor decisions in order to satisfy the firm's costing/performance criteria.
- Does the respondent understand the firm's costing/accounting system, does he/she think it is accurate, does he/she think it is helpful.
- Is the respondent familiar with any of the following terms: standard costing systems, full cost systems, marginal cost systems, activity based costing, throughput accounting.

- Has the respondent had any education/training with respect to basic accounting/costing principles and techniques.
- Does the respondent believe that an improved knowledge of the firm's costing systems would help him/her to make better decisions.
- Does the respondent use any computer based system for information/analysis e.g. spreadsheet, data base, MRP, accounting, process planning, CAD, etc.
- What does the respondent believe could be done to improve the effectiveness with which they carry out their job e.g., organisational change, information/information systems, computer support, etc.
- Does the respondent understand the meaning of the terms: corporate strategy, strategic objectives and manufacturing strategy. If so can the respondent define the current manufacturing strategy and objectives for his/her firm.
- How do the decisions made by the respondent help in the achievement of objectives.
- To what extent does the respondent have contact with the functional areas of: product design, process planning, manufacturing systems design, production planning/scheduling, marketing/sales, purchasing and accounting.

Has the respondent had any involvement in capital expenditure. If so, in what capacity. How was the investment justified, who was responsible for the proposal to senior management, was there a post implementation audit, did the expenditure improve the effectiveness of the business (if so - how).

1.2 QUESTIONNAIRE

Respondent:

Company:

Job title:

How many with same job title:

To whom do you report:

Responsibility for other staff:

How long in current job:

Previous jobs / training:

Respondents description of job:

What do you see as major functions / responsibilities:

What objectives have you sought / satisfied over the last 10 days and over the last 6 months:

What sort of decisions do you make in the course of a day:

Identify the people you deal with on a regular basis:

Information from	Information to

What information do you give / receive and what is done with it:

How do you and the person to whom you are immediately
responsible, measure your performance:

e.g. 1 How would you identify a good engineering design solution as opposed to a bad one.

e.g. 2 How would you identify a good process plan as opposed to a bad one.

e.g. 3 How would you identify a good shop floor schedule as opposed to a bad one.

What are your most important sources of data and how are these data bases established accessed and shared:

Are any of your decisions based on cost considerations. If so where do you acquire the information and how do you use it:

Do you consciously make what you feel are poor decisions in order to satisfy the firm's costing / performance criteria:

Do you understand the firm's costing / accounting system. Do you think it is accurate. Do you think it is helpful:

Are you familiar with any of the following terms:

Standard Costing System
Full Cost System
Marginal Cost System
Activity Based Costing
Throughput Accounting

Has your education/training included basic appreciation of accounting/costing principles and/or project evaluation:

Do you believe that an improved knowledge of the operation of the firm's costing systems would help you to make better decisions:

Do you use any computer based systems for information or analysis e.g. MRP, Data Base, Spreadsheet, accounting etc. Are these systems useful, could they be improved:

What could be done to improve the efficiency with which you carry out your job, i.e. in terms of: organisation, communications, your authority, computer support systems, etc.:

What do you understand by the term corporate strategy or manufacturing strategy.

What do you understand to be the current manufacturing strategy of your organisation (alternatively describe the corporate objectives):

How do the decisions you make on a daily basis help in the achievement of these objectives:

To what extent are you involved with other functional areas - in particular:

Product Design

Process Planning

Production Engineering

Manufacturing System Design

Production Planning / Scheduling

Marketing / Sales

Purchasing

Accounting

To what extent are you or have you been involved in capital investment decisions / projects

1) In what capacity i.e. project leader

team member

supplier of service

supplier of information

2) Who was responsible for investment proposal i.e. request for capital expenditure:

3) Who was responsible for project implementation:

4) Was there a post implementation audit:

5) What were the accounting/operational/performance results of implementing the scheme. Was it/is it a success:

APPENDIX 2

Application Of Multiple Linear Regression Using Microsoft EXCEL for WINDOWS.

Multiple Linear Regression - Example

This example demonstrates the principle of MLR and illustrates the ease with which the technique may be applied to the estimation of product cost, in ***appropriate*** situations i.e. where linear relationships exist between the independent variables and product cost and where the cost assigned to particular products during their manufacture is sufficiently accurate. The latter issue is discussed in sections 8.3 and 8.7 of the thesis.

The example relates to the manufacture of welding manipulators/fixtures by a company which specialises in the manufacture of such products. The company believe that the parameters of: table diameter, maximum weight of component and number of axis of movement are the major influences on cost. Information relating to the actual cost associated with 30 manipulators, manufactured over the last 9 months, is provided in Table A2.

Given the data provided in Table A2a. the regression coefficients and statistics shown in Table A2b. and the comparison between actual and predicted costs, shown in Figure A2, may be determined quickly and easily by means of the REGRESSION/LINEST functions within EXCEL. The statistics provided by EXCEL enable evaluation of the suitability of the data for use as a basis for cost estimation. In this example the equation for cost estimation is determined to be:

Cost (£) = [Table Diam. (m) * 236 + Max. Comp. Wt. (kg)* 0.445 + Num. Axes * 76.8] + 195

The coefficient of determination (a measure of how closely the regression line fits the historical data) is given as 0.993, indicating a good fit and the standard error for a 90% confidence level is given as £52.9.

TABLE DIAMETER (metres)	MAXIMUM WEIGHT OF COMPONENT (kg)	NUMBER OF AXES OF MOVEMENT	ACTUAL COST (£)
1.0	250	3	810
1.0	290	5	950
1.1	240	3	799
1.2	230	4	890
1.2	400	4	910
1.3	350	5	990
1.3	290	3	830
1.3	370	5	1190
1.4	400	4	990
1.5	620	4	1101
1.7	840	4	1280
1.7	890	3	1190
1.8	900	5	1420
1.8	890	3	1200
1.9	1000	5	1385
2.1	1000	4	1400
2.1	2800	3	2298
2.3	1500	5	1700
2.5	1500	3	1680
2.5	1180	4	1630
2.5	1053	5	1640
2.6	2800	5	2490
2.6	2050	3	1940
2.7	1800	5	2040
2.8	2000	3	2030
2.8	3600	3	2600
2.8	2500	4	2300
2.9	3800	5	2900
3.0	3500	4	2750
3.0	2020	5	2200

Table A2a. Historical Cost Data For Welding Manipulators/Fixtures.

SUMMARY OUTPUT

Regression Statistics

R Square Coefficient of Determination	0.993726475	
Standard Error 90% Confidence Level	52.95835932	
Observations	30	
	Coefficients	**Standard Error**
Intercept	195.3073548	56.684058
Variable 1 (Diam.)	236.1442625	28.67476374
Variable 2 (Comp. Wt.)	0.445086686	0.017730039
Variable 3 (No. Axes)	76.81877122	11.76688558

Observation	**Predicted Y**	**Residuals** (Actual-Predicted)
1	773.1796025	26.82039755
2	944.6206123	5.379387676
3	792.3431618	6.656838156
4	888.3254925	1.674507548
5	963.9902291	-53.99022905
6	1042.169092	-52.16909223
7	861.8263486	-31.82634864
8	1051.070826	138.9291741
9	1011.219082	-15.21908155
10	1132.752579	-31.7525787
11	1277.900502	-4.900502098
12	1223.336065	-33.33606517
13	1405.038901	14.96109928
14	1246.950491	0.049508575
15	1473.161996	-88.16199556
16	1443.572077	-14.57207684
17	2167.90934	130.0906598
18	1790.163044	-3.163043506
19	1683.754354	1.24564643
20	1618.145385	11.8546147
21	1638.438147	1.56185259
22	2439.619014	54.38098608
23	1952.166457	-12.16645706
24	2018.146754	21.85324573
25	1977.140975	52.85902473
26	2689.279673	-89.2796727
27	2276.503089	23.49691057
28	2955.548979	-55.54897857
29	2768.818628	-18.81862783
30	2186.909104	13.09089608

Table A2b. Summary Of Regression Statistics.

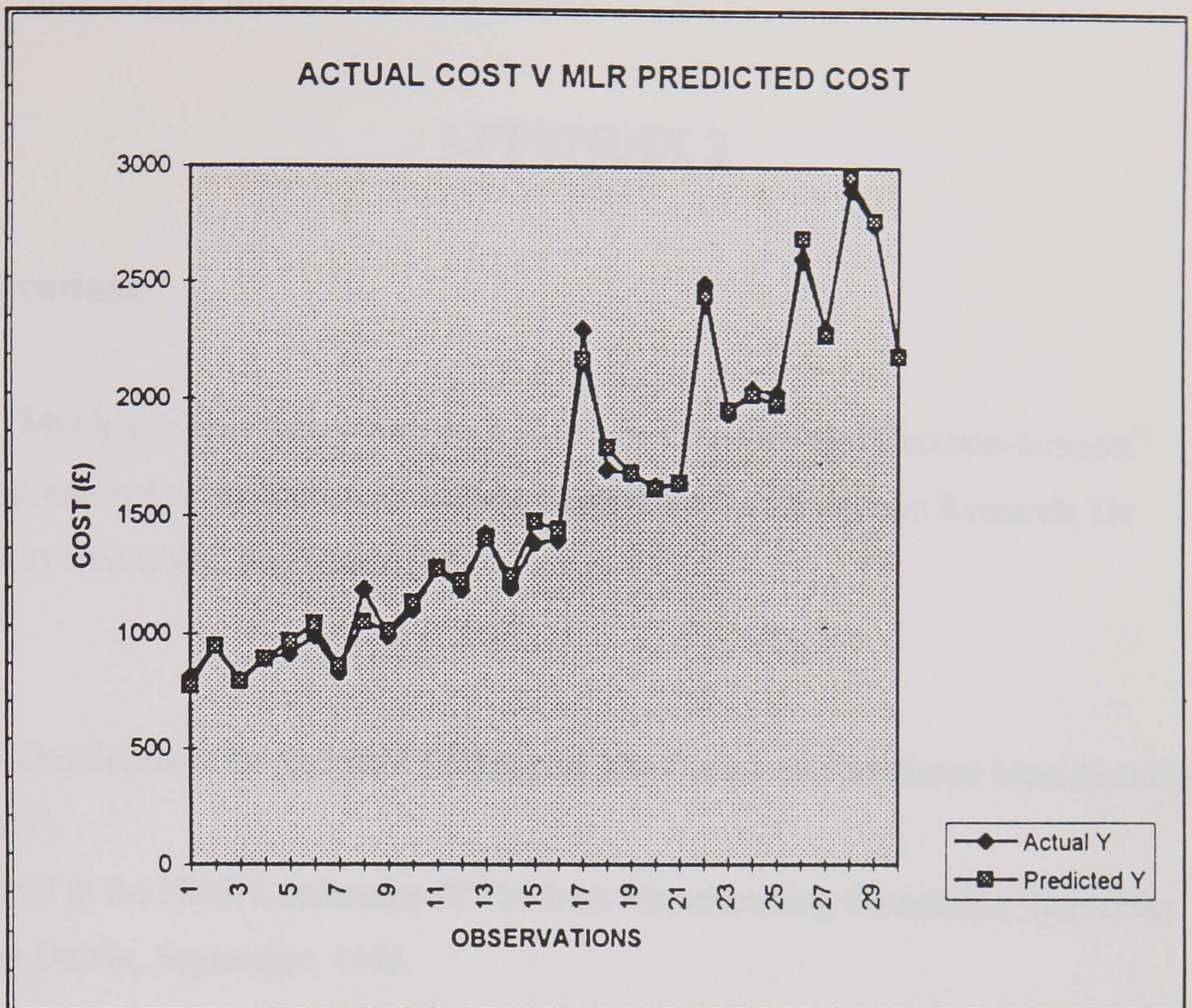

Figure A2. Actual Cost Versus MLR Predicted Cost

APPENDIX 3

Publications

A3.1 "Multiple Linear Regression As A Basis for Cost Oriented Decision-Support".
To be presented at the Eleventh National Conference On Production Research, De Montfort University, September 1995.

A3.2 "Development Of Software To Support The Design Of Cell Based Manufacturing Systems".
Presented at the Ninth Conference Of The Irish Manufacturing Committee, University College Dublin, September, 1992.

A3.3 "Automatic Generation Of Business Oriented Performance Measures From Manufacturing System Simulation".
To be presented at the Eleventh National Conference On Production Research, De Montfort University, September 1995.

A3.1

MULTIPLE LINEAR REGRESSION AS A BASIS FOR COST ORIENTED DECISION SUPPORT

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and

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Despite the availability of powerful, "user friendly" facilities for multiple linear regression (MLR) within modern spreadsheet software, the technique appears to enjoy little practical application in areas such as product design, process planning and operations management. This paper makes the case for increased use of MLR, as a basis for stand alone systems for "rough cut" time and cost estimation in the areas of product design and process planning and describes a practical application within British Aerospace. The practical limitations of the approach are discussed and the potential for links with costing systems based upon the principle of "activity based costing" is identified. The work is part of a broader programme of research, concerned with the development of a model for the use of cost information in AMT Environments.

1.0 Introduction

Multiple linear regression (MLR) is a powerful technique which may be used to quantify the contribution of particular parameters with respect to some overall parameter e.g. the individual contributions of price, promotion expenditure, number of outlets and hours of sunshine/day upon the sale of soft drinks in any given month. MLR has been used extensively as part of scientific methodology but has received relatively little practical application in the areas of business and engineering. The survey by Drury, Braund, Osbourne and Tayles suggests that only 10% of companies use MLR "sometimes" and that only 3% use it "often" or "always", for costing and sales estimation. The survey was directed primarily at the accounting function of the organisations covered, rather than the engineering and operations management functions. Reference to collaborating organisations in the author's current research, published literature and the author's experience suggests even less awareness and application of MLR on the part of operations managers and engineers. MLR appears to be a technique which engineers in particular perceive as relevant to experimental analysis rather than to more general day to day activity. There appears also to be extensive ignorance of the capability of modern spreadsheet software to support MLR and to provide the basis of systems for relatively accurate and realistic estimation of time and cost.

The application of MLR in business appears primarily to be associated with demand forecasting and the prediction of cost at relatively general, "aggregated" levels. Application of the technique at the detail level in areas such as product design and process planning appears to have been largely ignored. The exemplar application discussed in section 2.0 illustrates the potential for using MLR at the detail level for time and cost estimation and in section 4.0 the potential links with activity based costing are introduced and discussed. A comprehensive introduction to basic concepts and techniques for MLR based cost estimation is provided by Drury.

2.0 Use of MLR in Estimating Time/Cost of CNC Part-Programming.

British Aerospace (BAe), Chadderton have extensive capability for the design and manufacture of high quality tooling associated with the manufacture of complex products. In addition to manufacturing tooling for Chadderton and other parts of the BAe business Chadderton carry out sub-contract work for other companies, on a commercial basis. A special division (Chadderton Aerostructures) has been set up to facilitate operation of the new business and in this new commercial environment the accurate and timely estimation of manufacturing time and cost has become of increasing importance.

One of the most significant activities associated with tooling projects is that of CNC part-programming (an activity that in many companies is "lost" in the general assignment of overhead). Manual estimation of programming time/cost requires considerable time and effort on the part of manufacturing engineers, and is tedious in its nature. The company decided to assess the feasibility of implementing a computer based approach to speed up the operation and to release the manufacturing engineers for more productive activity.

Two basic approaches to computer aided estimating were available:

1. A detailed approach based upon the development of detailed algorithms for each element of programming activity, an approach likely to be expensive in terms of development time and cost.

2. A "rough cut" approach based upon MLR. This approach would be relatively cheap in terms of development time and cost and would be relatively easy to implement and operate.

The company decided that a pilot project using MLR and based upon the part programming requirement of wing "stringers" (see Figure 1) would be initiated. Stringers range from 300mm to 17m in length and there are over 100 stringers in a typical wing, each one being unique in length and thickness. The CNC programming associated with producing the stringers for a new or modified aircraft is significant . A spreadsheet (Lotus) was used to carry out MLR analysis on historical time and cost data associated with 58 stringers, using the variable parameters of stringer length and the number of "ribs" in contact with the stringer. The resulting regression data provided a coefficient of correlation of 0.99 (i.e. a very good fit) and a standard error of 1.9 hours at the 99% confidence level. Given that the range of part-programming times was from 60 hours to 247 hours this was judged to be acceptable. The pilot system has been incorporated successfully into an integrated system for preparation of quotations and project management.

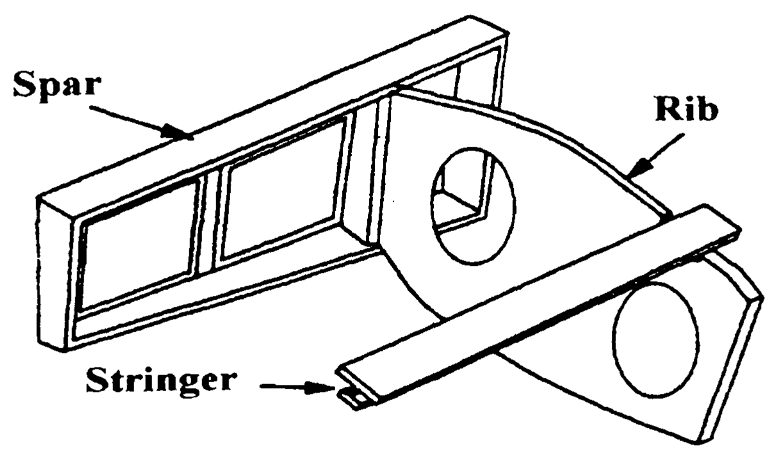


Figure 1. Airbus Wing Construction.

3.0 Issues Associated With The Implementation Of MLR

In some situations product or process variability is such that it is not possible to determine a set of coefficients which provides an acceptable level of correlation with established data. In such cases alternative approaches must be adopted.

By definition estimating systems which incorporate MLR are subject to errors caused by changes in cost structures over time. Such changes may be the result of inflation in material costs, inflation in labour rates, changes in process planning, changes in technology, etc. It is necessary therefore to make provision for the periodic revision of the data base of historical data and/or to make some provision for weighting of the coefficients of regression towards more recent data. The ease with which regression data may be stored, manipulated and analysed within modern spreadsheet software makes the incorporation of measures for maintaining the validity of the historical data, on an ongoing basis, a very practical proposition. The advantages offered by regression based approaches are:

- The simplicity and speed with which pilot systems may be set up and evaluated.
- The inherent ability of such systems to be updated as new information concerning actual data is included in the data base and used to refine the regression coefficients (subject to the reservations identified previously).

4.0 Links Between MLR And Activity Based Costing (ABC)

In the exemplar ABC structure illustrated in Figure 2 CNC part-programming is identified as one of the "activity" related overheads. In the simplified structure illustrated an averaged cost of £100 is assigned to products which consume the activity of part-programming. In a more realistic situation it may be desirable to estimate/report a more realistic assignment of programming cost for a given product. Given the nature of activity in the process planning function i.e. time spent on particular programs may be fragmented and therefore difficult to record, it may be appropriate to use an estimated value for both the cost estimate and the cost allocation (although the latter would pose some problems with respect to the updating of regression coefficients). This being the case appropriate cost drivers for the activity of CNC part-programming must be established. The exemplar approach suggested in section 2.0 could form the basis for fulfilling this need. MLR may form the basis for evaluating particular parameters as determinants of activity consumption in other areas of the ABC cost structure on a continuous basis and so help to maintain the integrity of the system.

The research has stimulated the introduction of pilot schemes for cost estimation based upon MLR in two companies. In each case the primary motive of the company was to reduce the amount of time spent by manufacturing engineers in providing estimates of cost for quotation purposes. An additional and potentially more valuable "spin off" was an increased awareness, on the part of the manufacturing engineers concerned, of the factors which determine the consumption of particular activities and hence cost. The increased understanding of what are effectively "cost drivers", in the context of ABC, increases the cost awareness of manufacturing engineers, design engineers and other personnel involved in the design and implementation of estimating systems based upon MLR. It provides also a sound basis for introducing the concept of ABC to non-accounting personnel.

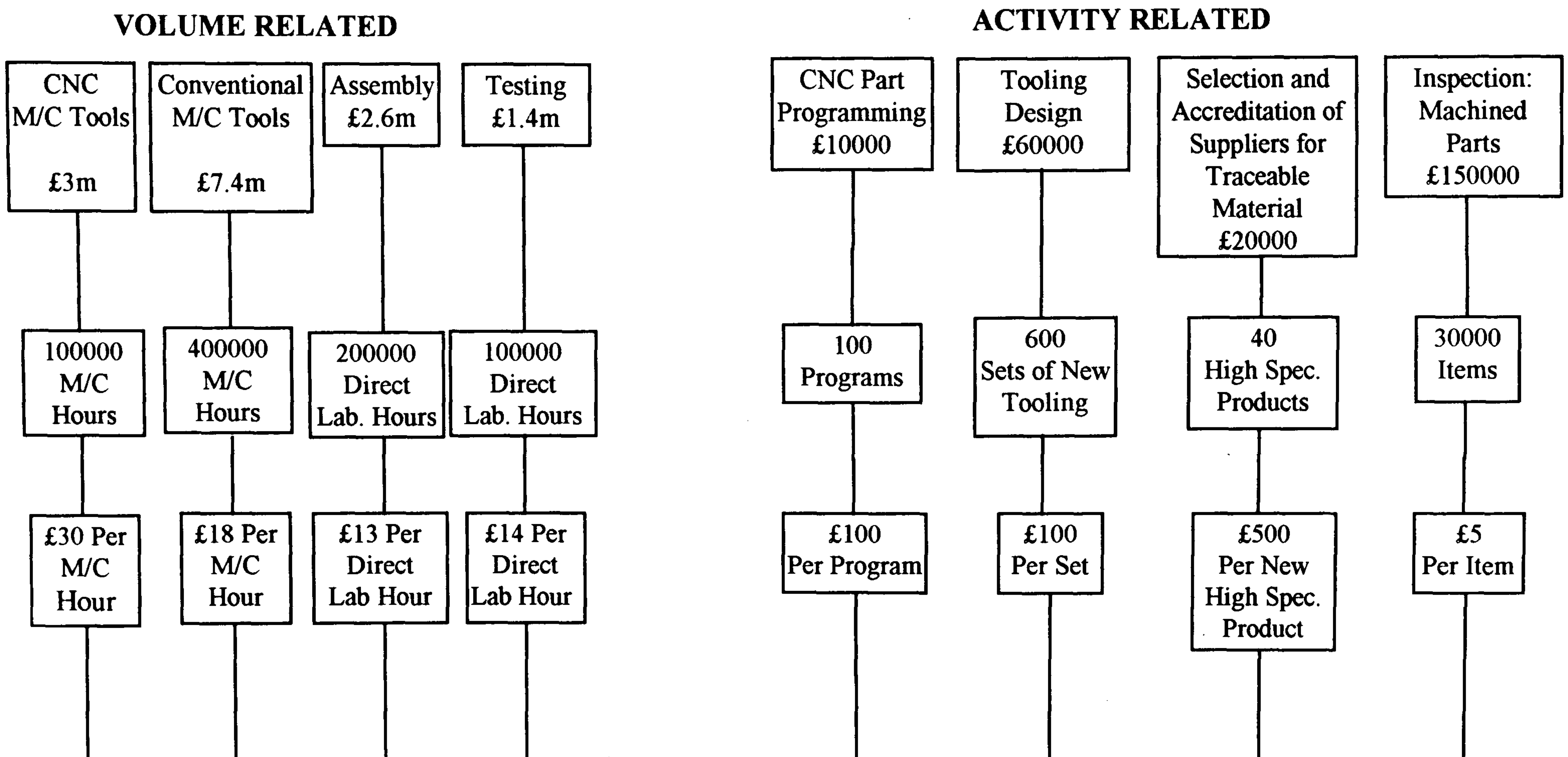
5.0 Conclusions

Multiple linear regression may in appropriate circumstances provide the basis for effective computer based estimation of time and cost, with a minimum of expense in terms of software and specialised expertise. Such systems may operate on the basis of stand alone rough cut estimation of time and cost to support decision-making in areas such as product design and process planning, or may operate as part of more comprehensive systems e.g. activity based costing systems. The development of simple systems by engineers, operations managers and other non-accountants provides an added benefit in that it acts as a focus for providing increased awareness of the major drivers of cost and an awareness of the relevance of activity based costing.

References

Drury, J. C. Braund, S. Osbourne, P. and Tayles, M. 1992, A Survey Of Management Accounting Practice In UK Manufacturing Companies, *Certified Accountants Educational Trust.*

Drury, J. C. 1993, *Management And Cost Accounting* - Third Edition, Chapman and Hall, P642-653.



Product A repeat batch (50)	Not Applicable	(51)x(18) [inc. set up] £918	(50)x(13) £65	(50)x(14) £700		Not Applicable	Not Applicable: [standard tooling]	Not Applicable	Not Applicable: [no off M/C inspection]
Product B one off batch (50)	(51)x(30) [inc. set up] £1630	Not Applicable	(50)x(13) £65	(50)x(14) £700		£100	£100	£500	(50)x(5) £250

Total Batch Cost Product A £1683
Total Batch Cost Product B £3051

Figure 15 Product Costing Using an ABC Approach.

A3.2

DEVELOPMENT OF SOFTWARE TO SUPPORT THE DESIGN OF CELL BASED MANUFACTURING SYSTEMS.

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Polytechnic of Huddersfield

Abstract

The introduction of cell based manufacturing systems is an important element in the strategy of many organisations, in the pursuit of more effective and profitable operation of their business. The effective design, implementation and control of such systems requires the adoption of appropriate approaches to family/cell design and configuration, together with appropriate methodologies for planning and control.

This paper describes the development of an integrated approach to cell design, the approach comprising two elements:

1) "Rough Cut" grouping of parts and cell configuration, using spreadsheet based software for production flow analysis and "rough cut" capacity analysis.

2) Detailed evaluation of family/cell configurations, based upon discrete event simulation (WITNESS).

The work is in collaboration with David Brown Vehicle Transmissions Ltd. and has benefited from the help and advice of Mr. R Bailey and Mr. D Sheard.

1.0 Introduction

In recent years we have seen a large number of changes taking place within manufacturing industry. Companies are increasingly under pressure to improve their effectiveness and become more responsive to market forces. As product life cycles become shorter and variety increases there is increasingly a need for companies to become more flexible in their response.

A large proportion of manufacturing industry is faced with the same problems: long lead times, high work in progress and poor delivery performance. David Brown Vehicle Transmissions (DBVT) is addressing these problems currently and is involved in a review and reorganisation of its manufacturing facilities. A major part of the reorganisation involves a move from traditional "functional" machine layouts to "cell" based systems. This work is being supported by the Polytechnic as part of a Teaching Company Programme.

Having developed successfully the first production cell, designed to deal with specific areas of the business, the next step was to re-design the main "Park Works" manufacturing facility, which comprises some 120 machine tools and associated support. The re-design of such an extensive production facility is a complex and time consuming task and it was consideration of the amount of time and effort required to complete the work which highlighted the need for computer based support for manufacturing system design and evaluation.

The Teaching Company Programme provided an excellent collaborative link between DBVT and the Polytechnic, providing access to the expertise necessary for the development of appropriate software. The actual software was developed by a final year student as his individual project.

2.0 System Concepts

The Production Flow and Configuration Evaluation Software (PFCE) is based upon the use of King's Algorithm (King, 1979) to establish potential part families and cell configurations. King's Algorithm uses part routing information and processes it in such a way as to show parts requiring similar machining processes to be grouped together, in a two dimensional matrix. This element of the system is thus able to provide information with respect to potential part families and machine groupings. The system identifies also the rough cut capacity requirements for particular part families and their associated machine groupings (PACKS) on the basis of the period demand for each part.

The use of King's Algorithm and rough cut capacity planning is limited in that it does not take into account the sequence of machining operations required to produce the product and is unable also to take into account the affect of batch quantities and production schedules. A solution to this problem is provided by the use of discrete event simulation to model, and analyse promising configurations. Simulation models may take considerable time to construct but have the advantage of allowing dynamic analysis of models to take place, at a relatively detailed level. It was decided therefore that software based upon King's Algorithm, in conjunction with rough cut capacity calculations, could form the basis for direct input into a discrete event simulation model, allowing detailed analysis to be carried out.

3.0 System Development

The PFCE system began with the development of a series of spreadsheets to apply King's Algorithm to part machining information and make rough cut capacity calculations. It was decided for various reasons that the system would be based upon the EXCEL spreadsheet package, operating in a WINDOWS environment. The inputs to the system are in tabular form, part details being stored in a series of up to thirty tables each of which gives details of the machining operations required to manufacture the part, from raw material to finish machining (see Table 1). Another table is used to store details of the machines required to perform these operations (see Table 2). The data in this latter table is used mainly in the rough cut capacity calculations, carried out after the identification of initial part families/cell configurations (see Table 3). The information contained in the part tables is transferred to a King's Algorithm matrix where part numbers are shown on the horizontal axis and their associated operations codes (N.B. it is assumed that operations are specific to a particular machine type and that machines perform one operation only) are shown on the vertical axis. This matrix holds the machining time data for the corresponding parts and machines, which is copied to another matrix (of the same dimension) where the spreadsheet co-ordinates holding the machining times are replaced with 1's and the spaces are left blank. This latter matrix may be described as a matrix of "occurrence" (see Table 4). King's Algorithm is applied to table 4 by means of a weighting table which sorts the horizontal and vertical axes. This results in the 1's in the matrix being grouped together so as to indicate potential part families and their associated cell configurations (see Table 5). The groupings of parts and machines may then be selected (manually so as to allow the exercise of judgement on the part of the cell designer) as possible part family/cell configurations and copied to another table ready for transfer to the simulation model. The overall concept of the system is illustrated in Figure 1.

The simulation system used was AT&T's WITNESS for WINDOWS. The information generated by the application of King's Algorithm, the rough cut capacity calculations and the family/cell selection is transferred into the simulation software and is used to generate, automatically, a model comprising up to thirty machines. The transfer of this information was initially carried out manually by entering it directly to the WITNESS software, the system was however developed further to allow for the automatic transfer of data from \EXCEL into WITNESS via a word processor (WORD for WINDOWS). The data is transferred into WITNESS in a "command" file, which is used to set up the model and a "part" file which holds the part process data. The word processor is used to make some minor alterations to the syntax and to remove illegal characters, thus making it suitable for execution within WITNESS. In addition it is possible at this stage to take account of batch sizes and production schedules. This is done by duplicating batches of the parts being processed and placing them in the order in which they are to be fed into the simulation model. Scheduling data is derived from the existing MRP system.

The information transferred from EXCEL into WITNESS is used to develop a large model showing each of the cell configurations derived from the production flow analysis and the rough cut capacity analysis. Each suggested cell configuration may then be assessed individually, by running the simulation and analysing the resulting reports. The reports give an indication of factors such as: machine utilisation, throughput times and numerical values of work in progress, indicating potential bottlenecks and the need for duplicate machines. The part family/cell configuration may then be modified to take into account potential problems highlighted by the simulation.

4.0 Conclusions

The integration of production flow analysis, rough cut capacity analysis and discrete event simulation, by the development of appropriate software, provides effective support for the design and analysis of cell based manufacturing systems . The approach and software is capable of further development and will form the basis of continued research.

One of the difficulties associated with the application of the system lies in the evaluation of the results provided by simulation of various part family/cell configuration options. It is difficult to rank alternative options effectively, given the range of parameters to be considered. With this in mind research is being carried out in an effort to establish an appropriate approach to the formulation of a cost oriented approach to the analysis of simulation results. Data from simulation models could eventually be evaluated automatically by the integration of such an approach into the PFCE software.

References

King JR (1979), Machine-Component Group Formation in Group Technology, 5th International Conference on Production Research, Amsterdam.

Table 1

Part No 7 AGsr 3			
No.	Op Code No	Setup	Cycle
1	101	79	22
2	107	89	34
3	112	100	22
4	113	111	44
27			
28			
29			
30			

Part No 8 AGsr 4			
No.	Op Code No	Setup	Cycle
1	112	44	23
2	113	60	23
3			
4			
27			
28			
29			
30			

Table 2

Machine Details			
Machine type	M/C Qty	M/C Time Avble	Op Code on M/C
M1	1	10800	101
M2	1	10800	102
M3	1	10800	103
M4	1	10800	104
M27	1	10800	127
M28	1	10800	128
M29	1	10800	129
M30	1	10800	130

(Simulated system tables)

Group 1									
Op Code No.	Part No.	Qty	Time for Op	Total Time Req	M/C	Qty of M/Cs	Cap of M/C	% Used	M/C Util %
111	ASecap	16	34	636	M11	1	108000	0.589	
	AShng1	16	45	1072				0.993	
	STwhl2	5	19	155				0.144	
	STwhl5	5	8	74				0.069	2.30
110	ASecap	16	44	824	M10	1	108000	0.763	
	STwhl5	5	21	164				0.152	1.61
103	ASecap	16	23	728	M3	1	108000	0.674	
	AShng1	16	21	608				0.563	
	STwhl2	5	19	175				0.162	2.02
102	ASecap	16	34	1024	M2	1	108000	0.948	
	AShng1	16	33	840				0.778	2.41

Table 3

Table 4

KINGS ALOGRITHM

OP CODES

Op Code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	Part Number																								
101						1	1																		
102			1	1																					
103			1	1																	1				
104	1	1															1		1	1			1		
105	1	1															1			1			1		
106									1	1	1	1		1	1	1						1			
107	1	1					1																		
108					1				1	1		1		1	1	1						1			
109					1				1			1	1		1										
110			1																					1	
111			1	1																	1			1	
112							1	1																	
113						1	1	1										1					1		
114									1		1		1		1										
999999																									
0																									
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Table 5

KINGS ALOGRITHM

OP CODES

	Part Number																								
Op Code	21	4	24	3	19	17	20	1	2	18	23	6	8	7	10	14	16	22	5	12	11	13	9	15	25
102		1		1																					
103	1	1		1																					
110			1	1																					
111	1	1	1	1																					
105						1	1	1	1		1														
104					1	1	1	1	1		1														
107								1	1					1											
101												1		1											
112													1	1											
113										1	1	1	1	1											
108															1	1	1	1	1	1			1	1	
106															1	1	1	1		1	1		1	1	
109																			1	1		1	1	1	
114																					1	1	1	1	
999999																									
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PFCE System Development Structure

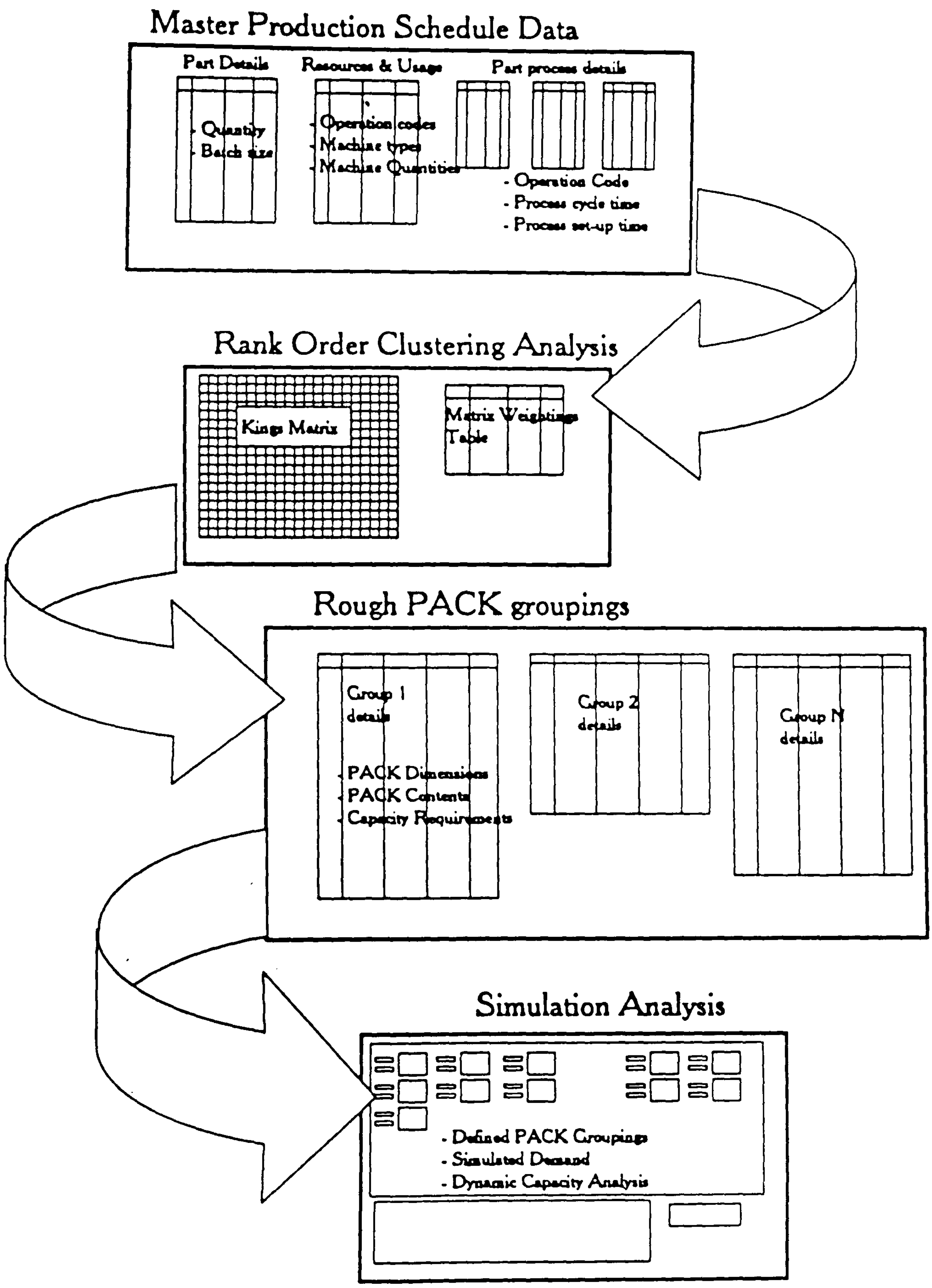

Fig 1

GENERATION OF BUSINESS ORIENTED PERFORMANCE MEASURES FROM MANUFACTURING SYSTEM SIMULATION

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and
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and
UMIST, M60 1QD

The use of discrete event simulation as an aid to the design and management of manufacturing systems has increased in recent years, along with advances in software for simulation. The emphasis in most simulation applications appears to be on "operational" rather than "business" measures of performance and it may be that an important dimension of decision support is being overlooked. This paper introduces the concept of "business" oriented measures of performance, with respect to manufacturing system simulation and describes the development of a methodology and software to demonstrate its application. The work is part of a broader programme of research, concerned with the development of a model for the use of cost information in AMT environments.

1.0 Introduction

Over recent years increasing use has been made of software packages for manufacturing system simulation. Simulation may provide valuable insights into the way in which existing or proposed manufacturing system configurations will respond to the demands created by different operational scenarios. Of particular interest is the response of manufacturing systems to variations in: level of demand, product mix, process planning and alternative approaches to scheduling. The availability of powerful computer based packages for manufacturing system simulation (e.g. WITNESS, SIMON/CINEMA, PCMODEL and SIMFACTORY) has increased the scope for application from relatively small, greatly simplified models to comprehensive models which are capable of close representation of real systems.

Modelling of manufacturing systems is an exercise carried out traditionally by operations research specialists or more recently (with the advent of specialised graphics oriented simulation packages such as AT&T ISTEL's WITNESS) by manufacturing systems engineers. The insights and performance measures provided tend to be "operations" oriented rather than "business" oriented - reflecting perhaps the perspective of the modellers. This view of the application of simulation is reinforced by reference to the standard reports provided by such packages; standard report information tending to be concerned primarily with issues of: capacity, utilisation and flow of materials. This provides direct measures of system efficiency but expert interpretation is necessary to provide insights into system effectiveness. Thus system evaluation tends to be carried out with no direct consideration of "business" oriented performance measures (e.g. cash flows and period profitability associated with particular system configurations and operating scenarios). An approach which made use of the software system's facility to customise statistical information and to import and export data, so as to provide more "business" oriented performance measures, would represent a more comprehensive base for decision-support. Such an approach may provide also a focus for collaboration and integration between engineering functions, operations management functions and business functions. The desirability of incorporating business oriented performance measures in an integrated approach to manufacturing system design and simulation was raised by the author in previous work, Babbs, Gilbert and Kelly (1992).

The generation of performance measures based upon cost information has been investigated as part of a research programme into the development of "a model for the use of cost information in AMT environments". It was decided, as part of the research programme, to devise a set of "exemplar" business oriented performance measures and to develop and demonstrate an effective methodology for extracting and communicating them from simulation models. The work is intended to demonstrate the potential for the approach and as such the range of performance measures introduced and the simulation model considered is limited in its scope.

The approach makes use of the facility within WITNESS to run a simulation in "experimental" (incremental) mode and to output statistical data to the spreadsheet package EXCEL for WINDOWS. Use is made also of the facility to export files from EXCEL to WITNESS, to provide a means of downloading various "part files" (effectively the product requirements for the production period to be simulated e.g. the schedule provided by an MRP system). Automation of the process of running a simulation, exporting data, analysing data and presenting results was facilitated by the use of "macro" routines in EXCEL. The latter was in line with a sub-objective of the work i.e. the provision of a "user friendly" "front end" to the WITNESS simulation software which would allow experimentation with respect to particular manufacturing system configurations to be made quickly and easily and allow access to personnel with limited knowledge of simulation. The approach taken was:

1. Devise an exemplar set of performance measures.
2. Devise an appropriate simulation model.
3. Develop a methodology, together with appropriate software (macro routines) for automatic importing, exporting, analysis and presentation of data from the simulation.

2.0 Business Oriented Performance Indices

The following are suggested as examples which may be of some value:

Work in progress: average value (all products/parts) and average value (by product/part type) over simulated period. Graphical representation of WIP statistics.
N.B. products/parts are assigned cost as they progress through the simulation (see 4.0), providing the potential to improve upon the relatively arbitrary valuation of stock applied in most current costing/reporting systems and simulation systems.

Sales Value and Profit: Sales value (all products/parts), sales value (by product/part type), profit (all products/parts) and profit (by product/part type) over simulated period.
N.B. Profit = (sales price - actual cost [derived from simulation]). This provides the potential for improving the visibility of profit as a direct factor in system design and operation.

Saleable Products/Parts: % Saleable products (all products/parts) and % saleable products (by product/part type) over simulated period.

N.B. Saleable products/parts are defined as products/parts having a due date within say 2 weeks or less of actual completion. The combination of this index with that of "sales value and profit" provides the potential for assessing period profitability in terms of actual cash flows rather than the "paper" based profits which may be associated with producing to long term stock. This may be of value when used in conjunction with throughput accounting approaches.

Tardiness: Average tardiness (all products/parts), average tardiness (by product/part type), maximum tardiness (all products/parts) and maximum tardiness (by product/part type) over simulated period.

N.B. Tardiness is defined as the difference between the date of completion of a product/part and the date of completion required to provide delivery on time when the former is later than the latter (i.e. a measure of delivery performance and customer satisfaction).

3.0 Simulation Model

A simplified representation of a typical manufacturing system was chosen (see Figure 1) as the basis for demonstrating the provision of one of the business oriented measures, i.e. the "dynamic" value of work in progress. A "family" of parts was devised, together with process routes and processing times in the various "functional" areas of the system. Distributions of demand and typical schedules for each part were specified and processing costs per unit time were established for each of the functional areas/departments.

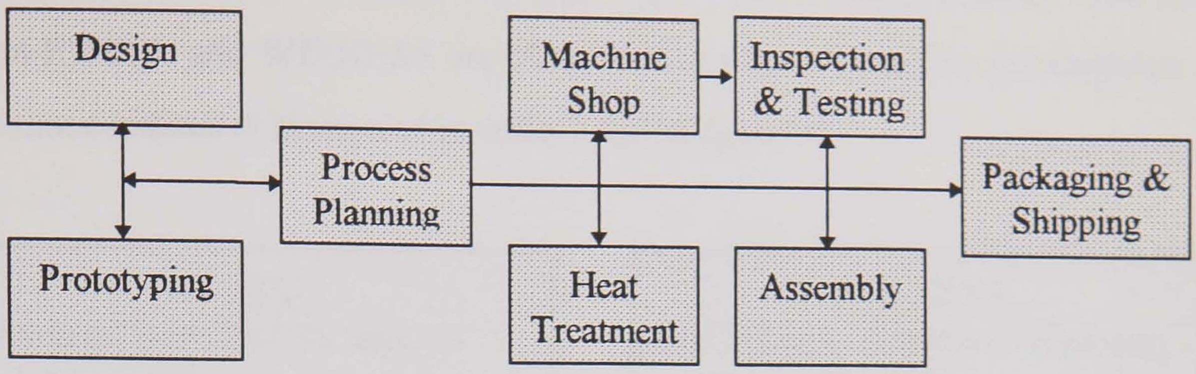

Figure 1. Simplified Representation of Manufacturing System.

4.0 Methodology And Software

The information described in 3.0 was used to develop a model within WITNESS, "action statements" (a method of initiating various functions and operations as particular parts progress through the simulation) being used to assign cost to particular parts as they progress through the system. Thus the build up of a more realistic measure of the cumulative cost associated with a particular part at a particular point in time could be determined. This provides for greater accuracy than methods based upon average values for parts and provides an ability to take into account the actual process route used to manufacture a particular product (where alternative process routes are possible within the model).

Within the WITNESS simulation software exists the option to run a particular model in "experimental" mode i.e. to run the simulation for a specified number of time increments, to allow for the capture of status information at particular points in the overall period of the simulation. This procedure together with appropriate "action" statements makes the collection of "dynamic" information feasible and it was by this means that a measure of the "real" value of work in progress over time was achieved. Editing of product/part data, together with the import and export of data within WITNESS was controlled by macro routines within EXCEL. Macro routines were used also to analyse data and display performance indices. The links between EXCEL and WITNESS are illustrated in figure 2 and the presentation of performance indices is illustrated in table 1 and in figure 3.

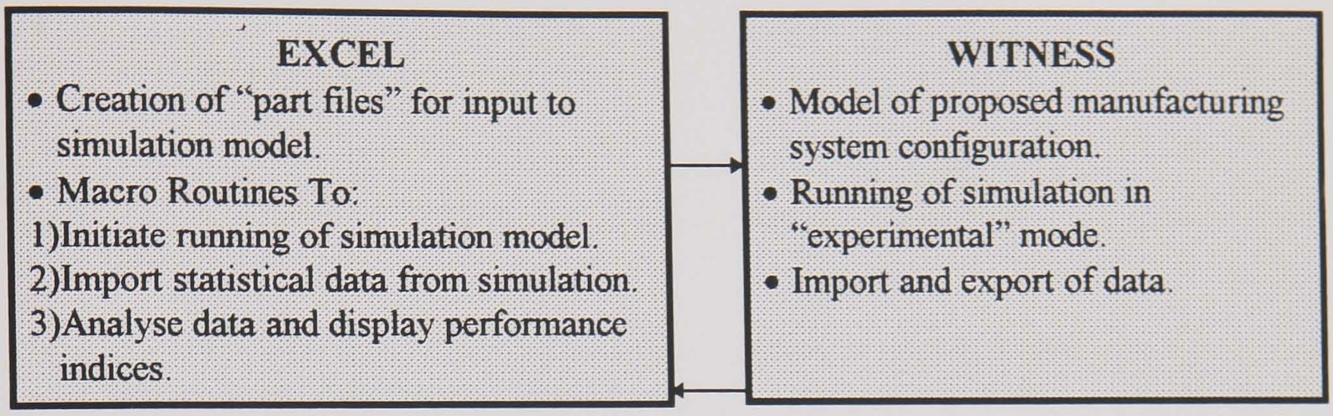

Figure 2. Links between EXCEL and WITNESS

5.0 Conclusions

Figure 3 together with table 1. demonstrates the potential for extracting business oriented performance measures from simulation models. The use of the spreadsheet (EXCEL) as a "front end" to the simulation software provides the potential for non-experts (with respect to simulation) to assess quickly and easily the business implications of particular patterns of demand and production schedules. Interfaces to the model may be provided as a basis for decision-support in various functional areas, so helping to reinforce the concept of integrated decision making focused upon a common database. One of the major potential applications of the approach is in identifying the likely affects of changes to product volumes/product mix, suggested by product review based upon "activity based costing".

References

Babbs, P. Gilbert, J. A. Kelly, P. F. 1992, Development Of Software To Support The Design Of Cell-Based Manufacturing Systems, *Ninth Conference Of The Irish Manufacturing Committee*, Dublin, P291.

Product A		**Product B**	
No. Shipped	95	No. Shipped	54
Sales Val. of Shipped	£9875	Sales Val. of Shipped	£2700
Current WIP (No.)	19	Current WIP (No.)	30
Average WIP (No.)	12.6	Average WIP (No.)	5.1
Current WIP (Value)	£1146	Current WIP (Value)	£800
Average WIP (Value)	£950	Average WIP (Value)	£100
Max. Value of WIP	£1090	Max. Value of WIP	£800
Min. Value of WIP	£108	Min. Value of WIP	£0
Product C		**Product D**	
No. Shipped	38	No. Shipped	15
Sales Val. of Shipped	£3230	Sales Val. of Shipped	£1050
Current WIP (No.)	20	Current WIP (No.)	0
Average WIP (No.)	3.4	Average WIP (No.)	2
Current WIP (Value)	£600	Current WIP (Value)	£0
Average WIP (Value)	£743	Average WIP (Value)	£20
Max. Value of WIP	£820	Max. Value of WIP	£300
Min. Value of WIP	£115	Min. Value of WIP	£115

Table 1. Output from WITNESS Simulation

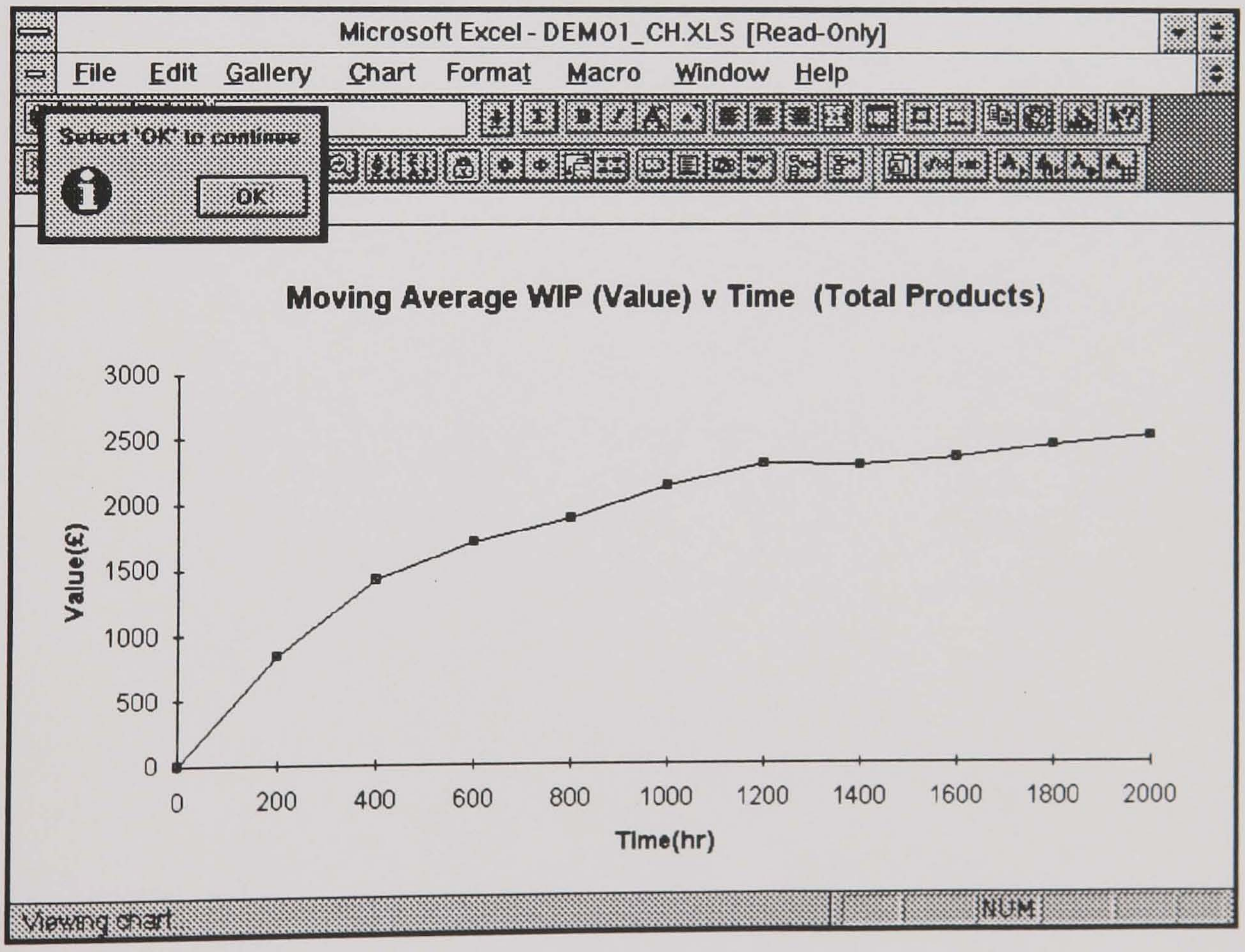

Figure 3. Example of Graphical Output from WITNESS Simulation.