Self-Evaluation of the Product Development Process

by

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ERRATA

Page numbers I-21 and I-31 have been left out of the page number sequence in Appendix I. Page I-22 should be numbered I-21, and so on.

ABSTRACT

An evaluation method for self-assessment of the product development process (PDP) has been developed and tested. A number of research issues have been identified and resolved. These are: the industrial approach, identifying important product issues (the determinants of profit), modelling the PDP, assessing activity effectiveness, and determining correlation factors. A solution to each of these issues was either tested by trials in industry, tested against current literature, or both. Test findings indicate that the designed solutions meet requirements.

Trials of the whole evaluation method at industrial sites indicate that the method has attained the primary objective of the research project. Namely, to provide companies with a method to enable them to assess for themselves the effectiveness of their current or proposed PDP. It is a quantified method that forces company practitioners to think about issues, so that results of the assessment can be used effectively to support argument for change. The method is non-prescriptive, accounts for the uniqueness of each company, and draws out and utilises company knowledge within a framework of current best practice in new product development (NPD) management. No other method achieves this objective in the same manner.

The following aspects of the evaluation method demonstrate more specific areas of innovation and novelty:

- The concept of determinants of profit (DoP) and their use as criteria against which the effectiveness of PDP activities is assessed.
- The generic model of the PDP meets all the identified requirements. It is novel in the way it is structured (i.e. activities and GEs at like level of abstraction) and the purpose it serves in the evaluation method i.e. to provide a non-prescriptive model, which provides a framework onto which the particular PDP activities of a company can be mapped to produce a company specific PDP model.
- The manner in which activity effectiveness is assessed i.e. by making judgements about the quality of activity characteristics in the context of realising each DoP.
- The manner in which the Analytic Hierarchy Process (AHP) is used to determine DoP impact on profit whilst accounting for DoP interactions.

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DEFINITIONS

Approved concept and business	A product concept has been designed and agreed to meet the requirements, and business plans have been approved.
Approved product idea	Product ideas have been evaluated and adopted for use as the basis of a product programme.
Design analysis	Design analysis must quantify the functional, strength, deflection and dynamic performance aspects of the product design.
Evaluation	Evaluation is a continuous process during the embodiment design. The results of the design synthesis and analysis are reviewed against the requirement of the Product Design Specification and against good engineering practice to ensure that the design is developing on a sound basis.
Procurement	Resolving the technical and quality requirements for material, components and bought out parts, through consultation with suppliers and the purchasing and quality groups of the company.
Product Development Process (PDP)	All those activities necessary to prepare for the realization of a physical product (new or improved) which can be produced, sold and supported as a commercially viable venture.
Product opportunity	The opportunity to develop a product that the company will be able to market profitably. Such an opportunity requires that: 1) a market need exists; 2) the technological capability to meet the need exists; 3) the opportunity fits the company's capability and objectives.
Proven product	The product has achieved a satisfactory service record.
Released product	The embodiment of the product has been fully defined in terms of its geometry, materials, parts and components. It has been evaluated and shown to satisfy the requirements. The manufacturing process has been fully defined and tested and the product is released into the product range ready for manufacture and for supply to the market.
Supply	All those activities necessary for supplying and supporting products in a market. Activities include manufacture, selling, contracting, purchasing, distribution, and support.
Synthesis of design	Evolving the description of the product in terms of its geometry, materials and parts.

SYMBOLS and ABBREVIATIONS

SYMBOLS

DI	Degree of Impact
η	Effectiveness
SI	Strength of Interaction
w	Correlation Factor

ABBREVIATIONS

AHP	Analytic Hierarchy Process
BPM	Business Process Management
BSI	British Standards Institution
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CAM	Computer-Aided Manufacturing
CE	Concurrent Engineering
CFD	Computational Fluid Dynamics
CNC	Computer Numeric Control
DFA	Design for Assembly
DFM	Design for Manufacture
DFX	Design for X
DOI	Degree of Interaction
DoP	Determinants of Profit
DSS	Decision Support System
DTI	Department of Trade and Industry
EFQM	European Foundation for Quality Management
EPSRC	Engineering and Physical Sciences Research Council
EQA	European Quality Award
ES	Expert System
EU	European Union
FEA	Finite Element Analysis
FEM	Finite Element Modelling
FMEA	Failure Modes and Effects Analysis
FRACAS	Fault Reporting and Corrective Action System
GE	Generic Element
GIM	Generic IDEF Model
IDEF	Integrated DEFinition (language)
IPD	Integrated Product Development
KBS	Knowledge-Based System
LoA	Level of Abstraction
MBNQA	Malcolm Baldrige National Quality Award
MCDM	Multi-Criteria Decision Making
NASA	National Aeronautics and Space Association
NPD	New Product Development
NPDP	New Product Development Process
NVA	Non-Value Adding

PDCA	Plan, Do, Check, Act (cycle)
PDP	Product Development Process
PDS	Product Design Specification
PDSA	Plan, Do, Study, Act (cycle)
PIP	Product Introduction Process
PIP	Project Implementation Profile
PMP	Potential for Maximising Profit
PS	Performance to Standard
PWC	Pair-wise Comparison
QFD	Quality Function Deployment
R&D	Research and Development
RACE	Readiness Assessment for Concurrent Engineering
RC	Resource Consumption
ROI	Return on Investment
ROS	Return on Sales
SA	Self-Assessment
SBU	System Business Unit
SE	Simultaneous Engineering
SME	Small/Medium Enterprise
SPC	Statistical Process Control
SQ	Solution Quality
SQC	Statistical Quality Control
TQC	Total Quality Control
TQD	Total Quality Development
TQM	Total Quality Management
UK	United Kingdom

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Introduction

Summary

Research has shown that the quality of the product development process (PDP), including the proficiency with which PDP activities are executed, impacts on new product development (NPD) success. Successful NPD is key to the growth and continual survival of many manufacturing companies and also to the health of the economy. However, many companies are still not achieving the rates of success that they, and their governments, desire. It is therefore potentially fruitful to conduct research into NPD and in particular the PDP.

The work presented in this thesis concerns the Product Development Process (PDP). Much of the literature dealing with the PDP refers to New Product Development (NPD) as a general title. The two are related in that a PDP is necessary for NPD. Research to determine factors that affect NPD success identify the PDP as crucial. The investigation presented in this thesis covers both products that are 'really new' i.e. new to the world and/or new to the company, and 'incremental' product developments i.e. modifications made to an existing product line (definitions as used by Song and Montoya-Weiss 1998).

To understand the impact of the PDP on NPD success, all factors that affect NPD success must be considered in order to relate these factors to the process. NPD literature is therefore considered and discussed in Chapter 2.

1.1. New Product Development (NPD)

It has been recognised for some time that successful new product development is crucial for survival. Cooper (1980 p277) notes, "New product development stands out as one of the most crucial yet deficient functions of the modern corporation. Thousands of new products are developed and introduced by firms each year. But *(sic)* only a minority brings home the profits needed to justify their development in the first place. Faced with staggering R&D expenses and no shortage of product failures, more and more firms are taking a critical look at their new product efforts." This sentiment is echoed more recently by Hart (1995 p15) who observes; "Recognition of the importance of new product development to corporate and economic prosperity, coupled with the high risk of failure in such endeavours, has triggered considerable research interest in the dynamics of new product development." NPD therefore remains an important field of research.

The importance of NPD research is highlighted by the fact that many companies are still not achieving the success rates they desire (Griffin 1997, Poolton and Barclay 1998). This lack of success is highlighted in *Budget 98* (HM Treasury and DTI 1998) which cites the UK government's Department of Trade and Industry's benchmarking report. The report notes the "under-performance of much of UK industry relative to the best in this country and overseas". The finding is supported by Cooper (1999 p115) who says, "… there is little evidence that success rates … have increased very much." It is therefore potentially fruitful to conduct research in this field with a view to enabling companies to improve their NPD success rates.

By way of introduction to the research the following questions are discussed. What constitutes NPD? What constitutes NPD success? What are the factors that affect NPD success and failure? How can these factors be controlled to ensure success and avoid failure? What are the research issues in this field?

1.1.1 What is New Product Development (NPD)?

New product development (NPD) is defined by Hart (1995 p16) as "the process by which new products are developed in companies." She continues (p21), "The process of new product development involves activities and decisions from the time an idea is generated (from whatever source) until the product is launched on to the market." This definition has been adopted for this work and the PDP does not therefore include the production phase. However manufacturing process requirements must be an input into all decisions and activities upstream of full-scale production. This is discussed in greater detail in Section 1.2.2.

Much work has been done on new technology development and how companies can acquire new technologies and feed technology into their PDPs. This thesis does not focus on technology development but treats it as a separate process and recognises where technology inputs to the PDP must occur. This approach is supported by Smith and Reinertsen (1992, 1995) who recommend that technology development occur in parallel to NPD to overcome associated high risk of missing optimum product launch dates due to key technology being unavailable when required.

Technology development can be viewed as a driver of NPD. Termed 'technology push', it compliments another NPD driver, 'market pull'. Market pull is the situation where customer needs and requirements drive NPD (Cooper 1983a, Veryzer 1998). Examples of technology push products are 3M's 'Post-it' notes and the Sony Walkman.

1.1.2 What is Success in NPD?

New product success is defined in many ways. A short answer to the question is that the product meets company objectives. Examples of objectives are: time to market (i.e. getting the product to market on schedule); market share (i.e. the company's product must account for a specified percentage of the total number of similar products sold in the market); number of sales (i.e. the company must sell a specified number of products in a given period); profit (i.e. the company must make a certain profit from sales of the product within a specified time period) (Cooper 1984a, Stalk and Hout 1990, Smith and Reinertsen 1991, 1992, 1995). Barclay and Taft (1992) report that 54% of companies rank profit as their number one measure and 24% as their number two measure. Wind and Mahajan (1991) note that 81% of the 200 Fortune 500 companies surveyed use profit as a means of new product performance.

The view of success taken in this thesis is one of profit, but which is broadly interpreted. For example, a company can profit in the longer term from increased market share.

1.1.3 What are the Factors that Increase Probability of Success?

Most of the significant research on factors that affect NPD success has occurred since the early 1960s. Research has focused on factors influencing success, factors influencing failure, and discriminants between success and failure. These factors can be divided between those that affect success and/or failure at corporate/company/firm level, product programme level (where decisions and actions concern all products that the company considers to form part of the programme) and product project level (where decisions and actions concern a single specific product only). Typical corporate level success factors are NPD strategy, formal development process, cross-functional interaction and communication, and measuring and monitoring product performance. A typical factor that affects NPD success at the programme level is commercial and technical synergy i.e. the measure of fit between the proposed product and existing company products, processes and capabilities. Examples of project level factors are: ensuring that certain necessary activities occur; creation and management of development teams; identifying and managing time to market; measuring and monitoring performance.

1.1.4 How can NPD Success be Controlled or Achieved?

The question arises of whether NPD success can be controlled at all. In a direct causal sense the answer is 'no'. There is no foolproof recipe for success. Factors internal and external to the company may contrive to defeat the best product development endeavours (Souder 1978). A company may have a measurement and reward system that rewards personnel for the wrong things (Zairi 1994), and which may jeopardise the potential for success of the project (Lawlor 1985, Walton 1989). For example a stress engineer may be rewarded for the number and quality of stress analyses performed. Accordingly the engineer may pay less attention to project deadlines, which could result in failure of the product to reach the market on time. Failure in this regard may occur irrespective of the quality of the formal development process.

Conversely, companies may produce successful new products in spite of a poor formal process. Success here may be due to extraordinary endeavours of company personnel (Hart 1995). Research, models, tools, consultants, procedures, etc. can at best only hope to increase the *likelihood* of successful product outcomes.

This does not imply that factors influencing NPD success and failure should not be monitored and controlled. Indeed this is of the essence in striving to maximise the probability of NPD success (Zairi 1994). "If you can't measure it you can't improve it" (Lawlor 1985 p267). Measurement and monitoring imply the need for metrics, measurement techniques and tools.

Metrics form the building blocks of measurement techniques and tools. McGrath and Romeri (1994 p214) state "a metric - even an approximate one - is needed to measure overall performance. Without such a metric, management of the product development process is purely subjective." They further note (1994 p214), "The study showed that the participants did not consistently use any single overall metric to measure their product development process, but they indicated that one was badly needed."

One metric of product success, for example, is profit. Much research has been undertaken into what should be measured in NPD and how this measurement should occur (a number of these studies are discussed in Chapter 2 with a critical review of methods to measure activity effectiveness presented in Chapter 7).

Management tools are available which have the objective to improve NPD success. These tools are applied at various levels, namely, corporate/company/firm level, programme level and project level. (A review of these tools is presented in Chapter 2).

Many models of the PDP have been proposed and are utilised in tools for assessing the quality of the PDP. A number of these models are presented in Chapter 2. The development of a model to meet the needs of the approach adopted in this thesis is described in Chapter 6 along with a critical examination and review of some existing PDP models.

1.1.5 What are the Research Issues in this Field?

The importance of research in this field to industry and national well being has been argued above. Research of this type has been ongoing for nearly 4 decades. Some companies have gained advantage from the research but not yet all (Poolton and Barclay

1998). A recent EPSRC Engineering Management Research Discussion Document raised as an important issue the low level of exploitation by UK industry of the results of management research in academia. Ullman (1997) observes that regardless of company size all companies face difficulties assessing: 1) their current process; 2) areas for potential improvements; and 3) the potential of new best practices.

The companies that have gained advantage from the research have been large companies that have been able to invest significantly in management systems and a number of them have developed NPD procedures. (For an example see Parnaby 1995)

Smaller companies (i.e. Small Medium Enterprises - SMEs) may have complex products, company structure and information flow, but are limited in the investment that they can make in management systems. However, there is no reason why existing management knowledge should not be extended to SMEs. An often-used approach to satisfy this need is to employ management consultants. This makes available a broad based knowledge and experience of management and design theory and methods. However, the cost can be high. Also, companies often find that they cannot, or do not, implement the full recommendations. (Coles 1998, Caulken 1997) Some resistance to external management systems and consultant recommendations exists due to the 'not-invented-here' syndrome.

What is needed is a less expensive and less resource intensive approach. The most effective way for a company to develop its PDP is to do so in house. The aid of a set of methods and tools that ensure that it is done in a rational way and in the context of current management theory makes the outcomes more likely to be both relevant and realisable (Fairlie-Clarke and Muller 1998).

In referring to past research, Calantone and Cooper (1981 p48/9) pose the question "Why have these research insights had so little impact on new product performance? One argument is that the way the results of these studies are presented is not readily amenable to management action." Cooper (1983b p2) suggests "What is missing is a shaping of the research conclusions into a managerial guide."

An approach to address this shortcoming is developed and presented in this thesis.

1.2 Introduction to the Research Project

The value of the work reported in this thesis is that it provides new procedures for understanding and organising the complexity of the PDP. Edgett *et al* (1992) supports the value of such research. They conclude (p10); "... most of the reasons for failure of a product cited by both the Japanese and British are controllable within the company. More formal development processes could eliminate many of the initial reasons given for a product's failure."

The output of the research project described in this thesis is a cost-effective method to evaluate a company's product development activities within the context of best practice (which includes accepted research findings) and to implement procedures to ensure that the strategic objectives for investment in product development are realised in the product outcomes.

1.2.1 Objectives of the Research Project

The primary objective of this work is to provide companies with a method to enable them to assess for themselves the effectiveness of their current or proposed PDP. This is to be a quantified method so that they are forced to think about issues, and so that results of the assessment can be used effectively as the basis of argument for change. The method is to be non-prescriptive, is to account for the uniqueness of each company, and is to draw out and utilise company knowledge within a framework of current best practice in engineering management.

The approach taken to realise the above objective was to develop an understanding of the PDP and create a framework that could be used to explain the process. "Processes can be better controlled if well understood" (Zairi 1994 p5). It was recognised that an evaluation method could only be derived if a framework was in place that could be used to control the complexity of the PDP.

There is a gap in current methods in that no method or evaluation framework exists that is non-prescriptive in nature and which allows proposed processes to be evaluated by quantified assessment of PDP activity effectiveness in relation to execution quality, resource consumption and time dimensions of important product issues. Herein lies the claim for novelty of the approach and method presented in this thesis.

The work is not driven by existing tools and is not an extension of existing tools. However, a number of existing tools were evaluated (see Chapter 2) as an aid to understanding PDP complexity and to source any material that could be drawn upon.

1.2.2 Scope of the Research Project

For the purposes of this research project 'product development process' is defined in a broad sense as embracing all those activities necessary to prepare for the realisation of a physical product (new or improved) which can be produced, sold and supported as a commercially viable venture (Fairlie-Clarke and Clark 1993).

The scope of this research project is limited to the engineering and manufacturing sector of NPD and does not include the service sector. Also, as discussed before, the approach does not include technology development. Technology development is considered to occur in parallel and to feed in to the PDP.

The PDP is taken as being completed upon release of the product for manufacture (product launch activities are included in the PDP - see Chapter 6). Thereafter manufacture is considered as a supply process. However all issues of *how* a product is to be manufactured are issues of development. For example, issues such as design for assembly, design for manufacture, design for quality, (in general known as Design for X (DFX) (Smith and Reinertsen 1992, 1995)) are viewed as part of the development process.

1.2.3 Method of Undertaking the Research Project

A problem solving approach is used in this thesis in which hypotheses are formulated and tested. This differs from the approach typically used in current management research, which is largely observational in nature with research issues being identified and the issues explored using questionnaires and interviews. Data is analysed and conclusions drawn (Easterby-Smith *et al* 1991). There is often no independent prior analysis. The objective is simply to understand what is happening or what people are thinking.

Phases of the research project were as follows:

- Research of NPD and PDP by means of ongoing critical literature review, interviews, modelling and discussion. Specifically: factors that affect NPD performance i.e. product success and/or failure; the definition of success and metrics for measuring NPD output quality; research on tasks and characteristics of NPD; metrics and measurement of the quality of particular elements of the NPD process; descriptive and prescriptive PDP models; and methods and tools to assess performance and/or improve the PDP.
- Development of an approach that will allow companies to understand their product development processes. This approach evolved via detailed discussion, modelling, analysis and evaluation against knowledge and experience of industrial practitioners and academics with industrial experience.
- Implementation of the approach in the design of a PDP evaluation method to provide a structure for organising information. Encapsulating the approach within the framework of a method raised a number of issues requiring further research.
- Research into computer based tools, decisions support systems (DSS), expert systems (ES), and knowledge-based systems (KBS). Specifically: computer based modelling tools in management; examples of management computer tools; specific mathematical methods to be used in the evaluation method; and related literature on DSS, ES, and KBS.
- Research, development, test and validation of solutions to various issues raised by the design of the approach.
- Assembly of the evaluation method and trials in industry.

1.3 Thesis Structure

The thesis is structured as follows:

A literature review is presented in Chapter 2. The introductory comments set the scene i.e. they explain why particular literature is reviewed and describe the manner in which the literature is organised to reflect the structure of the research project. The objective of the literature review itself is to provide the background for the work, support the approach adopted, provide relevance for the research project, and illustrate novelty of this work.

Chapter 3 presents the logic and evolution of the approach to allow companies to understand the PDP and organise its complexity. The chapter also describes how the approach is implemented. Various research issues are identified, namely: investigating the industrial context of the approach; identifying important issues about the product that impact on success; identifying elements of the PDP; assessing effectiveness of PDP elements and activities; and determining correlation factors. Chapter 3 also illustrates how the approach addresses shortcomings and limitations in the literature discussed in Chapter 2, and shows how assumptions underlying the approach are supported by the literature. The novelty of the approach is demonstrated against the claims made in Chapter 1.

Chapter 4 discusses the approach within the industrial context. Tests of the approach and results obtained are presented.

Chapter 5 discusses how important product issues that affect the likelihood of successful product outcomes are defined and identified.

Chapter 6 describes the evolution and tests of a generic PDP model. A list of constituent activities is presented.

Chapter 7 describes the design of an assessment procedure to determine activity effectiveness.

Chapter 8 describes a procedure to determine correlation factors used to link components of the evaluation method.

Chapter 9 details assembly, implementation and trials of the evaluation method.

Chapter 10 outlines suggested future work.

Chapter 11 gives a general discussion and concluding remarks.

It should be noted that the thesis describes the current state of the evaluation method. Appendices are used to explore chronological evolution issues that do not fall naturally into the body of the thesis or which might cause confusion if included in the body of the thesis.

2

Literature Review

Summary

The review highlights factors that contribute to new product development (NPD) success at company and project level. A key factor for success is the proficiency with which product development process (PDP) activities are executed. The review indicates those activities that should be present and executed effectively for high likelihood of successful product performance in the market place.

Project level development issues such as team selection, resource allocation, availability of information, communication, multifunctional team integration, co-location of team members, supplier and customer involvement, senior management support, project leader, and team member skills, are identified in the literature as being key to NPD success. The literature also shows that metrics, measurement and self-assessment of the PDP are important to performance.

Literature about PDP evaluation methods and tools, and PDP models, highlights important issues that impact on successful NPD, which must be included in the evaluation method developed in this thesis.

Findings of the literature review support the relevance of the work presented in this thesis. Further, a need can be identified from interpretation of the literature for a non-prescriptive, generic, evaluation method. The method should utilise the expert knowledge that exists in a company, to evaluate the proficiency of a company's PDP. Evaluation should include assessing the effectiveness with which PDP activities realise product issues identified as important by the company expert.

2.1 Introduction

The research project described in this thesis has been undertaken against the background of much world-wide research about NPD and the PDP, which provides both a context and support for the work presented here.

The purpose of this review is threefold: 1) to set the work reported in the thesis in the context of existing literature; 2) to seek reinforcement of the hypothesis that success of NPD is related to doing the PDP well; and 3) to provide relevance for the reported work. It is not the purpose of this chapter to examine the various constructs of the developed evaluation method. Literature relating to specific research issues, identified in Chapter 3 is discussed in the relevant chapters that address these issues.

The body of literature considered in this chapter is divided into six themes.

1. Factors that affect NPD performance (Section 2.2.1).

   The objective of the research project described in this thesis was to establish a method to enable companies to understand and take control of their PDPs. An output of the project is a method that will enable companies to assess the quality of their processes with a view to producing successful products. It was therefore important to identify factors that affect the likelihood of NPD success and failure at company, programme and project levels. These factors must be reflected in the developed PDP method.

2. Metrics and measurements for NPD output quality (Section 2.2.2).

   Part of the approach adopted in this research project is to determine the impact on success of identified product issues as a way of evaluating NPD performance. It was therefore necessary to discover how industry defines and measures NPD success, what metrics are available, and how industry uses these to monitor their NPD performance. The need for measurement, and its positive impact on successful NPD, has been established by this literature.

3. Research on tasks and characteristics of NPD (Section 2.2.3).

   General *high level* factors affecting NPD success and failure are identified in 2.1.1. In Section 2.2.3 literature concerning in-depth research of more *detailed* factors is presented. Review of the literature was undertaken to discover pertinent aspects of NPD that should be evaluated in the method (and those that should not). The manner in which these aspects have been addressed, i.e. the methods used in previous research work, was also identified.

4. Metrics and measurements for NPD process quality (Section 2.2.4).

   While Section 2.2.2 deals with metrics and measurements for NPD output quality, this section addresses the body of literature dealing with performance metrics and measurement of *individual* NPD aspects that impact on overall NPD performance: for example, development cycle time (Griffin 1993, 1997a) and research and development (R&D) effectiveness (Szakonyi 1994a, 1994b). The findings of this body of literature identify additional best practice issues that must be reflected in the developed method.

5. PDP models (Section 2.2.5).

   As with most tools that assess overall product development performance, the method developed in this research project incorporates a model of the PDP. The relevance of the literature reviewed in Section 2.2.5 is that it shows what types of models exist and to place modelling into the context of the work presented in this thesis.

   A more critical review of existing PDP models that relate to the requirements of the method is presented in Chapter 6.

6. Methods and tools to measure and improve the PDP and its constituent activities (Section 2.2.6).

   In an attempt to establish a method to enable companies to evaluate and improve their product development process it was important to study the field of application and the limitations of existing tools. This was to ensure that the method developed utilised existing work, where relevant, and addressed all pertinent issues.

This review considers tools with specific application areas such as marketing, design and analysis activities, as well as general management and change implementation systems. Total Quality Management and Business Process Re-engineering respectively being examples of the latter. Specific types of tools such as Decision Support Systems (DSS), Knowledge Based Systems (KBS) and Expert Systems (ES) are also discussed.

The volume of literature that has been, and continues to be, generated on subjects related to this research project is substantial. It was therefore necessary to identify and focus mainly on the work of established authors, on review papers, and on specifically relevant papers. Review of literature is a continuous process and a significant volume of literature has been reviewed. Primary sources have been covered and recent reviews (Griffin 1997b, Werner and Souder 1997b, Krishnan *et al* 1997, Brown and Eisenhardt 1995, Hart 1995) do not suggest any significant omissions.

2.2 Review

The approach adopted in this thesis is to evaluate current processes in the context of current knowledge about important factors affecting successful product outcomes, rather than measuring results that depend on historic processes. It is recognised that most metrics are used to good affect even though they are by nature historical and retrospective. It is also recognised that with many of these metrics the elapsed time between the activity and the measure of quality of the output of the activity is relatively short e.g. statistical process control (Zaloom 1984, Ishikawa 1985, Walton 1989, 1991). However, where the elapsed time between activity and performance evaluation of that activity is measured in months and years, the above criticism applies i.e. that which is being 'measured' may no longer exist. (Zairi 1994, Slater *et al* 1997) This is particularly true when PDP performance is determined in terms of performance of the product in the market place. This limitation is addressed by the method developed in this thesis.

2.2.1 Factors Affecting NPD Performance

An objective of this section is to show the importance of the PDP to successful NPD. The proficiency with which the PDP activities are executed is shown positively to influence successful NPD. This fact provides support for the approach adopted in this thesis. A further objective is to identify factors that are important, or of possible importance, to product development performance.

Most research into the factors and dimensions of product development performance has focused on factors contributing to product success or failure, or discriminants between success and failure.

Research into factors contributing to *success* has focused both on company programme level (Globe 1973, Cooper 1984a, 1984b) and on project level (Cooper 1996, 1999, Johne and Snelson 1987, 1988a, Pinto and Slevin 1987, 1989). In these studies the positive impact on success of process proficiency is either explicitly identified or implied.

Johne and Snelson (1987, 1988a) adapt the McKinsey 7S model as presented by Peters and Waterman (1982). Factors underlying efficient NPD are given as:

- Skills: specialist knowledge and techniques required to execute NPD tasks.
- Strategy: product development strategy to define the sort of new products to be developed and the resources to be released for the purpose.
- Structure: type of formal organisation structure used to implement the NPD activities.
- Shared values: acceptance by the company as a whole of the need to pursue a particular NPD strategy.
- Style: active support by top management for those involved in key NPD tasks as opposed to a 'divide and rule' style of management.
- Staff: type of functional specialists available for executing NPD tasks.
- Systems: type of control and co-ordination mechanisms used for executing NPD tasks.

Those of the above factors, which are pertinent at project level must be accounted for either in the generic PDP model as activities or in the procedure to assess activity effectiveness.

Cooper (1996) provides a synopsis of factors contributing to success of new products. He categorises them as NPD process factors and NPD project selection factors.

NPD process factors

1. Developing a superior differentiated product, with unique benefits and superior value to the customer or user.
2. Having a strong market orientation throughout the process.
3. Undertaking the predevelopment homework up front.
4. Getting sharp and early product definition before development begins.
5. Quality execution - completeness, consistency, proficiency - of activities in the new product process. He notes (1996 p9), "There is a quality of execution crisis in the new product process: things don't happen as they should, when they should, and sometimes don't happen at all!"
6. Having the correct organisation structure: multifunctional and empowered teams.
7. Providing for sharp project selection decisions that lead to focus.
8. Having a well planned and well resourced launch.
9. The correct role for top management: specifying new product strategy and providing the needed resources.
10. Achieving speed to market, but with quality of execution.
11. Having a multistage disciplined new product game plan. He says (1996 p14) "Leading companies have adopted stage-gate processes *(a system developed by him - see Cooper 1990)* to provide a road map from idea to launch, and to drive new products to market effectively and on time."

Project selection success factors

1. Having a unique, superior product.
2. The product - market environment:
   - Market attractiveness
   - Competitive situation (minor impact)
   - Stage of product life cycle
3. Synergy and familiarity.

Cooper (1996 p3) concludes, "Of the two sets of critical success factors, new product process factors have by far the greatest impact." Cooper (1999 p115) evaluates why "…product innovation does not happen as well as it should…" and why "… the critical success factors are noticeably absent from the typical new product project." His remedy is encapsulated in "eleven action items":

1. Leaders must lead.
2. Design and implement a new product process.
3. Overhaul the process.
4. Define standards of performance expected.
5. Install a process manager to oversee the process.
6. Build in tough go/kill decision points.
7. Use true cross-functional teams.
8. Provide training.
9. Seek cycle time reduction.
10. Institute portfolio management.
11. Cut back the number of projects underway.

The above factors and items that represent best practice must be reflected in the developed evaluation method.

Research into factors contributing to product *failure* can be divided into company/programme level factors (Davidson 1976, Hopkins 1981), and project level factors (Pinto and Mantel 1990).

Davidson (1976) finds that a product will fail unless its selling price is lower and its quality superior to that of its competitors. Deming (Walton 1989, 1991) and Ishikawa (1985) support the argument that a product will only achieve superior performance and price as a result of a good PDP. According to Hopkins (1981) poor execution of market research and analysis, and technical problems (i.e. quality of execution and over-engineering), result in product failure.

Pinto and Mantel (1990) identify shortcomings of 'technical tasks' (e.g. availability of the required technology and expertise to accomplish specific technical activities), as a reason for failure of the 'execution' stage of their PDP. This is particularly true for construction projects.

These findings show that a product will fail if it is not superior in quality and price to that of the competitors, and that poor performance of PDP activities has a direct bearing on this.

Research into *discriminants* between new product success and failure has been undertaken by Calantone and Cooper (1981), Yoon and Lilien (1985), Cooper and Kleinschmidt (1986, 1987) and Lilien and Yoon (1989), amongst others.

Calantone and Cooper (1981) identified 77 factors underlying new product projects. Their analysis reduced these to 18 dimensions, six of which are directly related to the PDP. Managers were asked to identify those dimensions that impacted on success and failure of their projects. The proportion of managers selecting the six process dimensions were as follows:

- Technical and production synergy and proficiency - 28.8%.
- Marketing knowledge and proficiency - 11.7%.
- Marketing and managerial synergy - 5.1%.
- Strength of marketing communications and launch effort - 3.1%.
- Product *determinateness* (clearness of product specification) - 2.8%.
- Proficiency of pre commercialisation activities - 1.6%.

Technical and production synergy and proficiency scored the highest amongst all 18 dimensions, illustrating the importance of the process.

Cooper and Kleinschmidt (1986) investigate the PDP and identify pre-development activities (i.e. initial concept screening, preliminary market assessment, preliminary technical assessment, business or financial analysis, and detailed market study) as being the most critical descriminant between success and failure *at process level*. Further, they report that regardless of the gauge of performance used, pre-development activities, product development, in-house product tests and market launch, are all strongly and positively related to new product performance.

Cooper and Kleinschmit's (1987) later study expanded these findings to include, along with pre-development activities, the proficiency of 'protocol' activities, i.e. those activities that define target markets, customer needs, product concepts, and product specifications and requirements. Also included in their study as impacting on success at a second level are proficiency of technological activities and proficiency of market-related activities. The former includes; proficiencies of preliminary technical assessment, product development, in-house testing of product (prototype), trial/pilot production, and product start-up, and the latter; proficiencies of preliminary market assessment, detailed market study/marketing research, customer test of prototype or sample, trial selling/test market, and market launch.

Gerstenfeld (1976) in West German and Rubenstein *et al* (1976) in the United States of America performed research into success/failure discriminants for companies in their home countries. Both studies focus on successful innovation. Gerstenfeld discovered that 'market pull' products have greater likelihood of success than do 'technology push' products. Rubenstein *et al* conclude that innovation performance is related to level of technology employed in the innovation process.

How discriminants vary between countries (i.e. in different contexts) has been researched in the following studies:

- Rothwell (1972, 1985) and Rothwell *et al's* (1972, 1974, 1985) SAPPHO projects in Britain and Hungary. They, amongst others, found that successful innovators perform their development work more efficiently than those who fail do.
- Maidique and Zirger's (1984) research into success in a high-technology environment in the USA - Stanford Innovation Project. They observed that factors important for new product success include: planning and co-ordination of the PDP - especially the R&D phase; emphasis on marketing; and management support throughout the development launch stages.
- Cooper's (1979, 1980, 1982) project NewProd in Canada. He discovered, as mentioned earlier, that one of the most important new product dimensions to impact on success/failure is 'technical and production synergy and proficiency'.
- Utterback *et al's* (1976) research compares success/failure discriminants in Europe and Japan at programme level. They do not focus on the PDP *per se*.

- Mishra *et al's* (1996) research compares NPD success/failure factors for South Korea, China and Canada. They note that proficiency of formal NPD activities is not as important to the South Koreans as market intelligence, product company compatibility, the nature of the new product ideas (i.e. market pull, clearly defined specifications by the market place), launch effort, and general characteristics of the NPD venture (i.e. technical complexity). It can be seen that a number of these factors such as market intelligence, specifications, launch, are elements of the PDP.
- Song and Parry (1997b) studied comparisons between Japan and the USA. They conclude that the level of cross-functional integration and information sharing, the companies' marketing and technical resources and skills, the proficiency of NPD activities, and the nature of market conditions positively influence Japanese new product success.
- Edgett *et al* (1992) present findings of an investigation into success and failure in British and Japanese owned firms conducting business in the United Kingdom. They note that failure rates between the companies are similar, but higher than those for companies based in the United States. They recommend a more formal development process to improve success rates.
- Souder and Jenssen (1999) discovered that proficiencies in conducting development, marketing, and customer service activities are important to NPD success in both Scandinavia and the United States. However, differences were found between the two countries with regard to the importance of R&D/marketing integration and project manager competency. With these aspects being more important to NPD success in the United States.

Song and Montoya-Weiss (1998) investigate discriminants of NPD success for 'really new' versus 'incremental' products. They report that four sets of NPD activities are key determinants of new product success for both really new products and incremental products. These are strategic planning, business/market opportunity analysis, technical development, and product commercialisation. Strategic planning and business/market opportunity analysis activities have opposite influence on the two types of products. Attempts to improve the efficiency of business/market opportunity analysis may be counterproductive for really new products, but can increase the profitability of incremental products. However the converse is true for strategic planning activities.

Reviews of NPD literature that focus on success and failure factors and identify directions for future research are presented by, amongst others, Barclay (1992a), Craig and Hart (1992), Brown and Eisenhardt (1995), and Hart (1995).

Brown and Eisenhardt (1995) identify 11 factors in their review paper. Each factor has one or more facets (in *Italics*) that make that factor pertinent to success. They are:

1. Suppliers: *involvement.*
2. Team composition: *cross-functional teams; gatekeepers; moderate tenure.*
3. Team organisation of work: *planning and overlapping versus iteration, testing and frequent milestones.*
4. Team group process: *internal communication; external communication.*
5. Project leader: *power; vision; management skill.*
6. Senior management: *support; subtle control.*
7. Customers: *involvement.*
8. Process performance: *speed; productivity.*
9. Product concept effectiveness: *market synergy; technical synergy.*
10. Market: *large; growth; low competition.*
11. Financial performance: *profits; revenue; market share.*

The manner in which the factors interlink depends on the particular focus of the PDP i.e. product development as rational plan, product development as a communication web, or product development as disciplined problem solving.

Hart (1995) uses a content analysis of a previous study (Craig and Hart 1992) to identify six themes that are crucial to the success of NPD. They are:

- NPD process
- Management
- Information
- Strategy
- People
- Organisational structure

She observes that these themes are detected at two different organisational levels:

1. Relating to a specific NPD project (i.e. NPD process, people, and information).
2. Relating to the way in which the company approaches the development of new products in general (i.e. management, strategy, and organisational structure).

Of the six themes Hart (1995) identifies 'NPD process' and 'people' as being central to the future of NPD research.

A number of studies identify the effective execution of the development process, or particular activities within the development process, as critical to new product success (Rothwell 1972, Rothwell *et al* 1974, Cooper 1979, Maidique and Zirger 1984, Cooper and Kleinschmidt 1987).

Cooper and Kleinschmidt (1986) develop a list of 13 activities from other authors (Myers and Marquis 1969, Booz, Allen and Hamilton 1982, Cooper 1983b):

- Initial screening
- Preliminary market assessment
- Preliminary technical assessment
- Detailed market study/market research
- Business/financial analysis
- Product development
- In-house product testing
- Customer tests of product
- Test market/trial sell
- Trial production
- Pre-commercialisation business analysis
- Production start-up
- Market launch

They found that there is a greater probability of commercial success if all of these process activities are completed. This finding is substantiated in a study by Dwyer and Mellor (1991c) who replicated Cooper and Kleinschmidt's study in Australian companies. (The way in which these activities form part of a process model will be discussed in greater detail in Chapter 6).

Evans (1990) indicates that there can be a price to pay for executing all of the above activities, namely, extension of overall development time. In recognition of time pressure facing those developing new products, Takeuchi and Nonaka (1986) suggest that activities should overlap or be performed in parallel (their approach is discussed in greater detail in Section 2.2.5)

Montoya-Weiss and Calantone (1994) performed a meta-analysis on research into determinants of new product development performance in an attempt to identify common underlying dimensions. They categorise the determinants as organisational, market environment, strategic and development process factors. They find that proficiency of technological activities, proficiency of market-related activities, product advantage and protocol are typically identified as the primary discriminants between success and failure. They observe (1994 p407) "The relative importance of these factors emphasises two major categories of drivers of new product performance; product advantage is a strategic factor and *the other three are development process factors* (Italics added)."

This finding emphasises the importance of focusing on the development process and supports the relevance of this work. Factors for NPD success and failure identified above form part of the foundation on which the output of this research project is built.

Cooper (1980 p281) makes the following comments on the general findings of this body of research "The quest for the secret of new product success appears more difficult than anticipated. One fact that is clear from the research is that there is no direct answer to the question 'what makes a new product a success?' Rather, the relationships and variables involved in determining product outcomes constitute a complex network of effects. A second fact is that the nature of the venture moderates the answer to the question. Different types of ventures appear to have different variables as the critical determinants of success."

Yap and Souder (1994) support Cooper's second point. They conclude from their study into success/failure discriminants in small high-technology companies that these companies must adopt strategies very different from those used by large companies.

Griffin (1992) also supports Cooper's second point and the notion that factors affecting performance are unique to context[1]. It is the "complex network of effects" identified by Cooper that is at the root of this phenomenon. The method developed in this thesis must (and does) account for this by allowing companies to express their uniqueness.

Although the list of factors identified from the literature is fairly consistent for each situation it must be supposed that the relative impact of each factor on success and/or failure is not the same for every context. Cooper (1980) and Griffin (1992) who observe that factors contributing to NPD success and/or failure cannot be universally applied to all companies, support this observation.

Mishra *et al* (1996 p530) comment on the universal applicability of success/failure factors: "Although considerable effort has been devoted to identifying the factors that contribute to new product success and failure, plenty of work remains to be done in this area.... It remains to be seen whether the findings from these studies apply to the new product development efforts of companies in other regions, let alone on a global basis."

Griffin makes a similar point that highlights the issue of global applicability of findings. Referring to the impact of quality function deployment (QFD) implementation on US firms, she notes (1992 p184) "Given that Japanese firms are managed very differently than American firms and have vastly different organisational structure and corporate cultures, it is not really surprising that QFD achieves somewhat different results in American firms than it does in Japan." In other words results and findings of research in specific contexts are not necessarily universally applicable.

Another limitation of the approach adopted in this body of research is that results are based on the memory of respondents. The problem of assessing a product development process that existed some time in the past (and perhaps no longer exists) arises. By the time the data is available the process is likely to have changed (Slater *et al* 1997). An attempt to assess a present development process using this approach is only valid if everything has remained unchanged over the life cycle of the product (i.e. from conception to launch to

[1] She cites Lorsch and Lawrence (1965) whose research suggests that environmental or contextual factors may affect product development success for any specific process.

product maturity to obtaining financial results). Clearly this is an unrealistic expectation given the dynamic nature of markets, competition, suppliers, personnel, management, etc.

A further limitation of the approach used in this literature is that it does not enable the impact of change (or proposed change) on development performance to be quantified. The papers present tools only in as much as they illustrate that addressing certain factors will improve performance. The quantifiable amount of improvement can only be guessed at. This leaves "improvers" none the wiser as to the affects of their actions (unless one variable or combination of variables at a time is changed which is time consuming).[2] Clearly an approach that will allow changes to be identified in a manner that quantifies the affect of those changes without resorting to empirical methods, is desirable (particularly if the method permits a study of "what-if" scenarios that is not dependent of product life-cycle data). The relevance of the work presented in this thesis is supported by the desirability of such an approach being incorporated in a management tool.

Cooper (1980 p287/8) provides further support for the work reported in this thesis. He observes "The outcome of a new product project - success or failure - lies more in the hands of managers and implementors than was otherwise assumed. There is no one key to success. Success depends on many characteristics and variables. There is much to be gained from focusing more on the new product process activities [as] little attention has been devoted to improving the various steps of activities that comprise the new product process. Yet it is precisely here that modifications and improvements are likely to have their greatest effects on product success rates."

Finally, Griffin (1997b) identifies the PDP as that which distinguishes the best companies from the rest. She notes that 'the best' are more likely to have a NPD process and strategy, start the process with a strategy, and include, for example, activities such as those identified by Cooper and Kleinschmidt (1986). Her conclusions support the work reported in this thesis. She notes (1997 p451) that use of a PDP "can be thought of as a necessary ... condition to produce high NPD performance. A significant number of firms still do not

[2] It is unlikely that the PDP will remain unchanged for the duration of such an experiment. Any change in the PDP (e.g. change of staff) would leave the improver/s guessing at the exact reason for improvement - assuming improvement occurred.

consistently use a formal process, even though they have been demonstrated to lead to higher NPD success."

The literature focuses on past PDPs and does not provide methods to assess proposed processes. Factors identified as constituting success and/or failure cannot be universally applied (Cooper 1980). The approach adopted in this thesis will be universally applicable to manufacturing companies and will permit evaluation of the effect on successful product outcomes of *potential* changes to *existing or proposed* PDPs.

This review of literature relating to factors that impact on successful NPD shows that a significant body of literature exists which supports the link between a formal PDP, proficient execution of a set of activities, and NPD success. This link supports the approach adopted in this thesis.

2.2.2 Metrics and Measurements for NPD Output Quality

The focus of this section is on what constitutes NPD success and how PDP performance is measured i.e. what is measured and what metrics are used.

<u>Importance of Measuring Performance</u>

Cordero (1990), Tarr (1995), Heflin (1995) and Curry (1996), amongst others, argue the importance of PDP performance measurement. Curry (1996) notes that performance measurements are the "health indicators" of the company and that the sole purpose for taking measurements is to help identify the areas of the company that need attention. This is an objective of the approach adopted in this thesis. Heflin (1995) says that development process metrics are crucial for maximising return from the substantial investment in development of new products. Cordero (1990) supports this and states that companies need to evaluate performance to determine whether investment in R&D is justified and to determine whether maximum productivity of a technology has been reached. Tarr (1995) sees performance measurements serving (amongst other things) as an early warning system that strategy needs to be revised. Performance measurement is used to indicate the health of the company and for controlling and redirecting individuals and departments.

Brookes and Backhouse (1998) state that without performance measures the operation of product introduction cannot be managed, and any changes to product introduction to improve its performance (and hence the performance of the company) cannot be properly evaluated. Johnson and Dooley (1992) support this point of view. They state (1992 p295); "the ability to measure various aspects of the product development process (PDP) is a prerequisite to any efforts designed to improve its performance and quality."

It is recognised that a danger exists when monitoring and measuring performance. Achieving a good performance score may become the sole objective and focus of the activity (Zairi 1994). The objective of performance measurement should be to determine the degree to which the activity has positively affected the product.

In order to measure PDP performance three issues need to be addressed. 1) What constitutes success i.e. how is successful product development defined? 2) What to measure? 3) What metrics to use? These issues are addressed below.

<u>Definition of NPD Success</u>

Some researchers argue (either implicitly or explicitly) that success and the factors contributing to success cannot be evaluated unless "success" is first defined. Only then can a decision be made as to how success and failure are to be measured.

Crawford (1979) observes that success is variously defined, but that researchers are generally using 'met company expectation'. In other words, success is defined by whatever definition or product performance measure is important to the company.

<u>Metrics and Measurements</u>

Griffin and Page (1996) present success measures for use at project level and company level.

<u>Project level measures</u>

Customer based success

- Customer satisfaction

- Customer acceptance
- Market share goals
- Revenue goals
- Revenue growth goals
- Unit volume goals
- Number of customers

Financial success

- Met profit goals
- Met margin goals
- IRR or ROI
- Break-even time

Technical performance success

- Competitive advantage
- Met performance specifications
- Speed to market
- Development cost
- Met quality specifications
- Launch on time
- Innovativeness

Company level measures

- Development programme ROI
- New products fit business strategy
- Success failure rate
- % Profits from new products
- % Sales from new products
- Programme met 5-year objectives
- Product lead to future opportunities
- Overall programme success
- % Sales under patent protection
- % Profits under patent protection

Griffin and Page found the use of these measures to be dependent on the company's project and business strategy. For example, customer satisfaction and customer acceptance were among the most useful customer based measures of success for several project strategies, but market share was most useful for projects involving new-to-the-company products or line extensions. These findings support Crawford's (1979) conclusion that success is variously defined.

With the exception of the technical performance measures, the above success measures and measurements are by nature retrospective in that they give an indication of the quality of a PDP that existed some time in the past and may no longer exist. Also, while these measures may indicate that *something* is wrong with the PDP they cannot indicate exactly *what* is wrong. The measures are thus limited as a means of improving the PDP.

Profit is inherent in metrics suggested by Griffin and Page (1993, 1996). For example, 'measures of firm's benefits' is directly related to maximising profits (or the potential for the product to generate profits) as are 'measures of financial performance' and 'customer acceptance measures'.

Loch *et al* (1996) and Terwiesch *et al* (1998) conducted research in the US electronics industry to determine the relationships amongst the following NPD measures:

Company Success

- Profitability (return on sales (ROS)).

Development Performance

- Market leadership (% of significant product innovations first to market).
- Technical product performance (technical product performance relative to competitor's).
- Product line freshness (proportion of sales from product introduced the previous 3 years).

- Innovation rate (number of significant product line changes over the last 3 years, multiplied by product life cycle in years, and normalised as the relative deviation from the industry mean).
- Development intensity (development personnel for the product group divided by product group revenues).

Market Context

- Industry profitability (average ROS for the industry).
- Market growth (average market size in last year divided by average market size two years ago).
- Market share (world-wide volume for the product group divided by world-wide volume market size).
- Product life cycle (average duration of the product life cycle).

All of the above measures (with the exception of 'technical product performance') are retrospective with long time lag. Therefore, as argued previously, their usefulness for identifying and driving improvement of a PDP is limited. However, these measures are still useful if the PDP has not changed during the period from product development to data availability.

Cordero (1990) identifies measurements that should be made during the planning and control stages of development. The measurements are used to evaluate alternatives and to select those that help the company accomplish strategic objectives. They should also be used during the control stage to monitor project resources. Similar measurement activities are included in the generic PDP model presented in Chapter 7.

Hultink and Robben (1995) look at the influence of differing time perspectives on the importance companies attach to success measures. The measures that they cite are similar to those presented by Griffin and Page (1996), and therefore the same limitations apply.

Johnson and Dooley (1992) develop a set of metrics using Shewhart's "Plan, Do, Study, Act" (PDSA) cycle (see also Walton (1989, 1991) and Clausing (1994) for Deming's

"Plan, Do, Check, Act" (PDCA) cycle). In their case study, the company's implementation team selected the following five metrics as a guide to improve their PDP:

1. New product contribution to sales and profit margin.
2. Development process lead time performance.
3. Schedule achievement.
4. Business plan achievement.
5. Product acceptance in the company's key markets.

Criteria for Performance Measurement

Brookes and Backhouse (1998) in their literature review identify characteristics of effective product introduction performance measures, which should:

- relate to strategy and business processes
- be simple and relevant
- be influenced by the user
- foster an attitude of improvement and not just monitoring

Neely *et al* (1995) consider that measures should be part of a closed management loop i.e. they should lead to improvement action. Gregory (1993) presents measures for manufacturing that are also true of NPD. He notes that external measurement of a company's performance as seen by its customers is the most important.

Brookes and Backhouse (1998 p3) state: "Existing work indicated that effective performance measures needed to monitor today's performance and to show how to improve performance for tomorrow..." Also, "... measurements needed to be balanced to avoid any dangers of sub-optimisation." They note that 'balance' in terms of product introduction arguably means simultaneously monitoring three categories:

1. Lead-time of product introduction.
2. Resources consumed by product introduction.
3. Quality of product introduction output.

Brookes and Backhouse present a summary of desired generic performance measurement characteristics as:

1. The level of the performance measurement - mechanisms should give results at the 'whole process' level.
2. The balance of performance measurement - mechanisms should incorporate measurement of lead-time, resource and quality.
3. Ease of comparison of performance measurement - mechanisms should facilitate comparison across different product introductions.

They also imply that process measurement should be objective, not subjective.

Brookes and Backhouse critically review, against their criteria, the following measures of performance proposed in a Department of Trade and Industry (DTI) guide:

- Time-to-market measures
- Average concept to launch time
- Time for each phase
- Average overrun, percent of project overrunning
- Average time between product redesigns
- Product performance measures
- Product cost
- Technical performance
- Quality
- Return on sales
- Market share
- Design performance
- Manufacturing cost
- Manufacturability
- Testability

They find that, although balanced, these measures are not linked together in a framework to assist performance improvement. An objective of the evaluation method developed in this thesis is to provide a framework to assist performance improvement.

Brookes and Backhouse (1998 p7) note: "It may be true that it will always be difficult to feedback quality measures to product introduction because of the time lag involved...". The issue of time and how the developed method addresses this issue are discussed in the chapters that follow.

From their case study experience Brookes and Backhouse (1998 p7) suggest that in order to create effective and practical performance measurement mechanisms the following problems should be addressed:

- The lack of an effective quality measurement mechanism (where the quality of a process is perceived as the extent to which the output of that process matches customer expectations).
- Difficulties in making comparisons across projects owing to system problems (e.g. lack of computer automation, data inaccuracies) or comparisons perceived as lacking meaning.

How these problems are addressed by the method developed and reported in this thesis is discussed in the chapters that follow.

2.2.3 Research on Tasks and Characteristics of NPD

The findings, conclusions and recommendations of the literature presented in this section highlight NPD good practice that must be reflected in the PDP evaluation method developed in this thesis.

The literature is categorised into that dealing with particular tasks and characteristics of NPD (Section 2.2.3.1), that dealing with interactions between NPD tasks and characteristics (Section 2.2.3.2), and issues that relate to NPD as a whole (Section 2.2.3.3).

2.2.3.1 NPD Tasks and Characteristics

<u>Marketing</u>

The importance of marketing activities (e.g. preliminary market assessment, initial concept screening, detailed market study) and their timing (i.e. early in the process) to NPD success has been discussed in Section 2.2.1. The impact of product launch activities on NPD success has also been established (e.g. Cooper and Kleinschmidt 1986). Hultink *et al* (1997) examine the interrelationships between product launch decisions and NPD success. They identify decisions that are important to success, and the associations between these decisions. They find that strategic launch decisions (i.e. what, where, when and why?) made early in the NPD process affect the tactical decisions (i.e. how to launch) made later in the process. Their findings also emphasise the importance of launch consistency i.e. the alignment of strategic and tactical decisions made throughout the process.

Planning and Scheduling

Schmidt (1996) presents a technique for scheduling R&D tasks necessary to bring a product to market, while Record (1997) details the actions necessary to produce good business and financial plans. Collier (1977) observes that business analyses and planning i.e. setting product objectives and projecting the value of the business opportunity generated, is an imperative input to "R&D" (or in terms of this thesis, the PDP).

Product Concepts

Kleinschmidt and Cooper (1991) investigate the relationship between degree of innovation of a product and NPD success. They note a U-shape relationship, i.e. high and low innovative products are likely to achieve success when measured against a number of performance criteria. Their findings explain why innovativeness is not often identified as a key success factor, and is sometimes shown to be counter to success. They conclude that highly innovative products need not be associated with high risk, as is often thought.

Wind (1973) discusses a method for evaluating and screening concepts. Baker and Albaum (1986) evaluate new product screening models for accuracy of success prediction. They find that based on the results of their research a simple model should be used for decisions about new product concepts at the idea generation stage. They conclude that using a screening model should reduce the risk of new product failure.

Cooper (1979) investigates the underlying dimensions of new product success and failure with the purpose of providing an empirical base to new product screening models. Cooper reports that the three most important success dimensions that must be used to screen new product concepts are product uniqueness and superiority, market knowledge and proficiency, and technical and production synergy and proficiency. Cooper and de Brentani (1984) investigate what criteria managers use to screen new product concepts and how these criteria are weighted. They report that the top four criteria are financial potential, corporate synergy, technological synergy, and product differential advantage.

Design and R&D

Pinto and Slevin (1989) present ten factors important to ensure the success of R&D projects:

1. Project mission: initial clarity of goals and general directions.
2. Top management support: willingness of top management to provided the necessary resources and authority/power for project success.
3. Project schedule/plan: a detailed specification of the individual action steps required for project implementation.
4. Client consultation: communication, consultation, and active listening to all impacted parties.
5. Personnel: recruitment, selection, and training of the necessary personnel for the project team.
6. Technical tasks: availability of the required technology and expertise to accomplish the specific technical action steps.
7. Client acceptance: the act of "selling" the final project to its ultimate intended users.
8. Monitoring and feedback: timely provision of comprehensive control information at each stage in the implementation process.
9. Communication: the provision of an appropriate network and necessary data to all key actors in the project implementation.
10. Trouble-shooting: ability to handle unexpected crises and deviations from plan.

This is a rather mixed list. Factors 3, 4, 7 and 8 are tasks within the PDP, while the rest can be viewed as characteristics of the tasks.

R&D effectiveness has also been investigated by the following: Goltz (1986) who found that success of any R&D activity depends on, amongst other things, technical proficiency and senior management support; Szakonyi (1994), who proposes a method of benchmarking R&D effectiveness, found that the R&D departments he evaluated scored well below average; and McGrath and Romeri (1994) who develop an R&D effectiveness index.

Pappas *et al* (1985) consider the problem of determining the productivity of R&D within the company. Fohl (1990) presents a method for assessing R&D performance by assessing the improvement in the product's performance as it undergoes its cyclic iterations through the development process.

The importance and role of design within R&D and the development process has been investigated and established by Morley and Pugh (1987) and Wall (1991). Kusiak *et al* (1994) instigate improvement of the design (and manufacturing) process using IDEF models and algorithms for model analysis. Maffin (1998) proposes that to be more effective design should be based on models that are more sympathetic to the context and the needs of design practitioners.

Hauser and Clausing (1988), Griffin (1992), Griffin and Hauser (1993), Powers *et al* (1997) and Verma *et al* (1998) present research about QFD. Griffin (1992) finds that QFD demonstrates relatively minor, short-term, positive impact on product development performance. She reports that, in the long term, QFD may have the potential to improve the development climate, possibly leading to future improvements in development performance. However, while the use of QFD may have limited impact, some method/technique must be used to ensure that customer requirements are addressed during product design.

<u>Personnel</u>

Darter (1985) and Baker (1992) note the necessity of matching the right personnel to the right job. Baker focuses on qualifications (e.g. university degrees) while Darter is concerned with expertise. They both consider (explicitly or implicitly) and establish the importance of the correct allocation of personnel to jobs for successful product development.

Feldman (1996) investigates the role of salary and incentives in NPD. He finds that the reward systems of many companies do not recognise the importance of the new product function. Nor do companies recognise and take into account the importance of cross-functional teams when rewarding NPD personnel. Pinto and Slevin (1989) identify personnel as critical to successful R&D projects. Page (1993), Smith and Reinertsen (1991, 1995) and Atkinson *et al* (1997) support the importance of rewards in motivating personnel, and the importance of motivated personnel in achieving successful product outcomes.

Teams and Communication

In a review paper about integration of R&D and marketing, Griffin and Hauser (1996) note the necessity of effective communication to the development of successful new products. They find that co-operation (that increases communication) often leads to success. Smith and Reinertsen (1991, 1995) observe from experience the role of interdisciplinary or multifunctional teams to facilitate good communication (to shorten development times whilst maintaining quality) and hence improve NPD performance. Hensey (1999) identifies open communication as a key characteristic of an effective team.

In their work Richter (1987), Evans (1990), Brown and Eisenhardt (1995), and McDonough and Kahn (1996) either report or assume the positive effect of teams and communication on successful product outcomes. Dyer (1996) investigates the impact of supplier management on Chrysler Corporation's NPD success. He finds that communication and development performance (i.e. product quality and time to market) are improved by including suppliers as 'partners' and members of NPD teams.

2.2.3.2 Interactions between NPD Tasks and Characteristics

Marketing/R&D Collaboration

Cross-functional co-ordination and collaboration between R&D and marketing is crucial to the success of the new product development process (Song *et al* 1996). Particular aspects of this relationship such as interdisciplinary teams, communication, information flow, and QFD have been discussed above. Hise *et al* (1990) find that collaboration between marketing and R&D during the actual designing of a new product appears to be a key factor in explaining the success levels of new products.

Griffin and Hauser (1996) consider the amount and type of integration required to improve development performance. They find that integration leads to success, and that the amount of integration depends on such factors as current project phase and the level of project uncertainty. They also find that structural and process dimensions such as relocation and physical facility design, personnel movement, informal social systems, organisation structure, incentives and rewards, and formal integrative management processes, impact on the amount and type of integration.

Marketing/R&D/Manufacturing Collaboration

Song *et al* (1997a) expand the marketing/R&D relationship to investigate the effect on NPD performance of R&D, marketing and manufacturing co-operation. They conclude that breaking down the barriers between the R&D, manufacturing and marketing functions, using techniques such as concurrent engineering and QFD can pave the way for more effective NPD. Nihtila (1999) supports this finding. Song *et al* (1997a p35) also find that professionals from all three groups "believe that the strongest, most direct effects on cross-functional co-operation and NPD performance come from a firm's evaluation criteria, reward structures, and management expectations".

PDP Front-End

Smith and Reinertsen (1991, 1995) discussed the importance of the 'front end'[3] of the development process on product development performance. They find from experience that the timeliness (correct schedule and optimum duration) of 'front end' activities impacts on development speed (i.e. shorter time-to-market). They present techniques for shortening the 'fuzzy front end', which include good market research to quickly determine customer needs and market trends, and fast resource (human and finance) allocation.

[3] The *front end* of the product development process "starts when the need for new product is first apparent [and] terminates when the firm commits significant human resources to development of the product" [Smith

2.2.3.3 NPD as a Whole

NPD Cycle Time

Cooper (1995) finds that although 'accelerated product development' is key to new product success, there is not the one-to-one relationship often imagined. Cooper and Kleinschmidt (1994) cite findings by McKinsey and Company, which reveal that it is better to launch a product on time (assuming the correct time has been identified) but well over budget rather than be on budget and late to launch. Under a very specific set of circumstance, a six-month delay will reduce a high-tech electronic product's profitability by 33% (also Evans 1990). Cooper and Kleinschmidt (1994) investigate the drivers of project timeliness and the impact of timeliness on profitability. They find that timeliness does not guarantee profitability if product development quality is poor.

The conclusion that the most profitable result is obtained by getting the right product with the right attributes to the right market at the right time is fundamental to the work in this thesis.

Cooper (1995) reports that most sound business practices that help profitability also lead to fast-paced, on-time products. These practices include use of cross-functional teams, undertaking sound predevelopment 'homework', a strong market orientation that recognises and heeds 'the voice of the customer', and quality of execution of development activities. Effectiveness of activities is assessed in terms of timeliness and quality of execution (as well as cost). Drivers of quality and timeliness are important to the work in this thesis.

Methods, approaches and techniques for accelerating NPD and shortening NPD cycle time are discussed by, amongst others Rosenau (1988), Millson *et al* (1992), Stalk and Hout (1990), Smith and Reinertsen (1991, 1992, 1995), Smith (1996, 1999), and Hundal (1998). Nijssen *et al* (1995) present a hierarchical approach to implementing the various acceleration techniques. Langerak *et al* (1999) adapt the approach for new-to-the-firm products. Cohen *et al* (1996) present a model to address potentially conflicting goals (i.e. reduction in NPD cycle time versus improvements in product performance). Crawford

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and Reinertsen 1992 p47]. Examples of these elements include market research, concept screening, business analysis, etc.

(1992) investigates the hidden costs of accelerated product development. For example, he finds that accelerated product development is often achieved by omitting PDP steps.

Organisation and Culture

Dwyer and Mellor (1991a, 1991b, and 1991c) show that company organisation and corporate environment impact on the success of NPD projects. Langerak *et al* (1997) investigate how successful companies organise their 'internal interfaces'. They observe that companies with highly developed interfaces between functions within the company exhibit better new product performance. Johne (1984) recognises the importance of organisation to successful NPD. He investigates how experienced (successful) product innovators organise themselves, and concludes (1984 p220) that only a few companies (the successful ones) "are pursuing organisational practices which have been shown to be functional for getting new technically advanced products to market efficiently". Barclay and Benson (1987) also recognise the link between company organisation and NPD performance, and propose the use of organisation development as a method for managing change to improve NPD performance.

Galbraith (1974) considers organisation design from an 'information processing' perspective, while Lorsch (1977) takes a 'situational perspective' to design. Kolodny (1980) explores the reasons for the high rates of new product innovation from companies that have matrix organisations. He finds that a matrix organisation can cope with many simultaneous activities in different stages of development, and that the matrix appears to be very adaptable to environmental change. Lundqvist (1994) relates company organisation to the PDP by showing how the needs of the process are satisfied by organisational structure. He also presents a scheme for assessing the impact of the organisational structure on the performance of the process.

McDonough and Leifer (1986) investigate the relationship between company organisation, culture and innovativeness. They find that a certain style of project leadership and a company culture that emphasises a business orientation can achieve the balance between control of NPD projects and technical creativity.

NPD Strategy

Cooper (1984a, 1984b) identifies a link between NPD strategy and NPD performance. Cooper (1984a) finds that a company's NPD programme strategy is closely linked to the performance results achieved but that this depends on how performance is measured i.e. strategies leading to high performance by one set of measures can be different to strategies leading to positive results by other measures. In his second study Cooper (1984b) finds that a unique strategy is called for to achieve exceptional performance on any single performance dimension. However, he identifies one strategy (the balanced strategy) that achieves good NPD performance irrespective of the measures used. The balanced strategy requires technological sophistication, orientation and innovation, and also a strong market orientation (i.e. identifying market needs and market derived new product ideas). In addition, in a balanced strategy new products have a high degree of fit or synergy with the firm's current product line.

Souder and Song (1997) recognise that strategy affects NPD performance and explore the possibility that the correct NPD strategy differs depending on a company's perception of market uncertainty. Their paper reports that the key to success often rests in finding the right combination of product design and market choice decisions.

Management

Souder (1978) supports the importance of management to NPD success. He investigates methods for managing the PDP for development effectiveness. The most common methods used in industry, and the success of projects utilising each method, are presented. He finds that, in general, results suggest that a team approach is the most effective way to manage NPD. Souder (1978 p306) cautions: "It must be noted that even an optimum method cannot guarantee success, since many non-managerial and non-controllable factors may influence a project's outcome."

Other approaches to management include focusing on technology management with the view to improve NPD performance (Birchall *et al* 1996). Koch and Jakuschona (1995) provide a computer based value management method for managing product development. Ascribing a customer value to product attributes carries out value management. The contribution of every product feature to total customer benefit is determined. The product is designed to optimise the customer benefit and cost relationship. Roquebert *et al* (1996) investigate the effect of markets and management on profitability. They find that corporate managers and strategic management theory has a significant impact on profitability.

Concurrent Engineering

Clausing (1991, 1994), Wu *et al* (1996), and Barker *et al* (1996) acknowledge the positive impact on development performance of overlapping PDP activities. Takeuchi and Nonaka (1986) describe a holistic approach to developing new products. They note that the approach has six characteristics: built-in stability, self-organising project teams, overlapping development phases, multi-learning, subtle control, and organisational transfer of learning. They note (1986 p137) "the six pieces fit together like a jigsaw puzzle, forming a fast and flexible process for new product development."

The Market

Yoon and Lilien (1985) examine the effects of market characteristics and strategy on development performance. They report that performance is closely related to competitiveness in the market place, product life cycle stage, market growth rate, number of competitors, and marketing efficiency.

Calantone *et al* (1997) conclude that a 'hostile' competitive environment (i.e. intense competition and rapid technological change that heightens pressure to reduce NPD cycle time) increases the impact of NPD proficiency on NPD performance. Therefore, improving the performance of key NPD activities under hostile market conditions can greatly increase the likelihood of successful product outcomes. Calantone *et al* warn that rather than simply cutting corners in the PDP a company must strike a balance between speed and quality of execution.

The literature that has been reviewed in this section identifies issues, tasks and characteristics of the PDP that are important to NPD performance. In the work of this thesis a method is developed to evaluate PDP quality in this context.

2.2.4 Metrics and Measurements for NPD Process Quality

Importance of Metrics and their Relation to the Adopted Approach

Ullman (1997) describes five levels of company maturity:

1. Initial: PDP is ad-hoc/chaotic.
2. Repeatable: disciplined PDP where basic project management processes are established to track cost, schedule and functionality.
3. Defined: process activities for both management and engineering activities is documented, standardised, consistent and integrated into standard PDP.
4. Managed: predictable process where detailed measures of PDP and product quality are collected.
5. Optimising: continuous process improvement is enabled by quantitative feedback from the PDP and from piloting innovative ideas and technologies.

He notes that most companies fall below level three. He observes that to achieve level four requires detailed measures of both the product and the development process.

The literature shows that measuring and monitoring of performance is important to successful execution of PDP activities (Curry 1996, Heflin 1995, Tarr 1995). It is therefore important that measurement and monitoring characteristics of activities are considered in the assessment of activity execution effectiveness (see Chapter 7).

The literature presented in this section is discussed in relation to these considerations. Other metrics and tools to assess particular aspects of PDP performance are reviewed in Section 2.2.6.

Performance Metrics and Measurements of Particular Aspects of the PDP

Beasley (1999) notes the importance to success of measuring performance and proposes a benchmarking approach. Focusing on the construction industry, Beasley identifies five aspects of the development project, four of which are applicable to the work of the thesis.

1. Schedule performance
2. Cost performance

3. Achieving output objectives (of project)
4. Customer satisfaction

Cartwright (1996) considers elements of TQM (discussed in greater detail in Section 2.2.6) in selecting appropriate measures. The paper notes that "what gets measured gets done". In other words measurements are not only important to monitor performance but they also provide impetus to execute activities well. The observation provides support for the relevance of the work described in this thesis.

Atkinson *et al* (1997) describe a measurement system for improving a company's strategic performance. The system recognises the importance of company employees to the profits made. Thus activity assessment in this thesis must take into account factors affecting employee satisfaction which leads to motivation to develop skills and increase effort. These factors include status, environment, compensation, organisation culture, management style, and job design.

Atkinson *et al* (1997 p35) identify a general limitation of many measurement systems: "by focusing on results, rather than their causes, the company resigns itself to being reactive rather than proactive in meeting the need for organisational change." By implication an evaluation method should identify potential problems (in order to avoid them) by focusing on their potential causes rather than looking for indicators of problems that have already occurred. The approach adopted in this thesis is based on such a view (see Chapter 3).

A similar point concerning retrospective measurement is made by Slater *et al* (1997) who present a scorecard of strategic measurement along the lines of Kaplan and Norton's (1992) balanced scorecard method (discussed in Section 2.2.6). Slater *et al* make the following observation about financial performance measures: "Financial performance is an outcome. By the time that information is available the game, or at least the inning, is probably over". In other words financial performance measures are historical and retrospective, and comment only on activities that occurred at some point in the past.

Griffin (1993) observes that there is little point in effecting changes to processes if there is no baseline against which to measure any resulting improvement. She proposes development cycle time (also called 'time-to-market') as the baseline for performance measurement. This approach is supported by Rosenau (1988), Stalk and Hout (1990), Smith and Reinertsen (1991, 1992, 1995), Kmetovicz (1994), Hultink and Robben (1995), Smith (1996), and Hundal (1998), amongst others.

According to Brookes and Backhouse (1998), while important at a certain level, focusing only on time measures does not present a balanced view of overall PDP performance. They note (1998 p5); "Time measures are by their very nature unbalanced as they focus upon only one category of performance measurement, ... the lack of balance in this approach is likely to make it less effective and in some cases, dangerous." However, the fact that faster development and shorter time to market requirements exist is beyond question. Therefore the activity assessment method reported in this thesis must reflect (in a balanced manner) the measures, tools and techniques presented in existing literature that facilitate faster NPD.

Jain (1997) describes a conceptual framework for involving key members of the organisation to identify particular aspects that may be crucial for effectiveness of engineering and research companies. The purpose is to provide companies with a proper focus for activities crucial to their success. The framework consists of process measures, result measures and strategic indicators. The objective (i.e. to identify particular aspects that may be crucial for effectiveness) is similar to that of the PDP evaluation method presented in this thesis. Jain's use of key organisation members to derive the framework provides support for the approach adopted in this thesis.

Lawlor (1985) focuses on productivity in general, and notes that although a high proportion of attention to productivity has been directed to blue collar jobs, the field of white collar efficiency is important due to the size of the resources consumed. His definition of 'white collar' workers includes those responsible for the PDP.

Productivity measures place an emphasis on evaluating people's performance against some pre-set standard. This is the same emphasis as that of Performance to Standard (PS) methods presented by Zairi (1994), a critical review of which is presented in Chapter 7.

McGrath and Romeri (1994) focus on R&D effectiveness. They describe a method for benchmarking performance using 'best-in-class' companies. An R&D effectiveness index is calculated using the amount of investment in R&D (input) and the profit derived from new products (output). However, the observation made by Slater *et al* (1997) about the limitation of financial performance measures due to retrospectivity is also valid for this R&D effectiveness index.

Rather than using an input/output ratio type measure, Szakonyi (1994a, 1994b) describes a semi-quantitative schema for assessing activities within R&D "based on what R&D managers intuitively know is important". Szakonyi (1994a p29), whose work is based on similar work by Reynolds (1965), Collier (1977), Pappas and Remer (1985) and Steele (1988), discusses these measures: "... the methods used by [the] Borg-Warner [company] and Brown and Svenson (1988) are called 'semi-quantitative', which means that they are qualitative judgements that are converted to numbers." According to Pappas and Remer (1985), who compare measures of R&D productivity, semi-quantitative techniques are the best.

Szakonyi (1994a) provides guidelines for a R&D measurement system, noting that such a system should 1) require as little qualitative judgement as possible, 2) be logical, and 3) provide benchmarks to define average R&D performance, preferably based on the experience of many companies. His system evaluates the effectiveness of ten activities:

1. Selecting R&D.
2. Planning and managing projects.
3. Generating new product ideas.
4. Maintaining the quality of the R&D process and methods.
5. Motivating technical people.
6. Establishing cross-disciplinary teams.
7. Co-ordinating R&D and marketing.
8. Transferring technology to manufacturing.
9. Fostering collaboration between R&D and finance.
10. Linking R&D to business planning.

Relative importance weighting may be applied to activities. Activities are assessed against the following checklist with a score from 1 to 6.

1. Issue is not recognised.
2. Initial efforts are made toward addressing issue.

3. Right skills are in place.
4. Appropriate methods are used.
5. Responsibilities are clarified.
6. Continuous improvement is underway.

Szakonyi notes the benefits of this method as 1) qualitative data is limited i.e. all that must be ascertained is whether something is in place or not, 2) logic gives credibility (i.e. the method is not too qualitative), and 3) an average benchmark for each of the ten activities has been attained from over 300 companies.

It will be seen that the approach to assessing R&D performance underlying Szakonyi's method is similar to the approach to assess activity effectiveness described in Chapter 7. Szakonyi's method and philosophy provide good guidelines for the approach described in this thesis. However, the procedure described in Chapter 7 is more generic, and thus able to evaluate all PDP activities using the same set of measurement criteria.

Werner and Souder (1997a, 1997b) review the state of the art of R&D effectiveness measures. They propose three classes of measures, namely: qualitative metrics, quantitative-subjective metrics, and quantitative-objective metrics. They observe that product development performance measurements fall between quantitative-subjective (Szakonyi's method being an example) and quantitative-objective (e.g. input/output ratios). Their observation that many quantitative-objective metrics overlook inherent time lags that may bias the measures provides support for the approach adopted in this thesis. Werner and Souder (1997b p41) conclude: "because R&D is fundamentally uncertain, its measurement will necessarily remain imperfect. Though metrics are often enlightening aids to decision making, studied judgement remains the ultimate method for managing R&D". The approach adopted in the thesis aims to include studied judgement within a procedural method.

Ullman (1997) presents a basis for developing metrics that track and evaluate the PDP. He considers the PDP as a series of decisions on interrelated issues that modify information describing the product. Thus a decision structure based on 1) noting the issue to be resolved, 2) criteria associated with the issue, 3) alternatives developed, 4) comparisons between alternatives and criteria, and 5) the rationale for the decision, forms the basis for developing the metrics. Ullman observes that each decision is reflected in a change to the design or product state.

The concept of product states is incorporated in the development of the generic model discussed in Chapter 6. Further, the concept of information changes is integral to the activity effectiveness assessment procedure described in Chapter 7.

Forecasting of the performance of new products in the marketplace provides a performance prediction method that overcomes the limitations of retrospective measurement. Mahajan and Wind (1988) review forecasting models and tools. They note that these methods use one or more of the following data sources.

- Management and expert subjective judgement.
- Analogous products with similar characteristics to those of the new product.
- Consumer response.

The approach adopted in this thesis uses expert judgement in a forecasting type role (see Chapter 3).

Use of analogous products to forecast performance has value for incremental NPD. However, its accuracy for new-to-the-world products is questionable. The same argument can be made about consumer response as a performance measure. The only way in which consumers can assess new-to-the-world products is to field test a prototype. However prototype testing is well down the development road, at which point errors may be difficult and expensive to correct. The approach adopted in this thesis seeks to overcome these limitations.

Comment on Measurement of Particular Aspects of the PDP

Cooper (1980) observes that while no single factor or group of factors can ensure success, a single factor not executed correctly can ensure failure. Therefore, ensuring through metrics that a *particular* aspect of the PDP is effectively addressed cannot guarantee good performance of the PDP. Conversely, by Cooper's reasoning, any one particular aspect not executed effectively is likely to result in failure. Thus the issue of balance identified by

Brookes and Backhouse (1998) is pertinent. A balanced approach to PDP measurement and evaluation will consider all of the aspects identified in this section.

2.2.5 PDP Models

PDP modelling is identified above as one of six themes into which the literature naturally divides. The body of literature concerning PDP models can be divided into two types. That which describes models with a specific focus within NPD (e.g. market research, design, time to market, information flow, communication) and that which describes models of the complete PDP. Models of the first type are discussed below and those of the second type, in Chapter 6. However, some models that are discussed in this section are also discussed in Chapter 6 when they are relevant to the development of the new PDP model.

<u>SBU Level Model</u>

Dvir and Shendhar (1990) argue that factors affecting the success of high-technology system business units (SBUs) are different to those at product level. They propose a high level conceptual model for SBUs that has the following elements:

1. Environmental Influences:
   - Socio-economic environment.
   - Competitive environment: market potential; competition; and technologies.
   - Corporate environment: marketing support; market research; goals; strategy; values; culture; resource information; and control.
2. The Market Connection: customer needs and marketing.
3. Business Strategy: technology; marketing; and operational.
4. The Creation Processes: activities; structure and manpower; information flow; interpersonal processes; and control.

<u>Success Factor Interrelationship Models</u>

Calantone and di Benedetto's (1988) objective is to demonstrate the nature of the complex inter-relationships that exist among a series of variables (from Cooper 1982) that are important determinants of new product success. They achieve their objective by empirical validation of a hypothetical model that reflects the inter-relationships. The variables considered are marketing activities, launch activities, product quality, and technical activities, all of which impact on success or failure of a commercialised product. Calantone and di Benedetto also consider antecedent variables such as competitive and market intelligence, possession of adequate skills for marketing and technical activities, and resources for these activities.

Zirger *et al* (1990) go beyond a simple list of critical factors necessary to develop successful new products by creating a testable NPD model. This they achieve by identifying quantifiable constructs among the success factors, and then empirically testing the model. Critical organisational sub-units, development activities and communication channels that influence product outcome, as well as external factors such as characteristics of the product and the competitive environment, are incorporated in the model.

As a result of an extensive review of NPD literature, Brown and Eisenhardt (1995) propose an integrative model of factors affecting the success of product development projects. This model is a synthesis of the "overlapping and complementary focal interests as well as the theoretical complementarities" of three models identified from the literature i.e. product development as rational plan, communication web, and disciplined problem solving. The integrative model has 11 interlinked categories of factors (see Section 2.2.1) that impact on NPD success. The method of interlinking is dependent on the focus of the particular development process i.e. rational plan, communication web or disciplined problem solving.

The organising idea behind the model "is that there are multiple players whose actions influence product performance... Specifically, (a) the project team, [team] leader, senior management, and suppliers affect process performance (i.e. speed and productivity of product development), (b) the project leader, customers, and senior management affect product effectiveness (i.e. the fit of the product with company competencies and market needs [synergy]), and (c) the combination of an efficient process, effective product, and munificent market, shape the financial success of the product (i.e. revenue, profitability, and market share)."

Song *et al* (1997), taking direction from Brown and Eisenhardt (1995), hypothesise a model to investigate antecedent relationships in new product performance among the following variables: process skills; project management skills; skills/needs alignment; team skills; and design sensitivity. Song *et al* observe that their model anticipates a more complex relationship between product quality and process than indicated in the Brown and Eisenhardt (1995) summary of the NPD literature.

The particular focus of these two models is the interrelationships of project level success factors. The models imply key activities rather than explicitly identifying them. Project level factors must be reflected in the activity assessment method developed in Chapter 7.

Management and Control Models

Barclay *et al* (1995) describe a 'sphenomorphic'[4] model for the management of the development process i.e. define, develop, confirm, launch, and support. The model focuses on the need to concentrate effort in the early stages of development by identifying a *range* of potential product options. As the process proceeds the options reduce until a single, dedicated product is produced. In this manner "order emerges from chaos". This reduction of options is depicted as wedge shaped. The specific focus of this theoretical high level model is on management of the PDP. While the primary objective for developing the self-assessment method reported in this thesis is to aid management of the PDP, Barclay *et al*'s model is more philosophical in nature. The model highlights styles of management and where those styles might be appropriately applied rather than specific development activities.

A high level model for the control of product design is discussed by Fairlie-Clarke and Clark (1993) (see Figure 6.1). Their model recognises three product states: approved idea; approved concept; and released product. Each product state is achieved or recognised after a review and decision control activity. The control activity focus is on product information available from the design phases product inception, concept design and detail design. Successful review and approval admit the product to progress to the next product state. Although this is a high level control model for product design, Fairlie-Clarke and Clark note the model can be extended to apply to the complete PDP. This is discussed in Chapter 6.

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[4] The name 'shenomorph' is derived from the Greek 'spheno' - a wedge, and 'morphe' - form.

Design Process Model

Ward *et al* (1995) describe a design model used by Toyota which the authors call a 'set-based concurrent engineering' system. This approach is described as follows:

1. The team defines a *set* of solutions at the system level, rather than a single solution.
2. The team defines a set of possible solutions for various subsystems.
3. The team then explores these possible subsystems in parallel using analysis, design rules, and experiments to characterise a set of possible solutions.
4. The team uses the analysis to narrow gradually the test of solutions, converging slowly toward a single solution. In particular, the team uses analysis of the set of possibilities for subsystems to determine the appropriate specifications to impose on those subsystems.
5. Once the team establishes the single solution for any part of the design, it does not change the solution unless absolutely necessary. In particular, the single solution is not changed to gain improvements.

They note that this method of design is different to that used typically in the United States (and the UK) as a result of the influence of Joseph Shigley, who prescribes a process that iterates through a sequence of steps in which a designer first understands a problem then synthesises a solution. The designer then analyses and evaluates the solution. Based on the analysis, the designer tries a new solution (and possibly modifies the problem definition). This is often described as a hill-climbing process. Each successive solution is another step toward the best[5] possible design at the top of the hill. Because the process moves from point to point in the realm of possible designs, it is also referred to as a point-based design model.

These points should be considered when assessing the effectiveness of design activities (see Chapter 7).

Design Process Modelling Using IDEF

IDEF is a method for system modelling based on Softech's (1981) Structured Analysis and Design Technique. IDEF0 is a method to produce hierarchical function models of a system with each function represented by a box and with arrows to represent inputs, outputs, control mechanisms and the means to perform the function. Associated techniques are: IDEF1 for information analysis; IDEF1x and IDEF2 for dynamic analysis; and IDEF3 for process description with definition of sequence of activities and relationships between them. (Use of the IDEF modelling technique is discussed in Chapters 6 and 7).

Belhe and Kusiak (1991) use IDEF3 to model a design process. Their list of activities in a design activity network for design of an electro-mechanical module includes:

- Prepare system specifications.
- Generate preliminary design.
- Evaluate cost of different alternatives.
- Build prototype.
- Perform test on prototype.
- Analyse test data.
- Finalise design details.

The focus of Belhe and Kusiak's model is on the design process, so it does not detail activities for the entire PDP (e.g. marketing and business activities are not reflected). However, the level of abstraction of the activities is appropriate for a generic model.

Concurrent Engineering Models

The models described in Chapter 6 provide a list of activities or phases that are, or should be, executed. These models do not describe the processes needed for rapid NPD and fast time to market, such as parallel working and overlap of activities. New models were needed, a number of which are presented below.

[5] Whether the resulting design is the best possible solution is debatable. The resulting design is 'a' solution that satisfies requirements. There may be many others.

During the past decade or so product life cycles have shortened and the need to get products to market faster has intensified. One method for shortening the PDP is to execute PDP activities concurrently. Such a method is described by Takeuchi and Nonaker (1986) who liken the approach to a game of rugby (as opposed to a relay race) where the ball (product) is passed back and fourth between all team members (functional groups) while the entire team (company) moves itself and the ball (product) toward the try/goal line (product commercialisation). Their model depicts activities occurring in parallel rather than sequentially. This method is called concurrent engineering (CE) or simultaneous engineering (SE), and is the focus of literature by Backhouse and Brookes (1996), Barclay and Taft (1992), and Coughlan and Wood (1991), amongst others.

Karandikar *et al* (1993) define CE as "... a systematic approach to integrated product development that emphasises responsiveness to customer expectations and embodies team values of co-operation, trust and sharing in such a manner that decision making proceeds with large intervals of ***parallel*** working by all life cycle perspectives synchronised by comparatively brief exchanges to produce consensus."

The concept of activities occurring in parallel is not a new one. Myers and Marquis (1969) cautioned that the sequence of activities in their model was not linear.

CE is sometimes referred to as Integrated Product Development (IPD) (Inchwood and Hammond (1993), Barclay and Poolton (1994), Vajna and Burchardt (1997), Prasad *et al* (1998), Moffat (1998)). Andreasen and Hein (1987) note that design is central to the manufacturing industry and can no longer be treated in isolation. Design impacts on every part of a manufacturing company's business and *vice versa*. This broad strategic approach, involving the whole business, can best be described as integrated product development.

Sol (1997) describes Andreasen and Hein's (1987) integrated IPD model. This model shows the concurrency of the market development, product development, and manufacturing process development phases. Although the IPD model still distinguishes different phases in the development process it also shows concurrency of activities. All phases are driven by a common goal, deal with specific subjects, and result in delivering a successful product to market, fast. Activities within the three concurrently occurring phases are:

1. Market development phase: *determine the basic need; user investigation; market investigation; preparation for sales; and sales.*
2. Product development phase: *determining the type of product; product principle design; preliminary product design; modification for manufacture; and product adaptation.*
3. Manufacturing process development phase: *consideration of process type; determining type of production; determining production principles; preparation for production; and production.*

Barclay and Poolton (1994 p531) note that CE encompasses the basic design process of design, verify, review, produce, and test, and extends it both forward and backward. The process is non-sequential, being, rather, parallel and iterative. They find (1994 p531) that "at the heart of the CE process is the exchange and sharing of information."

All of the above are high level models with a particular focus on integration, concurrency or simultaneity of activities. These issues have been shown to be important to NPD success, and should therefore be reflected in assessment of activity effectiveness (see Chapter 7).

Models of CE/SE/IPD Elements and Assessment

Backhouse *et al* (1995) describe a research project to validate a contingent approach model to CE. The model illustrates how a combination of external forces act to change the product introduction process (PIP) form-elements (i.e. people, process, structure, control and tools) that are considered to be rotating. The external forces are:

- Efficiency: cost, time and quality.
- Proficiency: quality of process.
- Concentration: incremental change.
- Learning: breakthrough product.
- Direction: significant emotional event e.g. down-sizing.

The model focuses on important elements and influencing forces that impact on NPD performance. Similar considerations must be reflected in the activity assessment method described in Chapter 7.

Moffat (1998) describes and tests three models drawn from the literature, of the relationships between the tools and methods of IPD (or CE) and project task performance. These models are: 'linear independence'; 'reciprocal interaction'; and 'serial'. As a result of her tests Moffat proposes her own model, 'CE as multipath'. Moffat's work highlights the importance of CE methods and tools to performance. This must be reflected in activity effectiveness assessment. The notion of information sharing and exchange identified by Barclay and Poolton (1994) is the focus of Prasad *et al* (1998) who develop a model for information sharing in IPD which they call 'concurrent work flow management'. In their model each of four organisation 'work groups' (i.e. market, design, process and production) have work occurring *within* the work groups categorised as: pre-activity; main-activity; and post-activity. The model accounts for the product life cycle in terms of the following phases: requirements; design; process planning; and manufacturing. While it does not list activities, the model highlights information sharing as a factor that is critical to successful product outcomes and that must be accounted for when assessing activity effectiveness.

Finally, Parnaby (1995) describes some models used at Lucas Industries. The models are:

- Relationships between strategic planning, marketing process and product introduction process (PIP).
- Organisational structure for change management.
- Role of the product programme office with regard to auditing, support, standards, and assignments.
- The development of excellence via project management maturity growth (the 'maturity staircase').
- The role of key tools (e.g. QFD, FMEA, DFA/M, Fault Reporting and Corrective Action System (FRACAS)).
- Business process concept for development process of product and services, delivery operations process, and support process.
- The need for performance improvement.

While Parnaby's models are company specific and not necessarily transferable, they highlight various activities to be included in the generic model and considerations to be taken up in the activity effectiveness assessment method e.g. use of tools, change management.

All of the models presented in this section have a particular focus and highlight issues that have been shown to impact on successful product outcomes. These issues and considerations must be reflected in the measurement of activity effectiveness (see Chapter 7).

It has been shown in this section that the literature establishes modelling as important for the type of work covered in this thesis.

2.2.6. NPD Methods and Tools

The purpose of this section is to set the work described in this thesis in context by presenting some methods and tools used as management aids for NPD and PDP. A further objective is to develop an understanding of the complexity of NPD in general and the PDP in particular. The methods and tools discussed identify some important issues that must be addressed in the method developed in this thesis.

The value of tools as a management aid in product development has been recognised by the European Union (EU) in a major programme of work, reported by Brown (1997), that took place in parallel with the work described in this thesis.

It should be noted that although the work of this thesis takes into account experience gained with existing methods and tools, the motivation for the work was not simply to extend or develop existing methods, but rather to allow companies to improve their PDP by their own efforts. However, the work does present a new method and must be evaluated against existing methods.

This section is organised as follows: general papers about methods and tools (Section 2.2.6.1); methods and tools that address particular elements of the PDP (Section 2.2.6.2); and methods and tools that address NPD (including the PDP) as a whole (Section 2.2.6.3). Concluding remarks are made in Section 2.2.6.4.

2.2.6.1 General Methods and Tools

The method developed in this thesis permits benchmarking and PDP performance assessment. It can also be considered a Decision Support System (DSS) e.g. regarding resource allocation and PDP improvement. Further, the method is a Knowledge Based System (KBS) with potential for development as an Expert System (ES). An ES uses expert knowledge imbedded in a computer programme and makes decisions based on inputs. However, in this thesis the method uses accepted good practice to provide guidance to experts *to make their own decisions*.

Given the similarities between DSSs, KBSs and the method developed in this thesis, this literature was used to understand the issues involved in developing a DSS or KBS. Also, with a view to further developing this method into an ES (although outside the scope of this thesis) it is important to be aware of issues that should be accounted for at early stages of development of such a system. Literature describing general high level work relating to KBSs, DSSs and ESs is therefore reviewed.

<u>Computer-Based Tools</u>

Noci and Toletti (1997) discuss a mathematical DSS using fuzzy logic and fuzzy numbers assigned to linguistic judgements. The system provides a tool, for managers of small companies, aimed at supporting the process of evaluating quality based programmes (such as those discussed above) and selecting the most suitable within different competitive contexts.

The findings of Perkins and Rao (1990) emphasise the importance of management experience in information use and decision making. Their findings support the approach adopted in this thesis, i.e. the use of knowledge of experienced experts as inputs to the evaluation method.

Court (1997) presents a detailed discussion on the relationship between information, knowledge and memory, and reports the importance of communication and accessible information to successful NPD. Fedorowicz and Williams (1986) discuss issues that arise when modelling knowledge in an intelligent DSS. They observe that an intelligent DSS must provide a general model of management activities, and a mechanism to refine and test the applicability of the model for each application. Landauer (1990) presents principles to ensure correctness of rule-based expert systems. The paper defines a set of requirements that should be satisfied before a set of rules becomes a rule-base, i.e. consistency, completeness, irredundancy, connectivity and distribution. These papers provide understanding of some of the complexity in designing a KBS.

Meyer and Booker (1991) present and discuss techniques to elicit and analyse expert judgement, some of which were used during testing of solutions to the research issues described in Chapters 4 to 9.

Blount *et al* (1995) support the use of a KBS for improving the product introduction process. They note (p31): "The adoption of KBS technology into engineering design presents a massive opportunity to companies in search of new ways to improve their product introduction process." They outline a method for selecting suitable KBS applications. They also note the importance of first developing a PDP model as has been done in this thesis. Further insight is provided by Dutta (1997) with general discussion on KBSs; Sen and Biswas (1985) who describe an ES approach to DSS; and Beulens and Van Nunen (1988) who give characteristics and objectives of ESs and DSSs.

Liberatore and Styliano (1993, 1994, 1995a, 1995b) present a development philosophy and framework for what they term "Expert Support Systems" (ESSs). They do this while developing tools for project assessment (1993), strategic market assessment (1994), customer satisfaction assessment (1995a), and NPD decision-making (1995b).

Ram and Ram (1996) propose and test a framework for validating expert systems designed for new product management. The proposed validation framework considers three aspects of the expert system; its knowledge acquisition methodology, its performance, and its utility. To quote (p54): "A system that is validated improperly or insufficiently can lead to poor decisions, resulting in poor confidence and ultimate disuse of the system."

Their validation framework is as follows:

1. Validation of knowledge acquisition methodology
    - Sources of knowledge used

- Criteria for selection of human experts
- Methods used for knowledge acquisition

2. Performance validation
   - Establish knowledge validity
   - Establish domain validity
   - Determine reliability of the system
3. System utility assessment
   - Relevance of the problem domain for which the system has been built
   - Evolution of the system's performance
   - Quality of the user interface

Appropriate issues and criteria were taken into account in the design and validation of the method developed in this thesis.

Thurston and Tian (1993) and Sambasivarao and Deshmukh (1997) describe DSSs that incorporate a specific decision making method known as the Analytic Hierarchy Process (AHP). Trials of these methods indicate the successful application and value of using the AHP. Thurston and Tian note that test results using the AHP were superior to those without. Calantone *et al* (1999) use the AHP to screen new products and find that:

- In most cases, respondents confirm that the AHP model captured their understanding of the decision problem and sometimes commented at how insightful the results were.
- The pragmatic validity of the AHP model was illustrated.
- Managers relying on a subset of information were likely to make a sub-optimal choice. The AHP addresses this problem, as all information is available and used during pair-wise comparisons of alternatives.
- The technique is particularly easy to implement, and its simplicity increases managerial "buy-in".

It can be seen in the papers of, amongst others, Saaty (1977, 1990a, 1990b, 1990c, 1990d), Forman (1990, 1992), Dyer (1990a, 1990b), Harker and Vargas (1990), Schoner and Wedley (1989), Schoner *et al* (1993) and Schenkerman (1997) that the AHP has been extensively researched. Zahedi (1986) lists 26 areas of application, indicating its versatility. The AHP is adopted in this thesis and is discussed in Chapter 8.

Non-Computer-Based Tools

Araujo and Duffy (1997) describe a method to assess and select from the large number of tools (e.g. methods, techniques, principles, methodologies), those that have the potential to help a company to formulate, control and/or undertake the wide variety of tasks and problems involved in NPD. Spring *et al* (1998) present a method that companies can use to evaluate their use of various techniques (e.g. QFD, FMEA, DFX) in product development. These papers identify tools and methods important to NPD performance. Utilisation of such tools and methods forms part of the method to assess activity effectiveness developed in this thesis.

Wind and Mahajan (1991) and Mahajan and Wind (1992) assess the role of new product models (mainly marketing) as tools for supporting and improving the NPD. They observe low utilisation among companies of such tools as focus groups, concept tests, attitude and usage studies, conjoint analysis, QFD, and product life-cycle models. However, those companies that used the models and methods did so because they believed that these methods improved the success rate of new products and identify problems with the product. Wind and Mahajan (1992) note that method usage must be simplified and 'black box' rationales must be avoided.

2.2.6.2 Methods/Tools for Evaluation and Improvement of Elements of the PDP

Computer based and other methods and tools have been developed to address most elements of the PDP.

PDP Front-End

Moutinho and Paton (1988) present ES tools for particular aspects of marketing e.g. SMART, BRAND*STAR (forecasting), DigiData Entry (market research). Cohen *et al* (1997) present a DSS for managing the NPD process in the packaged goods industry. The DSS evaluates the financial prospects of new product concepts. Ram and Ram (1989) describe INNOVATOR, an ES developed by them to assess the success potential for new products in the financial services industry. They demonstrate the feasibility of developing an ES specifically for screening new product ideas.

Kettlehut (1991) uses a DSS to incorporate expert opinion in strategic NPD funding decisions. Kettlehut concludes from test results (1991 p369) that the DSS "added structure to the decision process. Quantitative models aggregate numeric data for review, facilitating objective analysis and reducing cognitive bias." These conclusions support the approach adopted in this thesis which adds structure and facilitates a more objective analysis of the PDP.

Ahn and Dyckhoff (1997) describe a DSS concept to assist in selecting the most appropriate product development activities. Vajna *et al* (1997) describe the use of a KBS to select the correct tool (CAD, CAM, CAE, etc.) for each activity. Every step in the 'product creation process' is linked to suitable methods and tools that have been identified as appropriate for that step.

Akoka *et al* (1994) describe an ES to assess the feasibility and probability of success of a new product based on financial, marketing, and environmental (i.e. economic) factors. The ES assists in managing the complexity of interactions between the three dimensions and evaluates the commercial synergy of the project. The importance of synergy (technical and commercial) is recognised in this thesis and incorporated in the constituent activities of the generic PDP model developed in Chapter 6.

<u>R&D and Design</u>

Szakonyi (1994a, 1994b) determines R&D effectiveness by identifying ten activities considered important. Each activity is assessed and scored according to a six-level checklist. The method allows for relative weighting amongst the activities. McGrath and Romeri (1994) present a management tool to guide and measure improvement to the PDP by means of a R&D effectiveness index. The index is used as a benchmark by expressing the amount of investment in NPD in terms of profit from new products.

Wagner (1997) presents a method for improving the design process by evaluating design activity outputs against qualitative parameters e.g. form and function, ergonomics, aesthetics, operation assembly, safety. Fowlkes and Creveling (1995) discuss Taguchi methods for robust engineering design. McLinn (1994) discusses FMEA and Process Analysis, which identifies the shortest, most efficient process path as well as the impact of key process steps. Brouwer (1998) describes the European Design Innovation Tool (EDIT) to assist SMEs to improve competitiveness by improving organisation of their design management and design processes. Evaluation is made in the context of best practice issues (e.g. multidisciplinary teams, proficient market research, shorter time to market) that must be reflected in the evaluation method developed in this thesis.

Sen and Yang (1993) describe a Multiple Criteria Decision-Making (MCDM) method to make engineering design decisions, and include a discussion of the AHP. Sen *et al* (1997) describe the design of a multi-criteria decision system utilising Taguchi robust design methods.

McLinn (1994) and Verma *et al* (1998) describe QFD and its implementation. Griffin (1992) investigated the role and affect of QFD in American companies and found that the tool demonstrated relatively minor, short-term measurable impacts on product development performance. The most tangible benefits being improvement in time to market and development cost. She concludes QFD may have the potential to improve development climate in the long term, possibly leading to future measurable improvement in NPD performance.

Powers *et al* (1997) present a hybrid QFD/AHP methodology to measure the overall performance of an existing product and also to predict the performance of a new product concept. This method requires identification of product features (called 'design dependent parameters' - DDPs) for a company's existing product, future product and competitor's product. DDPs giving competitive advantage must be addressed by the PDP. The method is used to support conceptual design decisions rather than assess the effectiveness of the PDP.

Tan *et al* (1997) discuss a computer-based method to make simultaneously available to all NPD team members all information describing the current state of a product. Their method recognises the impact of communication and information availability on development performance and is relevant to assessments of activity effectiveness made in this thesis.

Cristofari (1997) describe the design of an interactive software tool that allows interaction between environmental decision making techniques, quality considerations, legal factors, benefit-cost analysis, as well as a powerful tool for multi-attribute decision analysis. The aim is the evaluation of alternative possibilities in the design and production phases of a product.

Organisation of Activities, Communication and Concurrent Engineering (CE)

Crawford's (1984) 'Protocol' addresses the problem of effective communication between Marketing and R&D. He focuses on the diplomacy of transferring user requirements saying: "marketing decides ***what*** the user is to get from the new product, and R&D decides ***how*** to provide it" (emphasis added). He notes (p86) that this method is not universally applicable and identifies three such situations:

1. Situations where the user specifies exactly what they want.
2. Non-technical situations.
3. Situations where the products produced are intended for pleasure i.e. the outcome cannot be predetermined (e.g. toys, sweets).

CE demands effective information management and communication structures. Oehlmann *et al* (1997) present a methodology for optimising availability of information by creating awareness about existing and potential problems and providing decision support for communication improvement. The methodology addresses 'needs' of activities i.e. information needs and the communication means and patterns used to satisfy these needs. They note that an activity can be described by its actors, resources, environmental conditions, inputs (other than its resources) and outputs.

The activity effectiveness assessment method developed in this thesis utilises a similar concept (described in Chapter 7). Oehlmann *et al's* descriptors i.e. actors, resources, environmental conditions, inputs and outputs, are considered as part of the characteristics of an activity which are assessed to determine activity effectiveness.

The importance of CE/SE/IPD principles to NPD performance has been argued. These issues are addressed in this thesis as part of the assessment of activity effectiveness. The importance of these principles is reinforced by the abundance of computer based and non-computer based CE and related tools and methods. Some of these are described here.

Eppinger *et al* (1994) present a model-based method for organising PDP tasks by capturing the sequence and technical relationships amongst the many design tasks to be performed. These relationships define the technical structure of the project, which is analysed to find alternative sequences and/or definitions of the tasks with the aim to speed up development. Krishnan *et al* (1997) build on the work by Eppinger *et al* (1994) and present a mathematical method for converting sequential (dependent) activities to overlapping activities that share information.

Tools and methods for implementing CE are proposed by Carlson-Skalak *et al* (1997a, 1997b) and Lettice *et al* (1995). Taft and Barclay (1992), Barclay and Taft (1992) and Poolton and Barclay (1996, 1998) assess the CE/SE implementation level required by a company. The level is based on the degree of complexity of the product produced by the company. Backhouse *et al* (1995) and Brookes *et al* (1995) describe a contingency approach to aid implementation of a form of CE suitable to any particular company.

Karandikar *et al* (1993) cite seminal work on CE assessment by Carter and Baker (1992) and describe a methodology called RACE (Readiness Assessment for Concurrent Engineering) to assist CE implementors to identify barriers and prioritise implementation actions. Schrijver and Graaf (1996) describe the use of RACE as a benchmarking tool. Graaf and Kornelius (1996) use RACE to identify process deficiencies pertaining to customer and supplier communication.

Ahrens *et al* (1997) are concerned with the financial implications of implementing CE/SE. They propose a method that aids those responsible to decide to what extent changes to the PDP can be made simultaneously and "whether or not the effort to realise the reorganisation of the product and process structure is [financially] acceptable"

Place (1992) discusses tools integral to a CE approach to product development. He divides tools into seven general areas applicable to the PDP: requirements generation; design optimisation/integration; rapid prototyping; production control[6]; test/assessment; supportability; communication tools.

Thoben *et al* (1997) presents a computer based DSS to aid selection of CE tools from a database to suit a particular development stage, in terms of benefits, application, specialities, etc. of each tool.

Agrell (1994) presents a DSS to address Design for Manufacture (DFM) issues. The DSS brings issues of manufacturing, production planning, and maintenance to the knowledge of the designer, "while not hampering creativity and flexibility". The proposed approach also forms a methodology for collaboration and communication between function groups.

Bayliss *et al* (1997) describe a DSS for design improvement in CE called DE-ACE (DEcision-Aid for Concurrent Engineering). DE-ACE has two goals: 1) to produce the best global design, and 2) to ensure the design can be produced without costly or time-consuming modifications.

D'Souza and Greenstein (1996) use an ethnographic based approach to understand and identify issues relevant to the design of a DSS to support the PDP. The results suggest the need for a computer based system to support a more responsive, collaborative approach to the PDP. D'Souza and Greenstein (1997a, 1997b) develop and test their DSS. They report that use of their system resulted in reduced task completion time, primarily due to a 44% reduction in time devoted to non-value adding (NVA) activities[7] (where NVAs accounted for 6% of development time).

Zanker *et al* (1997) describe an Interactive Protocol and AnalysiS method (IPAS). The objective of the DSS is to support the continuous process of data acquisition and analysis. Project managers can retrieve any relevant information concerning project status and any weaknesses i.e. recorded problems, in the development process. The system may be used as a 'lessons learned' database.

[6] Not part of the PDP as defined in this thesis

[7] Non value adding activities are defined as any activity that does not directly impact on progressing the state of the product e.g. waiting at a photocopier, walking to printer, etc.

CE methods and tools focus on organisation and timing of activity execution. None of the tools/methods presented above focus on quality of activity execution.

2.2.6.3 Methods/Tools for Evaluation and Improvement of NPD

Strategy

Souder and Song (1997) observe that NPD strategy affects performance. They note that the key to success often rests in finding the right combination of product design and market choice decisions. They describe a tool for determining product strategy based on market uncertainty. Padillo and Nuno (1992) describe a method for evaluating synergy between a company's manufacturing structure and business strategy. The diagnostic tool determines the degree of fit between the manufacturing structure and business strategy. The pair-wise comparison method of the AHP is used to determine a course of action to improve the degree of fit.

Kaplan and Norton (1992, 1993), describe their 'balanced scorecard' method to measure performance and set strategy by tracking the key elements of a company's strategy. Schollnberger (1996) illustrates use of Kaplan and Norton's balanced scorecard method and notes that the method "supplements traditional financial and physical measures with metrics that cover intangibles such as customer relationships, the ability to innovate and learn, and internal business processes."

Crawford (1980) describes a "Product Innovation Charter" that consists of a set of policies and objectives designed to guide NPD.

These papers illustrate the importance of strategy and synergy of strategy with company capabilities to NPD success. It is not the focus in this thesis to look at detailed aspects of policy and strategy. However, PDP activities must implement company strategy and policy. Activities to evaluate product concepts and ideas against company strategy and policy are included in the generic PDP model developed in Chapter 6.

Improving PDP Quality

Johne *et al* (1988) describe the McKinsey 7S framework popularised by Peters and Waterman (1982) to audit the innovation process at the business unit or company level. The seven 'S's (also discussed in Section 2.2.1) refer to NPD *strategy*, *shared* values (for business growth), *style* (management i.e. support for NPD team), *structure* (organisation for NPD), *skills* (knowledge and techniques for NPD activities), *staff* (to execute NPD), and *systems* (NPD control and co-ordination mechanisms).

Parnaby (1995) presents a generic planning, marketing and 'product introduction process' (PIP) model as elements of a method used by Lucas Industries to improve the PIP. Features of the method include accelerated PIP implementation, implementation of quality techniques, CE, co-located cross-functional teams, and implementation of PIP support tools - DFM, QFD, Design to Cost, FMEA. The method recognises the impact of these features on a product's market performance. PIP improvements due to application of this method are:

1. PIP cost - 43% reduction - 28% fewer personnel.
2. 95% reduction in changes per drawing.
3. Product cost - 15 to 20% reduction.
4. PIP lead-time - 30% reduction to produce manufacturing instructions.
5. Parts rationalisation - 29% increase in use of proprietary parts.
6. Improved schedule adherence.
7. 55% reduction in effort to process drawing changes.

However, results do not indicate degree of improvement of the particular product's performance in the market place.

Spivey *et al* (1997) describe a 'fractal paradigm' framework for improving the PDP. Their framework consists of a set of concerns (i.e. fractals), which must be addressed regardless of the level of detail at which the framework is viewed. Improving the NPD process thus requires attention by all levels within the company to two sets of factors: 1) management factors - leadership (NPD commitment and support) and management system (communication, structure, tasks to increase customer satisfaction), and 2) resource factors - information, infrastructure, time and money.

Smith (1996) presents a change management method for ongoing improvement of the PDP. The method provides a 12-step process for capturing lessons learned from each project. He notes benefits of faster product development, higher value products, lower cost products, more products per dollar, and more responsiveness to turbulence in markets, technologies and the regulatory environment. Smith argues that lessons learned must be captured and that ongoing change must occur through formal company procedures. These arguments are accounted for in the method developed in this thesis. Activities that facilitate feedback and change to the PDP are included in the generic model developed in Chapter 6, and are evaluated for effectiveness.

Yazici and Tugcu (1996) present a change management method based on quality, for redesigning the PDP. They comment (1996 p566): "A quality based approach providing the means of managing techniques with a synergy of all system components can affect the success of redesigning engineering processes." The method is infused with process quality principles from Total Quality Management (TQM), Business Process Management (BPM), ISO-9000, and CE/SE.

The importance to NPD success of particular dimensions and tools is confirmed by the literature presented above. These dimensions and principles must therefore be reflected in the method developed in this thesis.

NPD Performance

Mahajan and Wind (1988) evaluate strengths and weaknesses of new product performance forecasting tools (including the AHP). They conclude the use of such tools reduces the probability of new product failure.

Yoon and Lilien (1985) present a method to determine innovation performance based on R&D and marketing decisions, sales performance and market characteristics. They state (1985 p143) that the method can be used as a "quantitative checklist for the manager of a 'soon to be launched' product, identifying an appropriate set of objectives and a marketing strategy.... the manager can receive a *prediction* of the level of first year market share performance and the likelihood that the product will grow into a product group." However, the method only permits prediction of a product *already in the market*. The method can also be used retrospectively to assess past processes.

Pocock *et al* (1997) describe a method to determine NPD project performance based on the degree of interaction (DOI) between designer and builder. They observe that, discounting deficiencies in design, project performance is significantly better for projects with higher DOI across all facets of the project. They combine results with statistical analysis to predict the performance of future projects based on the DOI scores of the particular project. A limitation is that the method does not consider the *quality* of interaction. Quantity of interaction does not guarantee quality.

Atolagbe (1990) presents a method for assessing the 'product development capability' of a company. Customer identified product characteristics are mathematically evaluated to give a product score. According to Atolagbe, scores above a certain level indicate the product has a good chance of success. The method can be used for benchmarking. However, although the method takes into account the calibre of personnel, it does not consider the quality of the development process. While the stated purpose of the method is to identify areas of the product requiring attention this is not drawn through to identify corresponding PDP areas requiring attention. (I.e. if a problem exists with the product there must be a problem with the process). Atolagbe's approach of assessing the product from the point of view of the customer through identification of important product issues is similar to the approach taken in the method developed in this thesis.

Paolini and Glacer (1997) describe a project selection method to select products with high probability of success. According to Paolini and Glacer projects with an 'innovation potential' score of 70% or more are likely to be winners. Innovation potential is determined from quality of cross-functional communication (20 points), technical proficiency (20), product champion (15), market (15) and technical opportunity (10), senior management interest (10), competitors (5), and timing (5).

Cooper (1985) uses the results of project NewProd (Cooper 1980) to develop a tool to select NPD projects with high probability of success (based on past history of the company and industry) at the idea screening stage. He also develops an efficiency rating based on firm inputs and outputs by way of a firm benchmark (Cooper 1982). The efficiency rating is a function of the percentage of sales by new products introduced in the last five years, annual company sales, and annual R&D spending. However he notes (1982 p219) that "measurement problems, including differing accounting procedures across firms, prediction of the sales over the product's life, and the choice of an appropriate discount rate [i.e. bank interest rate] made such a computation impractical"

Arleth (1987) presents DanProd (based on Cooper's NewProd), a decision tool for evaluation of new product ideas and concepts. The tool will predict the probability of, and state the reasons for, success of a new product development project. The tool provides a fixed list of important product issues and NPD activities. The tool does not permit a unique company approach because each issue and activity is considered to be of equal importance to success.

Slevin and Pinto (1986) describe the "Project Implementation Profile" based on their previous work to determine critical factors for successful project implementation (Pinto and Slevin 1986). They note (1987 p22) that this management tool is a "behavioural instrument to be used as a diagnostic for assessing the status of any product as determined by the ten factor model". (The ten factors are discussed earlier in this thesis.) The objective of the method is to provide project managers with a numerical tool to assign scores to critical success factors and to monitor them over time. Thus each of the ten factors includes a number of prescriptive considerations. Each consideration is scored on a scale of 1 to 10. Scores can be compared with a benchmark derived from a study of 82 successful projects. As stated earlier (see Section 2.2.3.1) the ten factors provide an input into the method developed in this thesis by highlighting elements that must be included in the generic PDP model and activity effectiveness assessment method.

Wadhwani and Schroeder (1998) describe a mathematical model to address the apparent conflict between speed to market and product quality. This seeks to maximise profitability associated with a NPD project by balancing the economics of too early introduction (excessive speed resulting in poor quality) against late introduction to market (excessive quality resulting in poor speed). The model shows the quantified effect of product price, unit cost, demand, and investment in NPD on the level of product quality at introduction. These issues are addressed in the method developed in this thesis as solution quality, resource consumption and time dimensions of important product issues (discussed in Chapter 4).

Benchmarking

Cooper and Kleinschmidt (1995, 1996) present a method for benchmarking NPD performance. Their empirical research identified 10 metrics related to NPD performance. Measuring successful companies using the metrics indicated that as well as a formal PDP, successful companies have a high quality process, a clear and visible strategy, sufficient resources (human and financial) and a 'respectable' R&D budget.

Modelling Tools and Techniques

Tools and methods are often based on models. Thus a tool to assess completeness of the PDP is likely to incorporate a PDP model. IDEF is a method developed by Softech (1981) to model manufacturing systems. Colquhoun *et al* (1993) present a state-of-the-art review of IDEF0. Brookes *et al* (1994) discuss the use of IDEF to model the PIP. Ang *et al* (1994) present a KBS to automate generation of generic IDEF models (GIMs). Childe and Smart (1995) discuss the use of process modelling (using IDEF) to identify the correct activities to study when benchmarking a business' competitive performance.

The use of IDEF to model the PDP (Brookes *et al* 1994; Childe and Smart 1998) and produce a generic model (Ang *et al* 1994) supports the approach adopted in this thesis to develop a generic model of the PDP using IDEF principles. This is discussed in detail in Chapter 6.

Total Quality Management

Total Quality Management (TQM) recognises the importance to company (and national) well being of successful NPD and ongoing improvement of the PDP, and promotes measurement and metrics to facilitate improvement. TQM uses a number of methods and tools to drive quality improvement. Ishikawa (1985) presents statistical methods for Total Quality Control (TQC). Clausing (1994) describes use of Taguchi methods and QFD in his Total Quality Development (TQD) system (i.e. application of TQM principles to product development). Spring *et al* (1998) discuss the use of quality tools and techniques in product introduction. Zaloom (1984) describes the use of statistical quality control (SQC) to measure changes in organisational effectiveness. Other aspects of TQM include measurements of competitiveness (benchmarking), measuring for quality culture (self-assessment), performance improvement (performance appraisal), quality policy deployment (QPD), and implementing effective performance measurement systems (Zairi 1994). Aghaie and Popplewell (1997) illustrate the potential of computer simulation methods applied to TQM.

Total Quality Management (TQM) is the name given by the United States Navy to the Deming management method, the essence of which (and of TQM) is encapsulated within the 'fourteen points', the 'seven deadly diseases' of management, and the 'obstacles' to excellence (Walton 1989, Walton 1991). Deming teaches several other important principles: the 85-15 rule; "know thy customer"; and the plan-do-check-act (PDCA) cycle (Walton 1991).

Dale's (1997) description of the characteristics of five organisations not committed to total quality management illustrates the relevance of TQM principles. Today these principles are axiomatic and widely applied (Katz *et al* 1998). For example, Markert *et al* (1999) present Deming's fourteen points adapted to service sector companies.

The importance of TQM can also be illustrated by searching databases of management periodicals. The database used in this instance contains 12 500 periodicals published from January 1990 onward. Searching for publications containing the keyword 'TQM' returned 1136 'hits'. Thus, approximately one publication in ten has an article on TQM. This number could be even greater should search terms also include 'total quality management', 'quality', and 'Deming'.

TQM principles must, therefore, be reflected in the developed PDP evaluation method. This has been achieved in the procedure to assess activity effectiveness described in Chapter 7. However, a limitation of TQM relative to this thesis is that the statistical process control (SPC) methods of TQM are retrospective. This implies that due to elapsed time between product generation and data generation a development process deemed to require improvement may no longer be in existence. However, it is recognised that this 'problem' is minimised if time periods between the execution of an activity and the gathering and analysis of data are relatively short.

An aspect of TQM philosophy that supports the approach presented in this thesis is that of basing important improvement decisions on data (Ishikawa 1985; Walton 1989). A feature of the method developed in this thesis is to quantify subjective knowledge so as to provide data to guide management in continuous improvement of a company's PDP.

Self-Assessment Tools and Methods

Zairi (1994) evaluates the role of self-assessment (SA) tools in the context of TQM. He does this by discussing the Deming Prize (Japan's highest quality award), America's Malcolm Baldrige National Quality Award (MBNQA), and the European Quality Award (EQA). These frameworks help senior management to assess their strengths and weaknesses in various areas and whether they are deploying their quality efforts in the right way. Zairi also discusses objectives of the Australian Quality Award and NASA Quality and Excellence Award.

The European Foundation for Quality Management (EFQM) (1996 p9) self-assessment model is based on the following premise: "customer satisfaction, people (employee) satisfaction and impact on society are achieved through leadership driving policy and strategy, people management, resources and processes, leading ultimately to excellence in business results."

A concern about self-assessment tools is that they require that certain issues be addressed based on a model of the company processes at a high level of abstraction. Thus they tend to focus on the existence of certain elements of the process but do not focus to any depth on the process itself, or the quality within the process e.g. activity effectiveness. Further, scoring systems are fixed. Thus the relative importance to quality (and therefore to success) of each particular aspect tested is prescribed. This limits companies in expressing their uniqueness. The method described in this thesis addresses this issue by allowing experts to judge the relative importance of particular elements of the PDP to successful product outcomes.

Dale and Coulambidou (1995) perform a state-of-the-art study on the use of SA tools in the UK. They find that one of the obstacles to implementing and operating a SA process is failure to gain top-management support. Teo and Dale (1997) discuss the application of SA tools (i.e. EFQM, EQA and MBNQA) in four companies. They identify that effective management and using a team to manage the self-assessment process is key to successful SA. The most important SA activities are reported (1997 p365) thus: selection of a suitable SA model, appropriate approach/approaches for the assessment, provision of appropriate training, monitoring the progress of improvement actions, establishment of a "closed-loop" structure for the improvement cycle and integration of improvement with the strategic business. SA difficulties included scarcity of time, over-emphasis on scoring and scores, failure to follow up improvement actions and lack of communication.

Other SA tools to evaluate product development include those by Scottish Design (1997), Hurst (1995), and a computer based SA tool developed as part of the Sector Challenge programme (Royal Academy of Engineering 1997). These are high level tools that reflect important NPD issues at company level and project level.

Issues addressed by SA (e.g. senior management support and commitment, training, measurement and metrics, communication and organisation, project manager/management) are recognised and broadly addressed in the method developed in this thesis through the evaluation of activity effectiveness.

Cook *et al* (1995) describe the development of a self-assessment framework for global new product introduction. They conclude that very few companies use self-assessment techniques to improve their PIP.

2.2.6.4 Concluding Remarks about Methods and Tools

Literature has been discussed that presents methods and tools to improve the quality of NPD in general and the PDP in particular to aid understanding of the complexity of the PDP. This literature also highlights good practice that must be incorporated in the method developed in this thesis. For example:

- Product performance forecasting

- Concurrent engineering
- Design
- Market research
- Concept screening and product selection
- Project selection
- Interaction and communication
- Planning and scheduling
- Performance measurement
- Change management
- Staff quality
- Use of tools e.g. self-assessment and benchmarking

Over and above aspects of good NPD practice, the literature aids the development of the method described in this thesis by highlighting good and desirable features and characteristics of successful methods and tools e.g. DSSs and their validation.

Limitations of Existing Tools

The review also illustrates that a gap exists for a non-prescriptive method, which uses company knowledge to identify important product issues (for customers, market and company) and assess activity effectiveness with regard to three dimensions (execution quality, cost and time) to evaluate a proposed PDP. While some of the methods and tools presented and discussed above may have one or more of the features, no single method or tool exhibits all. The method developed in this thesis and presented in the following chapters addresses this issue.

3

A PDP Evaluation Method

Summary

The requirements of a PDP evaluation method that will satisfy the objectives are identified, and the main features of a method designed to meet these requirements are described.

The key foundational constructs of the method are identified as determinants of profit (DoP), the PDP model, activity effectiveness assessment, and correlation factors. Comparison with current methods and tools identified from the literature indicates that the developed method has some advantageous features.

3.1 Introduction

A number of requirements must be met by a PDP evaluation method intended to enable companies to understand and control their processes. Further, the assumptions on which the developed method is based must be sound. These two issues are explored in this chapter. The foundational constructs of the method, that will be addressed in detail in later sections, are identified, and the method is compared to existing methods and tools from the literature.

The chapter is structured as follows. Requirements for the evaluation method are presented in Section 3.2. The evaluation method is presented in its current form in Section 3.3 (the evolution of the method is described in Appendix A). How the method satisfies the requirements is discussed in Section 3.4. The underlying assumptions of the method are discussed in Section 3.5. The evaluation method is reviewed against the literature in Section 3.6. Issues in implementing the method are described in Section 3.7.

3.2 PDP Evaluation Method Requirements

1. The evaluation method must enable a company to assess a current or proposed process for developing products in the future.

   Retrospective assessment of a PDP in terms of the success of existing products will not be suitable because: a) by the time product success has been established the PDP that generated the product may no longer be in existence; and b) assessment relies on memory. In some cases the success or failure of a product may only be established some four to five years after product launch. It is, therefore, unrealistic to expect staff to remember exactly what constituted the PDP at the time of development of the product; c) the process may not suit the current situation.

2. The evaluation method must be non-prescriptive i.e. it should not impose a PDP model on the company. Rather the method should allow a company to model their current or proposed PDP in the context of their products, culture, processes, structure, and markets, and of accepted good NPD practice.

   This addresses some limitations of prescriptive PDP models: a) they are based on a specific company or industry and their universal validity may be questionable; b) they are generic at a high level of abstraction and as such omit much useful detail; and c) the company may wish to evaluate their own methods and ideas.

3. The evaluation method must assess the effectiveness of the execution of PDP activities in relation to their impact on successful product outcomes. Thus the method should allow critical activities to be identified and evaluated in a quantified sense.

4. Activity effectiveness must be assessed in terms of current best NPD practice and in a manner that is non-prescriptive, and should quantify the quality of the PDP as a whole.

   This allows a range of 'what-if' type examinations of the PDP in relation to requirements to achieve specific objectives. Various scenarios of actual or proposed processes can be examined for their effect on the likelihood of success of the product. For example, human or financial resources in key functions may be altered hypothetically to investigate the effect on product performance. A 'what if?' ability will also permit pro-active resource allocation supported by quantified data.

5. The evaluation method must enable a company to identify issues about the product that they deem important for successful product outcomes. Assessment and evaluation of development process activities can then be executed in relation to these issues.

6. The evaluation method must account for company complexity and uniqueness by drawing on the knowledge of company experts.

3.3 The Evaluation Method

For the purposes of this evaluation method the success of the PDP is measured by the profit achieved through the development, manufacture, sales and support of products. Barclay (1992) and Wind and Mahajan (1991), for example, support profit as a measure of product performance. Profit can be expressed by the equation:

$$\textbf{Profit} = \textbf{income from sales and service} - \textbf{cost of development} - \textbf{cost of supply and support}$$

This profit equation identifies two primary requirements that must pervade the whole product development process. First, to satisfy customer needs so as to maximise selling price and sales, and second, to control costs. Andreasen and Hein (1987) state that the objective of the PDP should be to simultaneously manipulate the structure, form and detail of the product so that sales price and costs are kept as far apart as possible (thus maximising profit).

At a more detailed level, for every product there are a number of factors that largely determine the manufacturers profit through their effect on the profit equation. For example, for a household toaster some factors may be number of slices of bread toasted, size, ruggedness, choice of materials, manufacturing methods, customer's perception of the product. These factors are called 'determinants of profit' (DoP).

The DoP establish the issues that must be addressed by the PDP, but they must not be identified in terms of the product outcome. There is a danger that the DoP may be confused with a specification of requirements, or a product design specification. DoP identify important issues that may include, for example, certain functional and performance requirements such as the number of passengers to be carried in a car and its maximum speed and acceleration. DoP do not set target values. That is a function of the PDP, which must ensure that optimum target values are set in the specifications.

Amongst the DoP will be those factors deemed to be of importance to the customer and factors that will affect the customer's predilection to purchase the product. However DoP must extend beyond this to include every factor that is important to the success of the product and which may be influenced by the PDP. Some categories that are useful to consider when identifying DoP include: form of the product; function of the product; performance; quality; customer perception; presentation of the product; safety; manufacture; installation; maintenance and repair. The primary requirements to 'satisfy customer needs' and to 'control costs' (i.e. resources and time) are represented by identifying three dimensions that allow a certain focus for the DoP. These were chosen as: Solution Quality (SQ), Resource Consumption (RC) and time. SQ dimension DoP address customer, market and company needs. RC dimension DoP address company requirements with regard to optimum utilisation of resources. Time dimension DoP address company requirements with regard to development timing. An implication of introducing these dimensions is that DoP must be identified at that level of abstraction. If manufacture, for example, is identified as a DoP, then its level of abstraction is too high because there are both resource and quality of solution issues involved. DoP must therefore be defined at a level of abstraction that allows them to be categorised as solution quality, resource consumption and time.

The successful execution of the various activities that constitute the PDP must ensure that the issues identified by the DoP are resolved so as to maximise the potential for profit. Thus market research, for example, must establish the optimum size of a toaster, the number of slices of bread accommodated, and, in conjunction with detail design and process engineering, the optimum materials. The activities that constitute the PDP can be classified according to their contribution to a number of abstractions, which are referred to as the generic elements (GEs) of the process. These might include, for example, market research, conceptual design, detail design, procurement, business planning, product promotion, product documentation, change procedures, time management, cost management, design evaluation, manufacturing process planning, prototype manufacture, testing (see Chapter 6 for the final selection of GEs). Typical relationships between activities, GEs and DoP are shown in Figure 3.1. Multiple links between the GEs and a DoP indicate that the DoP may be influenced by the activities under a number of GEs. Each GE has its own unique set of activities.

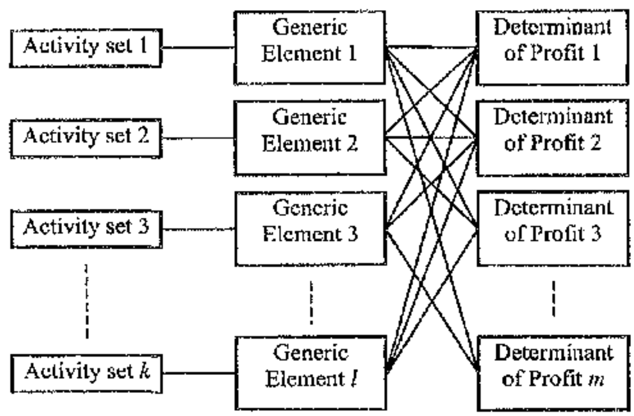


Figure 3.1. Activity/GE/DoP Relationships

The basis of the proposed method is to estimate how important each DoP is to success, and then to evaluate the effectiveness of the PDP in optimising the product in respect to that determinant. If important determinants are handled effectively then the probability of product success should be high (Montoya-Weiss and Calantone 1994). The method seeks to quantify the potential of the PDP for producing profitable products.

The method has evolved through much iteration. This is reviewed in Appendix A, while the main research issues are described in the chapters that follow (4 to 8). The current state of the method is shown in Figure 3.2, and involves the following steps:

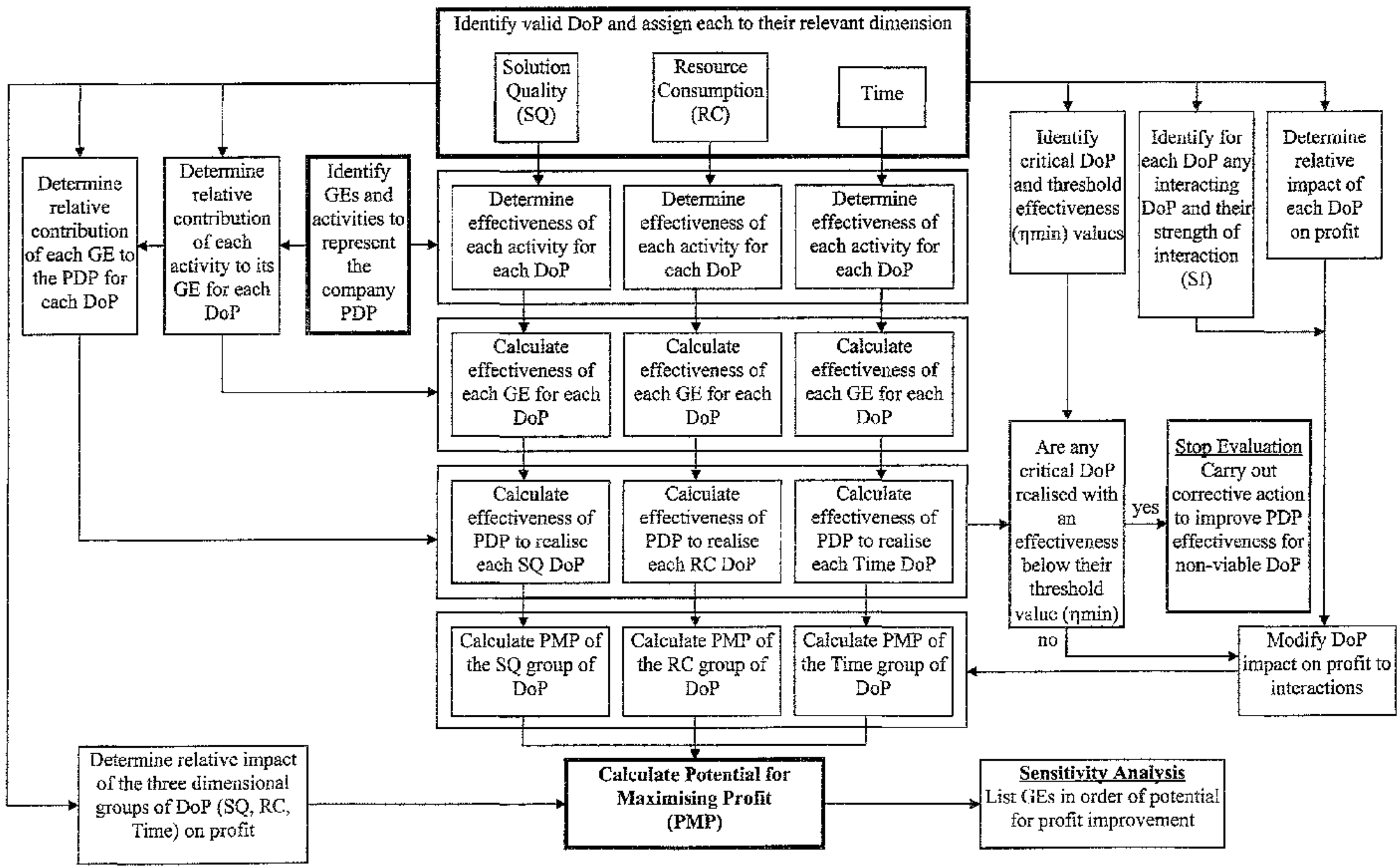


Figure 3.2. Flow Diagram of Current PDP Evaluation Method

1. *Identify GEs and activities to represent the company PDP.* Expert company practitioners use the generic model (developed in Chapter 6) as a basis to represent the company's PDP by allocating all activities within the process to the GEs of the generic model. Should this prove not to be possible then new elements can be added to the model at the same level of abstraction as the existing GEs to incorporate unassigned company specific activities. In this manner the generic model can be restructured to be specific to the company PDP.

2. *Identify valid DoP and assign each to their relevant dimension.* Important product issues are identified using the questionnaire described in Chapter 4. Validity of each DoP is established a) by checking that the DoP does not identify target values or objectives; b) by ensuring that the DoP is at the correct level of abstraction; c) by ensuring that each DoP relates to one dimension only. DoP relating to more than one dimension must be decomposed so that a separate DoP is identified for each of the pertinent dimensions. Identifying DoP is discussed in detail in Chapter 5.

3. *Determine the relative impact of each DoP on profit.* This is achieved by using the Analytic Hierarchy Process (AHP) (i.e. making pair-wise comparisons between each DoP to determine the relative weighting of all DoP) to establish correlation factors between each DoP and profit. The correlation factor reflects the relative importance of each DoP within their particular dimension. (The AHP is described in Chapter 8.)

4. *Identify, for each DoP, any interacting DoP and their strength of interaction (SI).* The various DoP are not necessarily independent of each other. Each (subject) DoP may have a group of interacting DoP that affect the subject DoP's impact on profit. Further, each interacting DoP has a particular strength of interaction on the subject DoP. The 'strength of interaction' is quantified to give a proportional multiplier that modifies the subject DoP's impact on profit by some factor (less than 1 but greater than zero). Respondents can choose to view interaction effects in this manner, or identify a threshold value of effectiveness for the interacting DoP below which the subject DoP's impact on profit is reduced to zero. A matrix is used to record these judgements. DoP interactions are discussed in Chapter 8.

5. *Identify critical DoP and threshold effectiveness values* (η_{min}). Expert company practitioners are asked to identify critical DoP i.e. DoP that must be realised with a certain minimum effectiveness for the product to be viable. This threshold level of effectiveness is independent of the effectiveness with which any or all of the remaining DoP are realised. Should the estimated effectiveness with which the PDP realises a DoP be below the threshold level, then action must be focused on remedying this situation. The method makes no provision to continue the evaluation in this instance. It is deemed that a product will fail should any DoP be realised with effectiveness below its threshold value.

6. *Determine effectiveness of each activity for each DoP.* Each PDP activity is assessed for its effectiveness in relation to each DoP. This is achieved by company experts responding to questions that have a specific focus appropriate to the dimension of the DoP, and that reflect current NPD management best practice.

   Activities are viewed as having a number of characteristics appropriate to each of the three DoP dimensions. The expert responds to the questions to make a quantified judgement about the effectiveness of each characteristic of an activity. The relative contribution of each characteristic to the overall effectiveness of the activity is determined using the AHP, which calculates the correlation factors. The product of the effectiveness values and correlation factors are then summed to calculate a total effectiveness value for the activity.

   Activity effectiveness assessment is described in Chapter 7, while the equations to calculate a total activity effectiveness value are presented in Chapter 9.

7. *Determine the relative contribution of each activity to its GE for each DoP.* A correlation factor that reflects the relative contribution of each constituent activity to the effectiveness of its parent GE is calculated. The AHP is used for the calculation, which is performed for each DoP.

8. *Calculate the effectiveness of each GE for each DoP.* The effectiveness of each GE is calculated by summing the products of the effectiveness value of each constituent

activity (item 6) and its correlation factor to the GE (item 7). The calculation is performed for each DoP. Equations are presented in Chapter 9.

9. *Determine the relative contribution of each GE to the PDP for each DoP.* A correlation factor that estimates the relative contribution of each GE on the total PDP effectiveness to realise each DoP, is calculated using the AHP.

10. *Calculate the effectiveness of the PDP to realise each DoP.* The effectiveness of the PDP to realise each DoP is calculated by summing the products of the effectiveness value of each GE (item 8) and its correlation factor to the PDP (item 9). The calculation is performed for each DoP. Equations are presented in Chapter 9.

11. *Identify DoP that are realised with effectiveness below their threshold values* (η_{min}). The calculated effectiveness (item 10) is compared to the threshold value (item 5), for each of the previously identified critical DoP (item 5). Those with a realised effectiveness below the threshold value are identified for immediate attention.

12. *Stop Evaluation. Carry out corrective action to improve PDP effectiveness for non-viable DoP.* Activities that will have the greatest impact on improving the effectiveness with which non-viable critical DoP are realised are identified and corrective action is taken to improve their effectiveness. (Note. The company as part of corrective action to improve a non-viable PDP executes this item. The item is not integral to the method *per se*.)

13. *Modify DoP impact on profit to account for interactions.* The impact of each subject DoP on profit (i.e. correlation factor) (item 3) is modified in accordance with the assessed 'strength of interaction' of each interacting DoP (item 4) and the effectiveness with which it is realised (item 10). This is discussed in Chapter 8.

14. *Calculate PMP of the SQ, RC and Time groups of DoP.* These PMP values are calculated by summing the products of the effectiveness to realise each DoP (item 10) in the dimensional group and its correlation factor to profit (items 3 and 13). Equations are presented in Chapter 9.

15. *Determine the relative impact of the three dimensional groups of DoP (SQ, RC, and Time) on profit.* The relative impact of each dimensioned group of DoP to profit is established using the AHP to calculate a correlation factor.

16. *Calculate Potential for Maximising Profit (PMP).* This value is calculated by summing the products of the effectiveness to realise each dimensional group of DoP (item 14) and their correlation factors to profit (item 15). Equations are presented in Chapter 9.

17. *Perform sensitivity analysis.* This analysis enables GEs to be ranked relative to their impact on the PMP value, which is a function of their effectiveness and strength of correlation (through the DoP) to profit. GEs that have low effectiveness but are strongly correlated to profit have high potential to improve the PMP. Conversely, GEs that have high effectiveness and weak correlation to PMP have low potential to improve PMP. Thus GEs with low effectiveness are not automatically marked for improvement unless they also have a strong correlation to profit.

3.4 How the Method Satisfies the Requirements

The evaluation method meets the requirements of Section 3.1 as follows.

1. The method allows current and future processes to be evaluated: this is achieved by using expert judgement to identify PDP activities that should be executed in order to improve a current product or create a new one. The identified activities are evaluated in terms of their effectiveness in realising important product issues (DoP). Expert judgement is based on experience and in-depth knowledge of the company in the context of best practice.

2. The method is non-prescriptive: company experts can map their own PDP activities onto the generic model, and need only use those GEs/activities that will fully represent their PDP. Further, the method permits a company to identify issues about the product (i.e. DoP) that are important to the company. These issues will depend on their particular industry and product type. The method does not prescribe what the important issues should be, nor the activities, nor how they should be undertaken. Finally,

activity effectiveness is assessed in the context of current best practice. Experts are required to judge the effectiveness of an activity to address the product issues (DoP). The method requires experts to consider best practice, but does not prescribe what is best practice for their context.

3. The method permits activities to be evaluated in terms of their impact on successful product outcomes. This is achieved by identifying important product issues (DoP) and their relative impact on success (in terms of profit). Each activity is then assessed in terms of its ability to realise each DoP to good effect. In this manner the link between effective execution of activities and successful product outcomes argued in Chapter 2, is integrated into the evaluation.

4. The method permits companies to identify important product issues (DoP) that are used as criteria against which to evaluate PDP activities. This has been discussed in the previous two points.

5. Company uniqueness and PDP complexity are accounted for in the method. This is achieved firstly through the creation of a PDP model specific to the company at the activity level, and secondly by relying principally on the judgement of expert company practitioners.

The complexity of the development process and interaction of important product issues cannot be reduced entirely to numbers. However, encouraging company personnel to make comparisons and to quantify their judgements uncovers and highlights hitherto obscured development issues. Quantification also supports arguments. For example, when a project manager argues for increased financial input into the PDP, a quantification tool can provide facts and figures. Pappas and Remer (1985), Steele (1988) and Szakonyi (1994a, 1994b) consider this to be superior to qualitative arguments.

3.5 Evaluation Method Assumptions

The evaluation method is based on a number of specific assumptions.

1. There exists a relation between product success and the effectiveness of execution of the PDP. Fairlie-Clarke and Clark (1993), Cooper and Kleinschmidt (1991), and Atkinson et al (1997) amongst others, argue the causal relation between good operating procedures for the PDP and successful product outcomes.

2. 'Success' can be defined as the maximising of profits generated by the sale of products and services.

   Hultink *et al* (1995) note that what is meant by success will depend on a firm's time perspective. Crawford (1979 p10) confirms this in a general observation; "Success is variously defined, but quite generally now researchers are using 'met company expectations'". Page (1993 p284) observes "Another type of performance measure is the impact of the programme on the organisation's sales and profits. These measures quantify the force the programme has on two important lines of the firm's profit and loss statement and convert the results of its new product activities into business financial performance". Cordero (1990 p187) states: "because firms and SBUs (Strategic Business Units) have profit objectives, profit can be used to evaluate overall performance." Wind and Mahajan (1991) point out that 81% of the 200 Fortune 500 companies surveyed in their research project, used profit as a means of new product performance measurement. Crawford (1980) discussing features of his 'Product Innovation Charter', says (1980 p4); " [A] firm's strategy policies include every strategy dimension deemed necessary to produce the particular flow of product innovation that ***will optimise profits***." He says that the product innovation charter charts a course, i.e. it says (1980 p7): "Go this way, and do these things. They offer the best bet for ***optimising profits from new products***". It is thus concluded that profit is a suitable criterion for success.

   Although success is defined as maximising profit, the nature of the generic PDP model and the PDP evaluation method allows for any success measure to be used and become the criteria for generating the 'determinants of profit' (DoP). The following example will serve to illustrate this point:

Assume a firm wishes to maximise customer acceptance of its products. Factors that enable the product to meet this requirement would replace DoP and perhaps become 'determinants of customer acceptance'. Thus the various categories of success measures identified by Griffin and Page (1996), for example, can be accounted for by the evaluation method.

3. There exists a relation between the effective execution of the GEs of the PDP and successful realisation of the important product issues (the DoP).

   This assumption is affirmed by Cooper and Kleinschmidt (1986), Johne and Snelson (1988), Zirger and Maidique (1990), Calantone and Di Benedetto (1988), and Montoya-Weiss and Callantone (1994), amongst others. The approach used by Page (1993) to assess NPD practices and performance for establishing crucial norms is to relate performance factors to 'activities' of the process.

4. The nature of the PDP affects the probability of successful product outcomes.

   Calantone *et al* (1997) state that those who have studied the link between NPD activities for industrial products and new product performance (e.g. Calantone and Di Benedetto 1988; Cooper 1979; Cooper and Kleinschmidt 1986, 1987; Dwyer and Mellor 1991b) have shown that the proficiency and completeness of the NPD activities (i.e. the form of the PDP) are key to success.

5. Having the constituent activities of the elements of a 'good'[1] PDP performed effectively improves the probability of success.

   Cooper and Kleinschmidt (1986) investigate the activities of the new product process and how they are related to success and failure. They consider whether the activities

[1] The term "good" implies that all the necessary generic elements are present i.e. a development process is in place. However the constituent activities may or may not be executed proficiently.

were performed or not and if so, how proficiently. As justification for their work they comment (1986 p71): "Most recently, there has been a call to focus on the new product process itself as the key to a more successful new product programme." On the likelihood of product success linked to process activities they say (1986 p82): "... there appears to be a strong link between project outcomes (success or failure) and doing certain activities and doing them well."

Thus it is argued that the profits generated by the sales of a product are related to product factors, the realisation of which, via the effective execution of the activities constituent of the GEs of the PDP, will maximise the likelihood of successful product outcomes and thus maximise the potential to generate profit. This overriding relation of effective execution of activities to profit is also shown by Loch *et al* (1996 p3) who state: "… success comes from more efficient new product development…" Finally, a quote from Cooper and Kleinschmidt (1986) establishes this point. They note (1986 p84): "the overriding finding of the investigation is that **new product success is closely linked to what activities are carried out in the new product process, how well they are executed, and the completeness of the process. That is people … doing tasks and, most importantly, people doing them well, contributed strongly to new product success."**

To conclude; it has been shown in this section that that assumptions made to develop the PDP evaluation method are supported (implicitly or explicitly) by the literature.

3.6 Comparison of the New Evaluation Method to Current Methods/Tools

The features of the evaluation method presented in this chapter are listed in Table 3.1 and are compared in Table 3.2 to some methods/tools selected from the literature (see Section 2.2.6.3) because they have been developed by prominent researchers, or are in some ways similar to the developed evaluation method. The table identifies which of the features can be identified in existing methods.

Item No.	Feature Description
1	The method is a quantified assessment of the effectiveness of a PDP to produce a successful new product. Thus the method provides quantitative data to support decisions about improvements to the PDP.
2	Evaluation of the PDP occurs in relation to important product factors (the DoP), which can be identified for a future product or a product currently under development.
3	The PDP and constituent activities are evaluated in relation to the impact on profit potential of each DoP.
4	The method permits evaluation of current and/or future PDPs as the method is not limited to historical data. In other words the method is not restricted to retrospective evaluation of the PDP.
5	The method is non-prescriptive i.e. it does not impose any particular view of the PDP, or how the PDP should be assessed, on a company.
6	The method allows company uniqueness to be expressed by utilising the knowledge and quantified judgements (through activity effectiveness and correlation factors) of company experts within a context of good NPD management practice to give the company a way of evaluating what they do and what they think they might do.
7	The evaluation method can be universally applied i.e. by any manufacturing company, in any market and industry sector. However, the PDP model is still able to retain a generic description of the PDP to a level of abstraction where a company can actually map its specific activities.
8	The evaluation method also provides sufficient detail to permit the assessment of effectiveness of each PDP activity, which is achieved by evaluating the characteristics of each activity in relation to their quality when realising a particular DoP.

Table 3.1. Features of the Evaluation Method

It can be seen from Table 3.2 that while the tools and evaluation methods identified from the literature have one or more of the features of the present evaluation method, none of them has all of the features. Atolagbe's (1990) method has the most features in common with the developed method but neither it nor any other includes any evaluation at activity level. Further, none of the above methods/tools are structured in the same manner, i.e. use of company knowledge[2] to identify DoP and GEs, correlation factors for DoP/profit relationships, correlation factors for DoP/GE relationships, correlation factors for

[2] This in itself is not new as shown by amongst others; Steele (1988), Pappas et al (1985) , Szakonyi (1994a, 1994b)

GE/activity relationships, activity effectiveness, and the use of the AHP to elicit judgements.

	Features of the New PDP Evaluation Method							
	1	2	3	4	5	6	7	8
Method/tools Identified from the Literature								
Crawford (1980)				x		x	x	
Peters and Waterman (1982); Johne and Snelson (1988)				x		x	x	
Slevin and Pinto (1986)				x	x	x	x	
Atolagbe (1990)	x	x		x	x	x	x	
Parnaby (1995)				x			x	
Cooper and Kleinschmidt (1995, 1996)	x					x	x	
Yazici and Tugcu (1996)				x	x	x	x	

Table 3.2. Evaluation Method Features Present in the Literature

Many other prominent researchers have developed methods or tools that have the same objective as the present evaluation method i.e. to improve the likelihood of new product success. However, instead of evaluating the PDP to achieve this objective, these researchers take different approaches. For example, Cooper (1980, 1985) and Mahajan and Wind (1988) present methods to select development projects based on the product's predicted likelihood of success. Yoon and Lilien (1985) present a method to predict the market performance of an existing (soon to be launched) product. Souder and Song (1997) describe a high level method to identify effective design and marketing strategy to achieve success based on a company's perception of market factors. Kaplan and Norton (1992, 1993) present a high level tool to evaluate the company in relation to four areas or 'perspectives'. The tool permits measures to be identified that 'balance' goals stated under each perspective.

Although they implicitly or explicitly recognise the importance of a good process to achieve successful product outcomes, none of these current methods or tools permits a detailed assessment of the functioning of the PDP.

3.7 Implementation Issues

Issues pertinent to implementation of the PDP evaluation method are identified and discussed briefly in this section, and are addressed more fully as research issues in Chapters 4 to 8.

3.7.1 Industrial Context of the Method (See Chapter 4)

An objective of the evaluation method is that it be used directly by industry. It is therefore important that companies can relate to the method in terms of the philosophy of approach and in terms of the elements employed i.e. DoP and GEs. It was thus necessary to determine whether companies found the method and the adopted approach useful. If not, why not? How could the approach and evaluation method be improved should companies experience difficulty in relating to them?

Specific issues had to be addressed. Did experts understand the concept of DoP? Could experts identify DoP for their own products? If so, would they be able to do so correctly i.e. identify issues to be addressed by the PDP rather than target values? Would experts be able to score the importance of each DoP in contributing to profit?

Further, could experts relate to the concept of GEs of the PDP? If so, would they be able to identify GEs in their own PDP for a particular product? Would experts be able to score the importance of each GE to realise the product?

Lastly, company experts would be asked to think about and quantify issues that they may not have consciously considered before, so it was important to ascertain what degree of difficulty they might experience in relating to the approach. Although a certain degree of difficulty was expected as the approach would be new to companies, it must not be so difficult that industrial practitioners would reject the method.

3.7.2 **Determinants of Profit (DoP)** (See Chapter 5)

A number of issues concerning DoP had to be addressed before the evaluation method could be implemented successfully.

Definition

The definition of DoP had to be refined. The following questions had to be addressed:

- What exactly are DoP?
- At what level of abstraction must DoP be defined to be handled successfully in the method?

Validity

It is necessary to test the validity of a DoP before it is used in the evaluation method. Thus the following questions had to be addressed:

- What constitutes a valid DoP?
- How is DoP validity tested?

Threshold Effectiveness Values (also see Chapter 8)

During industrial trials it became clear that for some DoP a minimum threshold level of effectiveness must be realised below which the product is not viable in the market. Should such a DoP not be realised then the product could not be sold, irrespective of whether all other DoP had been successfully realised. The following question had to be answered: how are threshold values to be identified and incorporated into the evaluation method?

Interactions between DoP (see also Chapter 8)

DoP are not independent of one another, and a procedure was needed to identify DoP interactions and quantify their effect. Thus the following questions had to be answered:

- What is the exact nature of DoP interactions?
- How do interactions effect DoP impact on profit?
- How should interactions be handled?

3.7.3 Modelling the PDP (See Chapter 6)

Identifying the GEs of the PDP and their constituent activities is integral to the evaluation method. The necessary activities and GEs must exist in a company's present or proposed PDP in order to realise the DoP successfully. It was decided to provide a generic model that lists all GEs of the PDP under which constituent activities can be identified. This will permit a company to generate a company-specific model by tailoring the generic PDP model to reflect the company's own unique context.

The need to provide a generic PDP model raised a number of questions. What is the purpose of this model? What are the GEs of the PDP? What are typical constituent activities of each GE? How can GEs and activities be represented at like levels of abstraction? Can an existing model be used? If not, can a new model address the shortcomings? How can the model be tested?

3.7.4 Determining Activity and Generic Element Effectiveness (See Chapter 7)

The effectiveness of every activity in the PDP must be assessed. To this end the following issues had to be addressed. What is required from a method or procedure for assessing activity effectiveness? Are there existing methods or procedures that meet the requirements, and can one be used? If not, can a new method or procedure be established that meets the requirements? How can the assessment method be tested?

3.7.5 Correlation Factors (See Chapter 8)

To make provision for the (strong) possibility that all activities do not have equal impact on the effectiveness of a GE (for example), some procedure must be used to determine the relative contribution of each activity to overall GE effectiveness. The same applies for relationships between: activity characteristics and activities; GEs and DoP; DoP and their relevant dimensions; and solution quality/resource consumption/time dimensions and profit. Methods are required to determine the relative contribution or relative importance of these relationships (see Section 3.3 steps 3, 7, 9 and 15) via correlation factors.

A number of issues were addressed to establish a suitable procedure. What correlation values must be determined? How should correlation values be determined within the philosophy of the approach? How should judgements be elicited? How should judgements be quantified? How can the procedure used to elicit and quantify judgements be validated?

4

Industrial Context

Summary

It is a fundamental requirement that the evaluation method is implemented in an industrial context. This was sustained throughout the development of the method by maintaining dialogue with industry and then by industrial trials.

Survey results indicate that industry recognises the need to improve its PDPs and that an evaluation method, such as described in this thesis, will be useful. The main finding was that industrial experts were able to relate to the approach adopted in the evaluation method, and to use it to express their knowledge about their products and processes. Although they did experience some difficulty with the novelty of the method and interpretations, their responses were, almost without exception, apposite. A number of aspects of the evaluation method need further refinement to allow better fit with the industrial perspective.

4.1 Introduction

This Chapter addresses the first of a number of research issues identified in Chapter 3, namely, whether the developed PDP evaluation method (and the underlying approach) will work in industry i.e. will it capture expert knowledge, and will industrial practitioners relate to the approach.

One of the objectives of the PDP evaluation method is to stimulate industry to think more deeply about its products and processes. The work described in this chapter explores whether this can be achieved and whether industry will be confident enough with the method to use it in-house.

Objectives of the industry survey are presented in Section 4.2. The method used, results obtained and implementation of findings are discussed in Section 4.3. Concluding remarks are made in Section 4.4.

4.2 Objectives

To determine whether companies can

1. Relate to and understand the concepts of DoP and GEs.
2. Identify DoP for their own products and GEs for their own PDPs.
3. Identify the degree of importance of each DoP in determining the potential for profit.
4. Identify the strength of focus of their activities on each GE.
5. Easily relate to these issues.

4.3 Method

The industrial context was explored by drawing up a questionnaire to be used in an extensive postal survey of industry. The questionnaire was piloted using a small sample of industrial practitioners. Feedback obtained from the practitioners was used to refine the questionnaire. Results obtained from the extensive survey were used to make adjustments and modifications to the evaluation method.

Feedback from the pilot survey that was used specifically to refine the questionnaire is presented in Section 4.3.1. All other results from the pilot survey (e.g. degree of focus on GEs, ease of response) are included with results from the extensive survey and described in Section 4.3.2.

4.3.1 Pilot Survey

4.3.1.1 Questionnaire Design

The evaluation method was discussed directly with senior managers in industry and academics with industrial experience prior to designing the questionnaire.

The questionnaire was aimed at the person with the most knowledge about the products and processes in the company, usually the technical director. It was designed to take no longer than 10 to 15 minutes to answer, so as to maximise the returns and avoid poor data due to hurried responses, - a danger highlighted by Griffin (1997). Follow-up telephone calls revealed that in many cases even this amount of time was deemed too much and the necessary commitment too great.

The questionnaire (see Appendix B) provided a short introduction and background to the method and philosophy of the approach. The challenge was to convey sufficient information without making the explanation too complex or tedious to read and understand. It was intended that the concepts and the execution of the exercise should challenge respondents to think of their products in a manner that was new to them.

Respondents were asked to identify important issues in determining the potential for profit of a particular company product. The questionnaire prompted responses by providing a list of possible headings under which respondents could place these issues.

- Form of the product - colour, shape, etc.
- Functionality of the product - user friendliness, extra features, etc.
- Performance of the product - size, weights, speed, accuracy, etc.
- Customer perceptions of the product - advertising, etc.
- Quality - level of quality, level of reliability.
- Safety - standards and regulations.
- Other - anything respondents felt had been omitted.

Throughout the questionnaire, respondents were asked to explain any difficulty they experienced in answering the questions.

The purpose of the questions pertaining to GEs of the PDP was twofold; first, to ascertain whether respondents could identify these elements in their own processes, and second, to obtain an indication of how important these elements might be to various companies and whether respondents could differentiate the importance for their own PDPs.

Respondents were asked to indicate how much time they had spent answering the questionnaire. The target was that the time required should not normally exceed 15 minutes. A requirement for more time to answer the questions might indicate that the respondent either experienced some difficulty in understanding the approach, or that they were not sufficiently knowledgeable about the company's products and processes.

Respondents were asked to indicate the degree to which they believed their knowledge of the product and PDP had been explored or captured. This information would indicate areas of attention required in the questionnaire and approach.

Lastly, respondents were asked to provide general details about their products, company and nature of their PDP. This information formed part of an effort to gain understanding about responses (i.e. the manner in which respondents viewed their PDPs e.g. formal, reactive, structured), industry and the complexity of products.

4.3.1.2 Execution of Pilot Survey

The pilot survey questionnaire was distributed to senior managers in six manufacturing companies in the following industry sectors: industrial machinery; ship motion control systems; industrial filtration systems; earth-moving equipment; aero-engines; and computer systems.

4.3.1.3 Feedback

Industrial Machinery Manufacturer

This respondent experienced some difficulty understanding the definition of DoP. He also felt that the categories overlapped with the result that a DoP could be assigned to more than one category. This is a valid observation. However, categories were provided as a prompt to facilitate and structure thoughts, and it was not important to which category a particular DoP was assigned. The questionnaire was altered to explicitly state that the list of categories should be used in this manner.

It is of interest that, although the respondent indicated he had trouble understanding the requirement, his responses were nonetheless appropriate.

The respondent also experienced difficulty understanding the scope of the questions regarding GEs. However, he was the only one of the six respondents to experience this difficulty and it was considered that to expand the explanation would make the questionnaire longer and more unmanageable, thus increasing the risk of non-response. The PDP evaluation method should incorporate a detailed explanation of the exact scope of the PDP and GEs, to facilitate and ensure understanding of the concepts.

Lastly, the respondent suggested that, to aid clarity, questions about DoP and GEs should be more specific. However, a concern was that respondents would become less objective, being 'guided' instead to answer questions in a certain manner, when what was desired was an independent response to the method.

<u>Ship Motion Control Systems Manufacturer</u>

This respondent also experienced difficulty relating to the concept of DoP. He commented that it was not easy to specify DoP in the terms requested in the questionnaire, nor was it easy to identify separate DoP. However, the results indicated that the DoP he identified were exactly as required, and it was concluded that although the respondent experienced difficulty in thinking about product factors and issues in the way presented, he was able to assimilate the new approach and to adjust his thinking accordingly.

The respondent was also able to identify the degree with which the company's PDP addressed the listed GEs, although he did not find this an easy task.

<u>Industrial Filtration Systems Manufacturer</u>

This respondent found that he was able to answer all questions with relative ease. The quality of his responses indicates that he was able to relate well to the approach.

Earth-Moving Equipment Manufacturer

This respondent also experienced little difficulty in relating to the approach and returned appropriate responses.

Aero-Engines Manufacturer

The respondent observed that in addition to controlling costs and satisfying customer needs so as to maximise selling price and sales (stated in the opening paragraphs of the questionnaire), the PDP must realise a product that it is preferred by the customer to that of the competitors. This is addressed in the evaluation method, which enables company practitioners to identify DoP that, when successfully realised, will ensure that their product is competitive.

Regarding DoP, the respondent noted that they are in a market where the product has to meet basic requirements to be even considered by their customers. Sales volume and prices are largely governed by financing deals and other commercial influences. He concluded that under these conditions profit is largely determined by supply and support costs.

The respondent suggested that GEs could be grouped in terms of product life cycle stages. However, such a grouping was specifically avoided as it is tantamount to being prescriptive with regard to a PDP model.

The respondent indicated that he had experienced some difficulty in recording the degree of focus on GEs in the absence of some absolute measure, such as percentage effort, or a common scale across industry. However, he was nonetheless able to arrive at suitable ratings.

Lastly, the respondent stated that he considered the approach (and method) better suited to consumer products rather than to large, made-to-order, capital type products.

Notwithstanding the above comments and difficulties experienced by this respondent, his responses were in almost all instances appropriate and indicated that he was able to grasp the concepts underpinning the approach.

Computer Systems Manufacturer

The respondent experienced some difficulty in completing the questionnaire. He thought it was not going to help him, in his role as a product developer, to improve his PDP in any really tangible way. He believed that the questionnaire needed to inform the recipient more helpfully as to its purpose and approach, and to provide better definitions. He suggested that an example of a completed questionnaire might be useful. A less academic and a more business orientated description should also be used in the preamble.

The observations indicate that the respondent had not completely understood the objective of the questionnaire, or his role in assessing it. He had understood the questionnaire to embody the entire PDP evaluation method and had assessed it in this context. The misunderstanding indicated a potential problem with the introductory paragraphs. However, it was felt that, in the light of the appropriateness of the responses from the other respondents, the introduction should not be significantly altered for fear of increasing the length, resulting in increased non-response.

4.3.2 Extensive Survey

4.3.2.1 Refinement of Questionnaire

As a result of the pilot survey, a revised questionnaire (see Appendix C) was produced with the following modifications.

- The introductory paragraphs were altered slightly to aid clarity. This was achieved without a significant increase in paragraph length.
- Two DoP categories (i.e. 'operation' and 'life costs') were added.
- The list of GEs was expanded to provide a more thorough representation of the PDP, and rearranged to aid clarity.

4.3.2.2 Execution of Extensive Survey

The extensive survey targeted senior managers (Managing Directors, Technical Directors, Engineering Directors, Chief Technical Officers, etc.) involved in product development. The reason being that senior managers are more likely to have on-hand the knowledge necessary to answer the questions.

Questionnaires were posted to 127 companies, identified from library databases, that were active in the manufacturing sector and engaged in design and development of their own products. These included mechanical, electrical and electronic companies.

4.3.2.3 Analysis of Results

A total of 29 responses were received (including the 6 from the pilot survey). Analysis indicates that respondents experienced some difficulty in assimilating the material and responding to the questions. However, despite this, respondents were almost without exception able to make appropriate judgements. This is a significant finding since it indicates that industry experts are able to relate to the method and respond in an appropriate manner.

Determinants of Profit

Approximately 175 different DoP were identified with a number of these taken directly from the headings given in the questionnaire, such as appearance, shape, finish, weight, size, reliability, ease of operation. There was a surprising variety, which supports the philosophy that the method must permit evaluation of the PDP in the specific context of the company.

A number of interesting DoP were identified. For example, the head of design technology at the aero-engine manufacturer (see Section 4.3.1.3) noted that an important DoP for their product is the financing package. The Engineering Director of the earth-moving equipment manufacturer observed that the importance of the "normal" (i.e. expected) features of their equipment is determined largely in relation to the competition. As a result two of their most important DoP are: "features competitors do not have" and "lack of features competitors do have". He also noted that, in their industry, a good quality product will not succeed in the market without the correct distribution and service back-up, and that poor dealers and poor spares availability are likely to result in customers purchasing from their competitors. Equipment that is not reliable raises doubts in the eyes of the customer about the manufacturer's whole product range.

Some new DoP were identified by a number of respondents. For example: system compatibility (6 instances); ease of customisation (4); ease of maintenance (3); versatility (3); fast cycle time (2); perceived value (2); track record (3); reputation (5); low down time (2); compliance with safety regulations (11); ease of installation (6); competitive price (6); low running and service costs (4). Examples of DoP cited are listed in Appendix D.

Few respondents rated the value of any DoP lower than 3 (on a scale of 1 to 5). This may be attributed to the fact that DoP are identified as *important* product issues that must be addressed by the PDP. Perhaps in the mind of the respondent any value less than three does not denote the DoP as important.

A number of pertinent issues arose.

1. Although respondents were able to identify DoP without referring to target values or specifications to be achieved (e.g. top speed to exceed 150 mph), the wording used to describe some DoP incorporate an axiomatic objective to be met or solution to be realised e.g. <u>low</u> down time, or <u>good</u> safety history. However, a DoP should not identify the required outcome. Examples of good DoP are 'down time' or 'safety'. This will be discussed in greater detail in Chapter 5.
2. Some companies identified DoP that are in fact activity effectiveness issues. For example, 'achieving required functionality, reliability, and safety for low product development cost', or 'control of manufacturing methods'. These issues cannot be realised by the process as they are part of the process.

<u>Generic Elements</u>

Generally, respondents experienced little difficulty in relating the listed GEs to their own PDPs and in identifying their strength of focus. Approximately 40% of respondents rated market research as medium to low focus, while most rated their technical activities (concept generation, concept development, concept evaluation, detail design, testing and modifications of detail design, prototype manufacture, testing and qualification of prototype) as high focus. Strength of focus on "management of overall cost of development" and "management of time to market" was medium or better in only 14% of cases. The respondent at the earth-moving equipment manufacturer considers that management of cost and how it is controlled throughout the process should be the most important aspect of any product design. He notes that a product that is not cost competitive will not succeed in a mature competitive market place.

The most important finding concerning GEs is that respondents did not automatically rate every GE as equally important. Respondents therefore recognise 1) that their PDPs do not execute all activities with equal effectiveness, and 2) that not all GEs are equally important to realise a product. This finding is fundamental to the evaluation method, which relies on an expert's ability to recognise and make judgements to differentiate the importance of various activities.

Ease of Responding

Slightly more than half the respondents indicated that DoP and their correlation to profit could be easily identified. Approximately two-thirds observed that they could easily indicate the strength of focus on identified GEs. The fact that many respondents did not find this an easy task, but were able to handle follow-up discussions about the method quite readily, suggests that much of the difficulty was due to the novelty of the method.

Approximately half considered that the method allowed them a satisfactory or better expression of their knowledge of their chosen product, although the quality of response indicates that this figure is possibly limited by the degree of difficulty experienced to express that knowledge. An indication of response quality is whether respondents avoided identifying target values as DoP (e.g. 'lifting capacity of 10 tons' as opposed to 'lifting capacity', the latter being an appropriate DoP). Results indicate that almost without exception target values *were not identified as DoP* (although some axiomatic objectives were identified (e.g. low cost), as discussed previously). In other words, while some respondents felt their knowledge was poorly tapped, responses were appropriate. This finding supports the adopted approach.

Nature of Business and Process

The majority of those companies who elected to give details of their business (this being optional) employ less than 1000 personnel. 33% produce high technology products, 45% produce low volume industrial products, 14% produce capital products, and the remainder produce low volume consumable goods or high volume industrial goods.

Of the respondents who identified their processes with descriptors (approximately 18% did not) the main descriptions chosen were "formal" (32%), "mature" (32%), "structured" (36%) and "proactive" (36%).

Two respondents indicated that their PDP either required urgent attention or was in the process of being developed. One low volume industrial product manufacturer acknowledged that their process was virtually non-existent, and concluded that the subject needed to be addressed urgently. Another respondent experienced difficulty in relating to the concept presented, and commented that their products are custom designed and do not easily lend themselves to this type of analysis. He considered the questionnaire to be slanted towards 'widgets' and therefore not to address their new products.

Interestingly, and somewhat surprisingly, only a single respondent rated his company's process as "efficient". It is tempting to conclude that, as few companies appear to be happy with their processes, the figure provides support for the work described in this thesis. However, caution must be exercised because the survey was not designed to be a statistically representative sample of the whole of industry.

Findings confirm that industry experts are able to relate to the approach used in the PDP evaluation method. However, this is only true when the questions are answered by the appropriate person i.e. one having sufficient knowledge about the company, its processes and products. When respondents were lower down in the company hierarchy (e.g. middle management, design engineers) responses were less appropriate (e.g. issues relating to costs being omitted) or response time was excessive (30 minutes or more).

Overall response (including feedback via telephonic follow-up) to the evaluation method was positive, and confirmed the value of this work. The responses generally indicate that the concepts were understood and assimilated. This was not without some difficulty, however, which can be ascribed to the novelty of approach adopted.

4.3.2.4 Modifications to the Evaluation Method and Questionnaire

Discussion of the survey results with some respondents brought to light a problem with the structure of the questionnaire. DoP categories (e.g. performance, form of the product, function of the product), which were provided to aid response, lead at least one respondent to conclude that each *category* should be considered as being equally important and having an equal impact on profit. The respondent indicated that he had confined his estimates of the DoP's relative importance to the DoP *within* each category, and had not considered all DoP simultaneously.

This problem can be resolved in a number of ways when implementing the evaluation method. Category headings can be left out, as they only serve as prompts and examples, or the user can be given clear instructions that categories are to be viewed as aids to identify DoP, and must be ignored when making judgements about DoP impact on profit. In the final method, correlation factors are determined using a procedure (presented in Chapter 8) that considers all components (DoP in this case) simultaneously, and therefore ignores DoP categories.

4.4 Concluding Remarks

A method to evaluate the PDP has been formulated and initially tested through industrial surveys, the results of which indicate that a) company experts are able to relate to the adopted approach and can identify DoP and GEs for their products and processes, b) industry is generally positive about the objectives of the project, and c) the method enables company personnel to effectively express their knowledge about their products.

Although respondents indicated that they experienced some difficulty in responding to the questionnaire, it is concluded that this is due to the unfamiliar approach, because almost without exception responses were apposite. That is, respondents identified as DoP product factors that raise issues to be addressed by the PDP, rather than specifications or target values to be achieved in the developed product. Also, respondents were able to identify and differentiate PDP strength of focus on GEs.

The survey results provide support for the work described in this thesis. Respondents are aware of the importance of a sound PDP and generally admit that their own processes require attention. One respondent expressed disappointment that the evaluation method was not yet complete, as he believed that the company could derive immediate benefit from an evaluation of their process to identify weak areas.

The results of the survey showed that it was worthwhile to continue with development of the method.

5

Determinants of Profit

Summary

Some further issues concerning DoP, beyond those identified and resolved in Chapter 4, are addressed. Procedures to handle the following issues are designed and then tested in industry. To avoid DoP being identified as objectives; to identify DoP that account for product brand issues; to identify the correct level of abstraction of DoP to permit them to be utilised in the evaluation method; to identify DoP dimensions; to identify DoP interactions; and to identify threshold levels of effectiveness for critical DoP. Results show that the procedures are effective, but in some cases return rather crude estimates and therefore require further refinement.

5.1 Introduction

Determinants of profit (DoP) are defined in Chapter 3 as those product issues that determine the manufacturers profit through their effect on the profit equation, and which establish the issues that must be addressed by the PDP. These are not only the issues that determine the customers predilection to purchase the product, but include all issues that impact on the success of the product, and which can be addressed by the PDP. DoP are not specifications and do not set target values, that is the function of the PDP, which must ensure that optimum target values are identified, set and achieved.

It was important to validate the concept of DoP and its use in the PDP evaluation method. This was achieved by an industrial survey, which has been described in Chapter 4. Aspects tested were whether industry could relate to the concept of DoP, and whether industry could identify DoP for their own products. The survey results established that these issues are not obstacles to implementing the method. However, the survey results, and development of the evaluation method, raised a number of additional issues to be addressed.

1. How to define DoP for product issues where there is an axiomatic desired outcome e.g. low down-time, fast time to market.
2. How to define DoP for product issues that depend on the performance of previous products e.g. previous good use of product, good safety history, reputation for reliability.
3. How to define DoP at an appropriate level of abstraction (LoA). For example, for a stabilising fin or wing, detailed product issues might be drag, lift, and weight. These can be consolidated as a higher level 'performance' DoP.
4. How to define DoP so that they relate to one (and only one) of the three PDP dimensions.
5. How to account for interactions amongst DoP. I.e. when realising the full benefit of one DoP depends on first effectively realising another. Questions to be answered were; what are DoP interactions and how are they identified and quantified?
6. Threshold DoP effectiveness. Some critical DoP can be identified that must be realised to some minimum level of effectiveness for the product to be viable in the market. The question to be answered was; how is the threshold level of effectiveness identified and quantified?

The above issues had to be addressed in a manner that satisfied the underlying philosophy of the evaluation method. A review of the relevant literature is presented in Section 5.2. The examination of the six items is presented in Section 5.3. Items 1 to 4 are discussed under the heading of identifying DoP (Section 5.3.1). Results of industrial trials to assess the guidelines to identify appropriate DoP are presented in Section 5.3.2. Item 5 is discussed in Section 5.3.3 and item 6 in Section 5.3.4. Concluding remarks are made in Section 5.4.

5.2 Literature Review

Existing literature was reviewed to seek solutions to these issues.

Griffin and Page (1996) and Hart and Craig (1993) give comprehensive reviews of the metrics of NPD success. The latter identify financial measures, which may be related to profit, assets, sales, capital or equity, and non-financial measures where a project may be deemed to be successful in terms of its impact on design, activity, market, technology or commercial outcomes. The former identify mainly financial measures at the programme level, while at project level they identify measures of customer-based success, financial success and technical performance success (these are listed in full in Section 2.3.2). A number of these metrics relate directly to DoP because they are issues that can and must be addressed directly by the PDP to increase the likelihood of successful product outcomes. For example;

Customer based success

- Customer satisfaction
- Customer acceptance

Technical performance success

- Competitive advantage
- Meet performance specifications
- Speed to market
- Development cost
- Meet quality specifications
- Launch on time
- Innovation

DoP that can be identified from Brookes and Backhouse's (1998) review of measures of PDP performance are:

- Time-to-market
- Average concept to launch time (i.e. cycle time)
- Product cost
- Technical performance
- Quality
- Design performance
- Manufacturing cost
- Manufacturability
- Testability

There are many other papers dealing with aspects effecting NPD success, which identify issues that can be viewed as DoP (although this may not be the primary focus of the papers). Some of these have been discussed in Section 2.3.

It can be seen that the reviewed literature identifies issues that impact on NPD success and therefore (implicitly) deals with DoP in a general manner. However, no paper has been identified that deals with DoP as a specific issue. Also, successful NPD is not assessed in the literature in terms of realising specific product issues addressed by the PDP, and therefore none of the detailed issues regarding DoP identified in 5.1 are addressed. It was necessary therefore to design solutions to resolve the research issues.

5.3 Research Issues

5.3.1 Identifying DoP

5.3.1.1 Links to Desired Outcomes

While a number of DoP can be identified from within the literature it was necessary to determine what industry would identify as DoP in their specific context. The survey results presented in Chapter 4 show that respondents were able to relate to the concept and to identify a large number of issues (see Appendix D) that are important to determine profitable outcomes of their products. For many respondents it appeared natural to link the issues with a desired outcome e.g. if the important issue is development cost then respondents were likely to identify '<u>low</u> development cost' as DoP. However, what is important is that the PDP gives effective and appropriate consideration to the development cost, and in fact a high expenditure on development may be justified in some cases. Thus DoP names should not include qualifying adjectives, e.g. environmental impact, service life, development cost, and cycle time, are better than low environmental impact, long service life, low development cost, and short cycle time.

5.3.1.2 Brand Issues

The survey results presented in Chapter 4 also show that a number of product issues were identified that are intrinsically historical although they affect the success of future products. However, future products must also embody these values in order for the company to maintain long term advantage. These are therefore issues to be considered at the programme level. For example;

- Previous experience of our product
- Perception of products relative to competition
- Previous track record
- Previous good use of product
- Reputation for company and product reliability
- Good safety history
- Strength of company name and reputation
- Company and product synonymous with quality and reliability

These issues require objectives to be set at programme level and are 'DoP' that must be perpetuated in future products, due to a history of their positive impact on product success. Each statement must be examined in some detail to extract the project level issue (DoP) to be realised by a current or future PDP. For example, the programme level issue 'safety history' requires a project level DoP 'safety'.

Other issues are more complex and may require extensive examination to extract the project level DoP; for example, 'previous experience of our product'. The company will have to discover what customers consider to be good (and bad) experience and ensure that the findings are appropriately reflected in project level DoP.

5.3.1.3 Level of Abstraction (LoA)

It became apparent during the first implementation of the PDP evaluation method (see Chapter 9) that many of the identified product issues were at too detailed LoA. For example, the company practitioner at the ship motion control systems manufacturer identified as DoP product issues concerning lift, drag and weight. DoP at too detailed LoA may result in the user ignoring individual DoP in order to save time when assessing the effectiveness of the PDP activities and evaluating instead their effectiveness to develop the product as a whole. The PDP may then be perceived to be effective, when in fact it is not, because the detail that should be exposed by the individual DoP has been lost, and effectiveness is therefore assigned at a higher LoA.

To address this, company expert practitioners must make judgements about the appropriate LoA at which DoP are identified. Where the PDP is similar, even though it addresses a number of detailed product issues e.g. lift, drag, and weight, the practitioner must identify a DoP that consolidates these issues. The appropriate LoA of the consolidated DoP is that at which the process to address the individual issues is essentially the same i.e. the same activities, information, skills, people and facilities. In other words, it is the LoA at which the process can be evaluated just once, even though it is applied a number of times to address the different product issues. DoP are therefore identified at a LoA that is as high as possible, but no higher than allows the company to relate PDP effectiveness to the product issues.

To speed up the evaluation process it is possible to consolidate product issues still further to create higher level DoP, with the product itself as the highest LoA (see example in Figure 5.1). However, it must be recognised that the strength of the method will be impaired by loss of specificity.

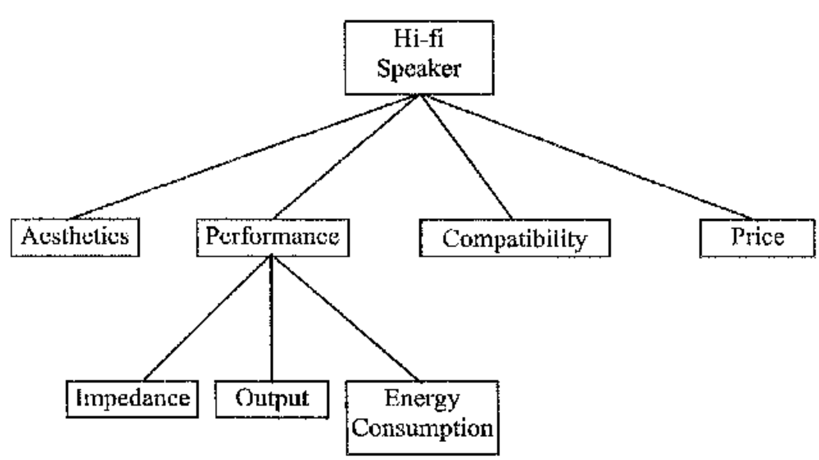


Figure 5.1. Example of Consolidated DoP

5.3.1.4 Dimensions

Assessment of activity effectiveness (described in Chapter 7) is carried out in relation to three dimensions: 1) Solution Quality (SQ) – the effectiveness of the activity is assessed in relation to progressing the state of the product; 2) Resource Consumption (RC) - the effectiveness of the activity is assessed in relation to the resources utilised, and 3) Time - the effectiveness of the activity is assessed in relation to the duration and timeliness (schedule).

To maintain the numerical integrity of the evaluation method it is important that each DoP be assigned to one of the three relevant dimensions (see Figure 5.2). Activities can then be assessed within the context of each dimension for effectiveness to realise DoP corresponding to that dimension. It will become obvious (once the procedure for assessing activity effectiveness using criteria that reflect the three dimensions is studied in Chapter 7) that it is nonsense to assess the effectiveness of an activity to realise solution quality DoP, for example, using criteria that relate to the resource consumption or the time dimension.

Furthermore, one dimension of the identified set of DoP may have a greater impact on company profits that another. For example, a company may decide that it is more important to get their product into the market quickly than for all the product features (performance, price, aesthetics, etc.) to be exactly right. In this instance the company expert can elect to place a strong correlation of the time dimensional group of DoP to profit.

Quantifying the impact of each dimensional group on profit through the appropriate correlation factors means that the strength of impact is independent of the number of DoP assigned to each dimensional group. In other words a strongly skewed distribution of the identified DoP to one dimension will *not automatically* result in profit being dominated by that dimensional group.

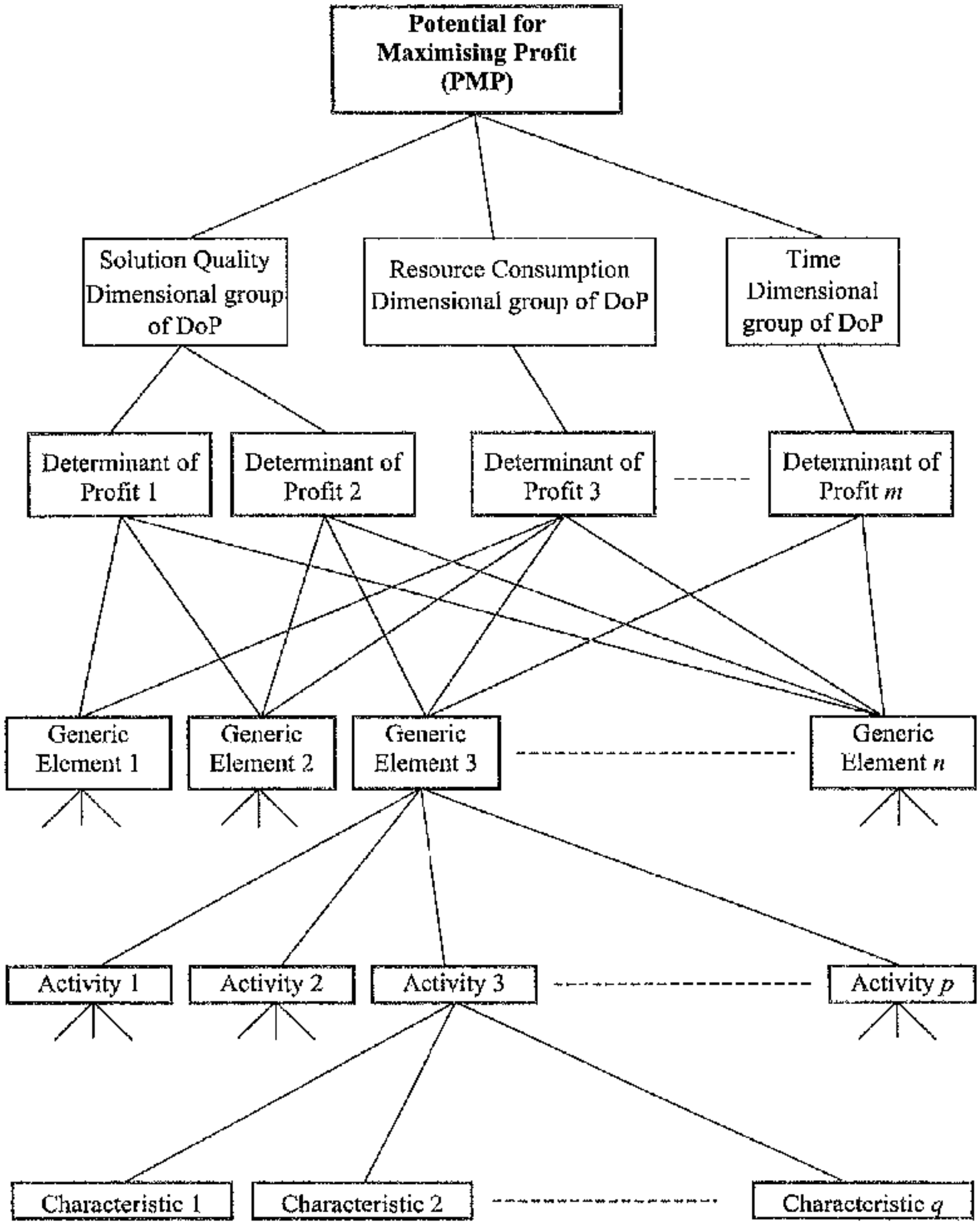


Figure 5.2. Evaluation Method Component Levels

Assigning DoP Dimensions

Some DoP may be proposed which can be assigned to two dimensions. For example, 'launch date' can be assigned to the solution quality dimension because the optimum date on which to launch the product (e.g. at an exhibition) must be identified. On the other hand, the DoP can also be assigned to the time dimension because ineffective control of time can result in the identified optimum launch date being missed. However, a DoP must not be assigned to more than one dimension since this is inconsistent with evaluating activity effectiveness. In the event that a product issue relates to more than one dimension, the issue must be explored further to identify new DoP that can be assigned to each of the appropriate dimensions. For example, two DoP can be extracted from the product issue 'launch date' such as 'set launch date' (for the solution quality dimension) and 'meet launch schedule' (for the time dimension).

5.3.2 Trials

As mentioned in Section 5.1, a number of issues concerning DoP arose from the results of the industrial survey described in Chapter 4. Changes to the way that DoP were defined in the survey have been discussed above. These changes form part of a set of guidelines to aid company practitioners to identify DoP for their products. An objective of the trials described in this section was to assess the above guidelines to identify appropriate DoP. The trials were carried out during full implementation of the PDP evaluation method at three industrial sites. Trial results indicate that the guidelines for identifying appropriate DoP are effective.

5.3.2.1 Results

Industrial practitioners, guided by a facilitator, identified the DoP shown in Table 5.1.

DoP	Dimension (SQ, RC, Time)
Ship Motion Control Systems Manufacturer	
Operator interface	SQ
Ability to customise	SQ
Performance	SQ
Reliability	SQ
Maintainability	SQ
Meet classification society rules	SQ
Ease of installation	SQ
Selling price	SQ
Development costs	RC
Computer Sub-Systems Manufacturer	
PC card standard	SQ
Storage and power performance	SQ
Environmental performance	SQ
Mean time between failure (MTBF)	SQ
Aesthetics	SQ
Plug and play	SQ
Product road map	SQ
Time to market	Time
Hi-Fi Systems Manufacturer	
Aesthetics	SQ
Technical compatibility	SQ
Acoustic quality	SQ
Reliability	SQ
Perceived value	SQ
Utilisation of resources	RC
Launch date	SQ

Table 5.1. DoP Dimensions

5.3.2.2 Analysis of Trial Results

Links to Desired Outcomes

All of the above DoP, with the exception of 'meet classification society rules', are good. They all identify issues to be addressed by the PDP without stating an objective or desired outcome. It can be argued that meeting society rules is also an issue to be addressed by the PDP as the product either achieves this requirement or it does not. It is therefore the function of the PDP to determine what rules must be met, and to ensure that the product meets them. On the other hand, the issue might be better identified as 'statutory and market rules', which would imply that the function of the PDP was first to determine whether or not the product has to meet these rules (through market/customer research), and if so, to determine the nature of the rules and ensure that the product does meet them. This is indeed the case. It is the task of the expert to identify important product issues from his/her experience and leave it to the PDP to: 1) determine whether the issue is pertinent in a particular instance i.e. the product under development; 2) determine the exact nature of the issue i.e. objective or solution to be achieved; and 3) ensure that the issue is realised in the product to the appropriate degree. It was thus an error to identify 'meet classification society rules' as a DoP. The error can be directly attributed to evaluating the PDP for an existing product (as in this case), because the expert knew that the product under consideration had had to meet the rules, as opposed to identifying the rules as an issue to be resolved during future development.

Brand Issues

The objective in the trial was to identify project level DoP. All of the identified DoP are appropriate in this regard. The industrial practitioners were able to either avoid identifying programme level issues as DoP, or extract the appropriate DoP from identified programme level issues.

Level of Abstraction

All of the above DoP are at the appropriate LoA. The industrial practitioner at the ship motion control systems manufacturer was able to consolidate four detailed product issues i.e. 'weight', 'force developed', 'size', and 'drag' as a single DoP named 'performance'. In doing this the practitioner judged that each of the detailed low level issues would be given equal treatment and be addressed by the same elements of the process.

Dimensions

The three practitioners experienced no difficulty in assigning their DoP to the relevant dimension. Table 5.1 shows the appropriate dimension for each of the identified DoP.

It can be seen that the hi-fi systems manufacturer assigned the DoP 'launch date' to the solution quality dimension. It is interesting that he did not identify a corresponding time dimension DoP (e.g. speed to market) as might be expected. The reason being that while it was important to identify the correct date/s on which to launch the product (an annual exhibition in this case) the practitioner judged that it was not critical if the date was not achieved the first time round. However, while the practitioner may have judged it to be financially prudent to wait for the next optimum launch window (one year later) rather than attempt to launch at an inopportune time, to miss the first launch opportunity must have had a negative effect on the company's income.

5.3.3 DoP Interactions

This section only deals with the existence and nature of interactions amongst DoP. Methods to identify these interactions and to quantify their effect are discussed in Chapter 8.

It was recognised from the outset that a complex set of interactions exists between DoP and their impact on profit. This was confirmed during discussions at two industrial trial sites. Both experts observed that identifying and estimating DoP impact on profit was too simplistic due to the action of other DoP, which, if not realised effectively, negate the effect on profit of the first DoP. For example, a household toaster may have as its DoP the number of slices of bread, aesthetics and selling price. It can be seen that the impact of the selling price on profit from sales of the product is not independent of getting the other DoP right. The situation may arise where an appropriate target selling price is set, but the potential benefit of this cannot be realised because the aesthetics DoP has not been handled effectively and causes customers to view the price as too high for a toaster that looks outdated or ugly or is the wrong colour.

The example illustrates that interactions are only an issue when DoP are not realised with complete effectiveness by the PDP. Thus there would be no effect on the impact on profit of the selling price if the aesthetics DoP were realised with 100% effectiveness. A DoP's impact on profit is estimated with the assumption that all other DoP will be realised with complete effectiveness by the PDP, and assuming that it will itself be realised with complete effectiveness. However, it is unrealistic to expect such a scenario in industry, and it is therefore necessary to design a procedure that permits a set of interacting DoP to be identified for each subject DoP, and their interaction effect to be quantified, should they not be realised with complete effectiveness. The design and test of such a procedure is discussed in Chapter 8.

5.3.4 Threshold Values of Effectiveness to Realise DoP

Threshold effectiveness values were raised as an issue during trials to validate the procedure to quantify DoP interactions. An industrial practitioner observed that there would be little to be gained from developing his product unless certain DoP were realised to minimum level of effectiveness by the PDP. For many products there exist certain critical DoP (e.g. reliability) that must be realised to some minimum level of effectiveness for the product to be viable in the market. In this instance the PDP must not only identify the correct value (e.g. level of reliability) but must also ensure that the product meets the requirement. Only if this is achieved can the other DoP contribute to profit. The effect of not addressing the reliability DoP above a certain minimum level of effectiveness results in the negation of the impact of all the other DoP on profit.

A procedure must be designed that permits critical DoP to be identified and threshold values to be quantified within the overall philosophy of the evaluation method i.e. through elicitation of expert judgement in a non-prescriptive context of current best practice. The design and test of such a procedure is described in Chapter 8.

5.4 Concluding Remarks

A number of issues concerning DoP have been identified during development of the PDP evaluation method. Research has shown that NPD performance is usually evaluated in a manner different to that proposed in this thesis. While research papers identify product factors and issues that can be used as DoP, they do not do so explicitly, and do not identify or, by implication, address any of the issues raised regarding DoP. It has, therefore, been necessary to design procedures to avoid DoP being identified as objectives, to identify DoP to account for product brand issues, to identify and redefine DoP at the correct level of abstraction, to identify DoP dimensions and assign DoP to a relevant dimension, and to identify DoP interactions and threshold values for critical DoP.

6

Modelling the PDP

Summary

A generic model of the PDP is developed using primarily (although not exclusively) the IDEF structured modelling technique. The philosophy underlying the development and evolution of the model is described. The model proved satisfactory in tests against a number of existing models, and in industry trials to determine completeness. Findings also show that the model satisfies all requirements for the PDP evaluation method.

6.1 Introduction

A feature of the method developed in this thesis is that the company itself undertakes the evaluation, and it can address any form of PDP, not just compliance with prescribed procedures. The method requires the company to identify the issues that primarily determine the success of their products (the determinants of profit (DoP)), and then to relate these issues to the activities that address them. If activities that relate to important issues are performed effectively then there will be a better probability of successful outcomes (Montoya-Weiss and Calantone 1994). The activities are organised into a number of generic (i.e. related to manufacturing industry in general) elements (GE) of the PDP in order to provide a structure for the evaluation of activity effectiveness.

A key requirement for the method is a model of the PDP onto which companies can map their own processes and then evaluate the effectiveness of each activity by examining the characteristics of the activity. This chapter reports on the development and tests of a generic model of the PDP to serve this purpose, and presents the final model.

The chapter is structured as follows. The scope of the model is discussed in Section 6.2. Requirements for the model are presented in Section 6.3. Approaches to realise a model are discussed in Section 6.4. The model itself is described in Section 6.5. Testing of the model is described in Section 6.6, and concluding remarks are made in Section 6.7.

6.2 Scope of the Model

The scope of the product development process is taken as described by Hart (1995) "... .. involves activities and decisions from the time an idea is generated (from whatever source) until the product is launched on to the market." The product may be entirely new, or it may be derived from an existing product. The 'supply' activities of sales, orders, purchasing, manufacture, distribution and product support are viewed as quite separate from, and subsequent to, the PDP. However, it is important that the model should be developed within the context of the overall sphere of operations of a manufacturing company. The developed model therefore embraces, at least at a higher level of abstraction (LoA), all the processes involved in operating a company with the objective to generate profits by supplying and supporting products in a market.

Thus the focus of the model is making profits through products, and the primary functions are represented as strategy, planning, execution and control. The control function involves evaluation of the outcomes of the execution activities against the objectives set by the operational plans, and approval to proceed to the next stage. Task management is viewed as an integral part of each activity and evaluated as such. Strategy and planning are functions that take place at a high level in the process and set the scene for the product development activities. The PDP itself is represented by a set of generic elements at a common LoA and comprises only execution and control functions.

The execution functions of the company comprise technology development, product development, product supply, implementation of processes[1] and provision of resources. The model described in this paper is designed to expose the detail of the PDP. This does not imply that the other processes are less important, nor that product development does not interact with them, but the main purpose of the model is to enable an evaluation of the PDP, and some boundaries must be drawn. It should be particularly noted that technology development is viewed as a separate process that provides necessary inputs to product development. This approach is supported by Smith and Reinertsen (1991, 1995) who recommend that technology development should occur in parallel to NPD to overcome the

[1] This includes design and implementation of new, and maintenance of existing, business processes.

high commercial risk associated with developing technology within the PDP. However, a consequence of taking this viewpoint is that the interactions between technology development and product development must be carefully assessed when evaluating the effectiveness of activities within the PDP generic elements. Song and Montoya-Weiss (1998) observe "The development process for really new products is often punctuated by numerous setbacks and delays because the technology, market and support infrastructure may still be evolving or non-existent. In fact, it may be the case that certain core technologies, market and infrastructures must be created concurrently."

An illustrative model of the above view of company operations, as given by Fairlie-Clarke and Clark (1993), is shown in Figure 6.1. This recognises three main product states: approved idea; approved concept; and released product. The strategy and planning functions set the objectives for execution of the product development and the criteria for judging whether a product has achieved a particular state. The control function evaluates and approves offerings from the execution function with the effect that approved ideas become part of the 'product programme' earmarked to be worked up as detailed proposals for product development projects; approved product development projects become part of the 'project programme' earmarked to be allocated resources and scheduled; approved products become part of the 'product range' to be manufactured and supplied to the market. This theme is evident in the final model.

6.3 Requirements of the Model

A generic model is required that suffices in every situation to represent the PDP of any company. The company will map the activities of its own PDP onto the generic elements of the model to create a lower level model that is specific to the company. Although the generic model must be sufficient to represent all PDP activities in any company, not all generic elements will be necessary in every case. Companies need use only those generic elements necessary to fully represent their activities, which will depend on their industry, product type and the nature of the product development.

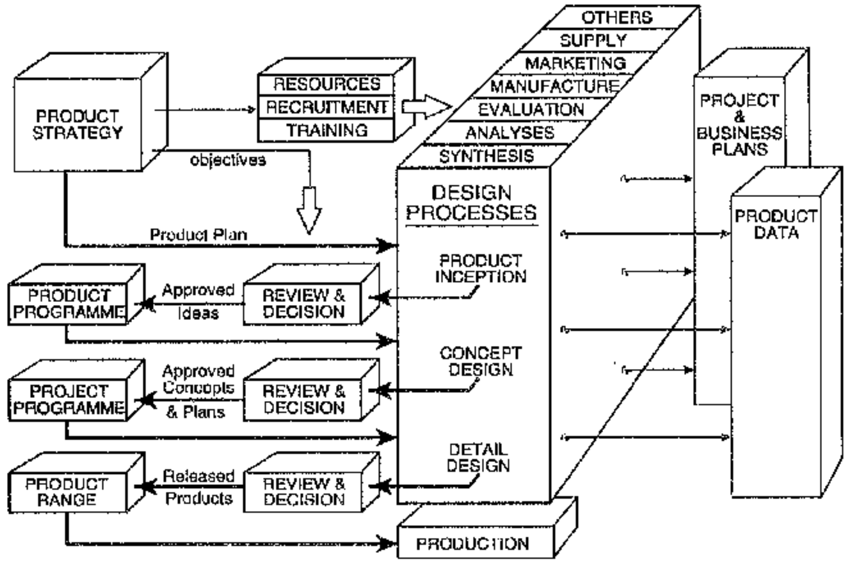


Figure 6.1. A Model for the Control of Product Development

The generic model must represent what activities take place, but not how they take place. Thus the model will not detail interactions amongst activities, nor the organisation and management of the activities. For example, a concurrent engineering approach would not be apparent from the model. These aspects are handled as part of the assessment of the effective execution of the activities, which will address issues of quality of solution, timeliness and resource, as well as other aspects of good product development practice such as multi-functional teams, performance measurement, senior management support, product champions, communication, IT tools, resource allocation, information flow, etc. Accounting for project and management dimensions in this manner enables a universal generic model to form the basis for company specific evaluations (Ang *et al* 1994, Childe *et al* 1997, Howard *et al* 1999).

Specific requirements for the model are:

1. The model must show product development as a distinct process.
2. The model must place the PDP in the context of the full product business operations of the company.

3. The model must define tasks in a hierarchical manner such that each higher level task is expanded into a number of tasks at the next lower level. Every task can then be traced back as a response to satisfying a higher level objective.
4. The model must account for the full scope of activities of the PDP. That is, idea generation to product launch.
5. The model must provide a complete set of generic elements onto which the activities of the PDP of any company can be mapped. The model must be universally applicable to all companies for all manufactured products. It is argued (Rosenau 1996; Veryzer 1998) that PDP models intended for 'continuous' (or incremental) development of products will not prove equally effective for 'discontinuous' development of completely new products, and vice versa. Thus the generic elements must be set at a LoA such that the distinctions between the processes for continuous and discontinuous development of products can be made at a lower level.
6. It should be possible to map any model of the PDP from the literature directly onto the chosen generic elements, provided that it covers the same scope.
7. The generic elements must be of like LoA to permit assessments of the relative importance of all activities. For example, activities to regulate the company, operate the company and supply the company are at like LoA. An activity to develop strategy would be at a more detailed level than the previous three because it is a constituent activity of operating the company.
8. The generic elements must be at the lowest LoA consistent with Item 7, such that the activities mapped onto the generic elements will be identifiable as tasks carried out by individuals or teams as part of the managed activities of the company. Only at this level is it possible to carry out a meaningful assessment of the effectiveness of the execution of each activity in the context of all other activities. At higher levels the abstraction is too great, at lower levels the number of activities is too great.
9. The number of generic elements must be manageable.

6.4 Solution Approach

The alternative approaches addressed to realise a model to meet the specified requirements were: (a) search the literature for a suitable existing model, or a model that could be adapted to suit, (b) develop a model from an existing model or models, (c) develop a model from experience and observation using a recognised system modelling procedure.

6.4.1 Literature Review

Because of the utility of models for organising information and representing structures there are a large number that exist in the product development literature. These serve a variety of purposes. Many of them focus on the existence of certain activities that are identified as necessary for successful product development, either generally or in specific scenarios. Others focus more on the structure and organisation of the process, including the sequence and interaction of tasks such as is seen in concurrent engineering. For this thesis it is the first focus that is important, and the published work may be relevant in two ways. Firstly it may represent the PDP in a way that can be used directly as a basis for the required model, and secondly the validity of the final choice of model can be tested by checking that all valid PDP activities in the literature can be mapped onto the generic elements.

The extent to which each of the reviewed models meets the requirements as given in Section 6.3 is shown in Table 6.1. No one model satisfies all requirements, nor can any be easily adapted to suit the purpose. These models, which are reviewed below, have been developed for purposes other than the mapping of existing or proposed processes and the subsequent quantification of activity effectiveness.

Each is unsuitable in some respect. The models identify an informed range of activities (these are mapped against the final generic model in Table 6.2), but in some the scope does not match the requirement, and in others the LoA is either inconsistent, or is not taken to sufficient depth. However, the models in the literature do contain specific stages, phases and activities important for NPD success, and these provide a useful breadth of input to the development of the generic model.

Authors	Model Type	Requirement Number 1	2	3	4	5	6	7	8	9
Yorke and Saville (Cooper 1983b)	- Four stage.	x								x
Roberts and Romine (Cooper 1983b)	- Four stage.	x								x
Booz-Allen and Hamilton (Cooper 1983b)	- Six stage.	x			x	x	x			x
Myers and Marquis (1969)	- Five stage.	x			x	x	x			x
Cooper (1983a)	- Seven stages and twenty activities.	x	x		x	x	x			x
Cooper (1983b)	- Seven stages, sixteen development activities, and seven evaluation activities.	x	x		x	x	x			x
Pahl and Beitz (1984)	- Design model.	x								x
Cooper and Kleinschmidt (1986)	- Thirteen activities.	x	x		x	x	x			x
Goltz (1986)	- Phase review model with four phases and three reviews.	x								x
Morley and Pugh (1987)	- Generic design model with six core activities.	x	x		x					x
Calantone and di Benedetto (1988)	- Similar to Cooper (1983b).	x	x		x	x	x			x
Cooper (1990), Cooper and Kleinschmidt (1991)	- Five stages and five gates.	x	x		x					x
Cooper (1994b)	- Four stages and five fuzzy gates.	x	x		x					x
Clarke and Fujimoto (1991)	- Three processes: includes a four-phase PDP model.	x			x	x	x			x
Wheelwright and Clark (1992)	- Six phases.	x			x		x			x
Ulrich and Eppinger (1995)	- Five phases	x					x			x
British Standards Institution (1997)	- Six phases and twenty-six activities.	x	x		x					x
Hart (1995)	- Multiple convergence model.	x	x							x
Carlson-Skalak *et al* (1997a, 1997b)	- Concurrent engineering model	x			x		x			x
Veryzer (1998)	- Discontinuous NPD model.	x			x					x
Song and Montoya-Weiss (1998)	- Six phases.	x	x		x	x	x			x

Table 6.1. Requirements met by existing PDP Models

Review of Existing Models

Booz, Allen & Hamilton (1968) describe an empirically based model that begins with exploration of the marketplace to identify customer needs. Myers and Marquis (1969) outline a five-stage model based on a study of 567 case histories of incremental innovations. Both of these empirical models are high level descriptions of industrial processes at project level. The scope of the Myers and Marquis model extends beyond that required, and neither model provides any detail of marketing or business activities.

In a paper that classifies NPD processes Cooper (1983a) reviews a model by Yorke-Saville and a similar model by Roberts and Romine. While both models are based in industry and set at the project level, their scope is limited to research and development (R&D) stages and does not include business and marketing activities.

Cooper (1983a) also classifies seven different industry-specific processes by identifying 20 constituent activities from the literature and determining the frequency of execution of each in 58 companies. Groupings of dominant activities form the basis of the classification. Calantone *et al* (1986) use the same 20 activities in a similar study. Cooper's project level model includes production activities and is therefore broader than required for the generic model. Although the list of activities is extensive they are not at a consistent LoA.

Cooper (1983b) proposes a process model for industrial product development. This normative model consists of seven stages and 16 activities. Evaluation points or go/kill decision nodes separate the stages. Although findings from many research projects are pulled together, the project level model is essentially a theoretical layout of the 20 activities presented earlier by Cooper. Calantone and di Benedetto (1988) present an adaptation of Cooper's (1983b) model, and later Cooper (1990) himself uses this model as the foundation for work on stage-gate processes. This describes a number of PDPs that Cooper has observed in practice, but the model is not tested in industry. Cooper (1994b) proposes a similar model with fuzzy gates. The focus of both models is on the structure and organisation of the process rather than the constituent activities and they are therefore at too high a level.

A design process model by Pahl and Beitz (1984) identifies a number of phases and phase outputs in moving from task to solution. The model is set at the project level, but at too high a LoA and with insufficient detail about activities.

Goltz (1986) provides a phase review model as part of his 'Guide to Development'. The guide proposes a simple model developed in the chemical industry consisting of a set of divergent and convergent activities with reviews undertaken before continuing to the next phase of development. This project level model is industry specific and omits business aspects of the process. Also the LoA is too high, with no lower level activities identified.

Cooper and Kleinschmidt (1986) develop a list of 13 activities from other authors (Booz, Allen and Hamilton (1982); Cooper (1983b)). They find that there is a greater probability of commercial success if all of these process activities are completed. Dwyer and Mellor (1991) who replicated the study in Australian companies substantiate this finding.

Morley and Pugh (1987) view Pugh's design activity model as core to all types of design. They present a business design activity model that locates product design activity firmly within the overall structure of a business. The specific focus of Morley and Pugh's model is to show how Pugh's design activity core can be used to model information flow between the business design boundary and the design core. The model is therefore at a high LoA in terms of PDP activities. Although the model has its roots in industry no results are given of any tests. While the model cannot be used as the basis for a list of generic elements, it does consider issues such as information flow, resources and cross-functional communication, which must be reflected in the assessment of activities required later in the evaluation process.

Clark and Fujimoto (1991) report on product development in the global automotive industry. They present a theoretical high level model of product development as a simulation of consumption[2]. Product development (by their definition) comprises three processes: a PDP; a production process; and a consumption process. The PDP has the phases product concept, product plan, product design and process design. Information from

[2] The underlying notion is product development as a rehearsal of future customers' product experiences. According to Clark and Fujimoto it is this notion that lies at the core of evaluating whether a design is attractive or not.

customers is fed in from the consumption process. Their model is generic only at a high LoA, becoming specific to the automotive industry at the detail level. Thus the model provides guidance only to the phases that should be present in a PDP.

Wheelwright and Clark (1992) present a generic model that relates to the motor industry to illustrate functional activities during cross-functional integration. However, as with Ulrich and Eppinger's (1995) model, activities in the list are not at the same LoA. Ulrich and Eppinger's model also does not reflect the full business operations of the company. Nevertheless both models presents an extensive list of activities that must be reflected in the generic model.

The BS7000 (BSI 1997) model is a high level model with a scope beyond that required. The activities are described at inconsistent LoAs and it is not easy to map all types of PDP onto this model. However, it is extensive and provides some useful checklists of activities. Song and Montoya-Weiss (1998) identify critical activities for developing 'really new' products as distinct to incrementally evolving existing products. Their industry based project level model presents activities at a high LoA. The model provides a framework of activities that should be reflected in the generic model. Another project level model for the development of discontinuous (i.e. really new products) is given by Veryzer (1998). It focuses particularly on the front end of the process and describes ten phases derived from research in industry. Veryzer observes that the process is more exploratory and less customer driven than typical incremental NPD processes. It is only in the ninth phase of his model that customer inputs are considered.

The models discussed so far are limited in that they only provide a list of activities or phases that are, or should be, executed. These models cannot be used to fully describe the processes needed for rapid NPD and fast time to market because they do not account for scheduling of activities and provision of resources. Other models do address these management issues. An early paper by Clausing (1985) presents a concurrent process (although not referred to as such) as does Carlson-Skalak *et al* (1997a, 1997b). Cooper (1994b) discusses third generation product development processes i.e. those where activities overlap. On the other hand, Hart (1995) argues that although success indicators point to functional integration, concurrency (i.e. parallel activities) implies the notion of functional separation. Thus she believes 'converge' to be a better description of what is required in NPD management and presents a 'multiple convergence model' for the early stages of the NPD process. Each point of convergence is identified as a source of information for the downstream activities of each functional group. These are high level project management models with a particular focus on integration and/or concurrency. These principles have been shown to be important to NPD success and as such must be reflected. However in the evaluation method these issues are addressed separately as part of the assessment of activity effectiveness, and therefore this type of model does not satisfy the more basic requirement for the generic model.

6.4.2 Develop From Existing PDP Models

Consideration was given to evolving the generic model from an existing model. However none of the models reviewed provide detail of the overall company structure in which the model is based, and without this it would be difficult to achieve the completeness and consistency in LoA that was sought. It was felt that a better approach was to evolve the model directly from an existing model of high level company processes while ensuring that proper account was taken of the activities identified in the literature.

6.4.3 Develop a New PDP Model Using the IDEF0 System Modelling Procedure

This was the approach finally adopted. The high level company model of Fairlie-Clarke and Clark (1993), which has as its focus 'generate profit through products' (see Node A0, Figure 6.2) was used as the starting point. This model was developed using the IDEF0 method, and it was decided to continue to follow the basic precepts of this method while developing the generic PDP model.

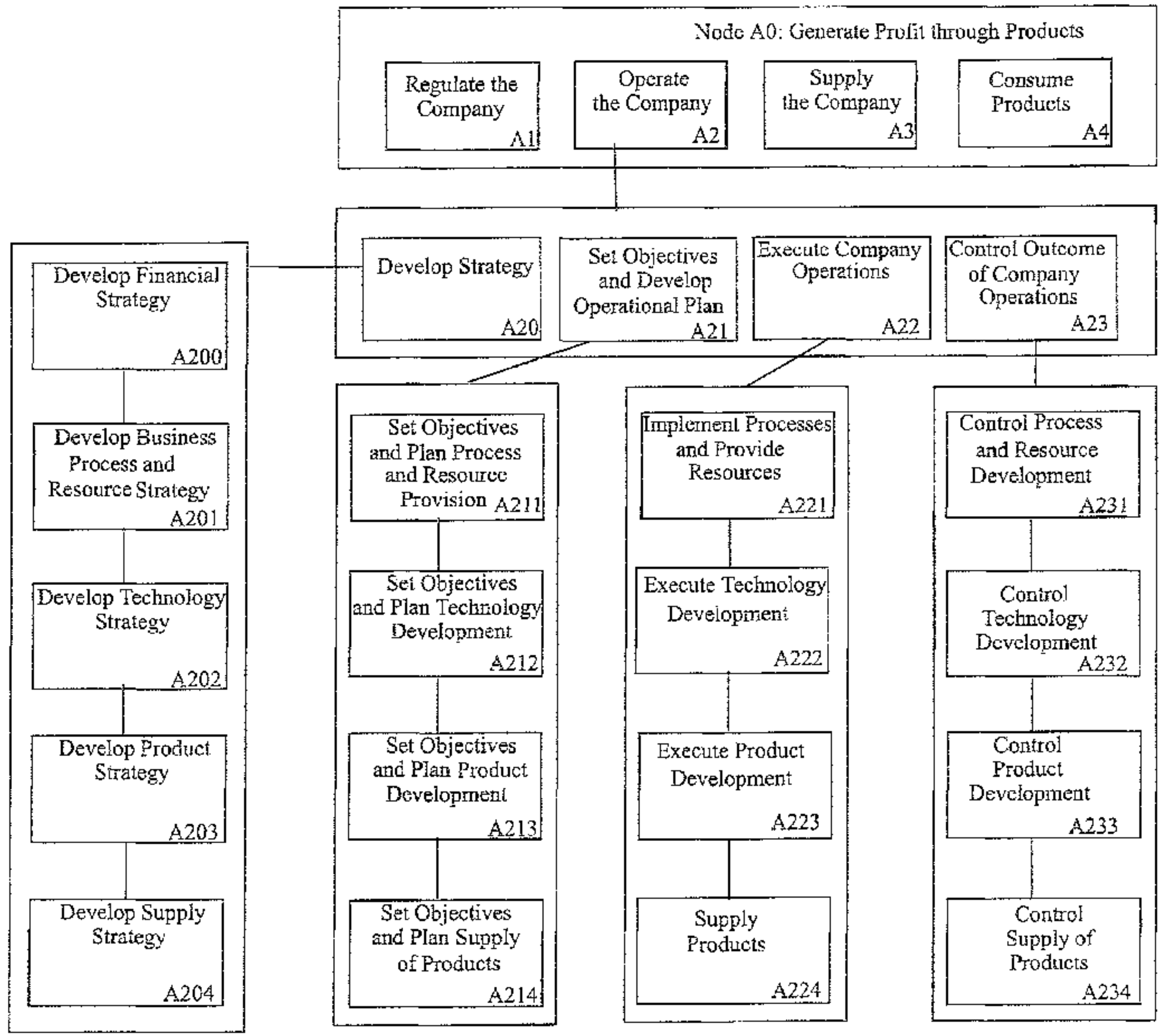


Figure 6.2. Business Processes

IDEF0 is a method for modelling system functions, which is based on Softech's (1981) Structured Analysis and Design Technique. A box represents each function, while arrows are used to represent inputs, outputs, control mechanisms and the means to perform the function. The model is hierarchical with a maximum of six functions at each level. Each function is expanded to reveal further detail at the next lower level, with the depth of the model determined by the amount of detail that is to be represented. These models provide good clarity in representing the process and are easy to review and modify since one is working with a small number of functions at any one level. At the same time they force a rigorous view of the process. A step by step expansion of high level company functions makes visible detailed activities at lower levels in a consistent manner providing for like LoAs. However, the IDEF0 procedure was not strictly adhered to in all respects. First, the limit of six functions per level was not imposed for the detailed activities under the generic elements since the intention of the evaluation method is to assess the effectiveness of all activities at the same level. Secondly, the inputs, outputs, controls and means flows between tasks were omitted. It is the hierarchical structure that is important to ensure rigour and to generate a complete list of activities, while the IDEF0 flow framework is used in the evaluation method as a basis for the assessment of the effectiveness of the execution of each activity. This was felt to be consistent with the objective to evaluate the merit of any type of process, and not just to compare with a prescribed process. Also the level of detail and complexity added by including the flows would defeat the purposes of the model.

Although IDEF was originally developed as a procedure for modelling manufacturing operations, it has been applied by a number of authors (e.g. Belhe and Kusiak (1991), Colquhoun *et al* (1993), Kusiak (1994), Wu *et al* (1996)) to modelling design and product development activities. Ang *et al* (1994) apply IDEF0 in a similar way to that here to create a generic model of a manufacturing enterprise with the focus on manufacturing activities. They argue that Generic IDEF Models (GIMs) provide a starting point to develop company specific models by means of interviews of company experts.

6.5 Description of the Generic Model

Figure 6.2 shows the top three levels of the IDEF0 model, which represent the overall business process. Node A0 is taken directly from Fairlie-Clarke and Clark (1993), but the expansion of Node A2 'Operate the Company' and of the lower levels has been adapted to follow the division of functions as outlined in Section 2. The expansion of functions has been limited to those nodes which feed directly into the final set of generic elements, or which are necessary to make clear the scope of the PDP by showing how related functions, such as technology development and provision of resources, are represented. The PDP is viewed as the means whereby a particular product is developed. The generic elements are therefore drawn only from the execution and control functions, which will operate in response to the product strategy (Node A203), and to the objectives and plans set for the development of business processes and resources (A211), technologies (A212), and products (A213).

The planning, execution and control functions are expanded in Figures 6.3, 6.4 and 6.5 respectively. The generic elements are derived from these figures and are shown with a bold border. To a large extent the model was developed by considering various relevant activities, and then deciding where in the scheme of things these activities should reside. Many activities that affect product development may not be an inherent part of the defined PDP. These issues were resolved by arguing the appropriate location for each activity. The figures show all such activities that were considered, but the model is only claimed to be complete in respect to product development. Other functions are expanded only so far as necessary to resolve the product development issues.

Figure 6.6 shows the generic elements and the nodes from which they are derived. The generic elements serve as a starting point for company specific models. For ease of interpretation and assessment they are arranged in a logical sequence against the product states as given by Fairlie-Clarke and Clark (1993), which are shown at the top of the figure. However, this does not imply rigid adherence to the sequence, nor any lack of integration or iteration of activities. Execution activities are shown in standard boxes while control activities are shown with a bold outline. The control activities control the outcomes of earlier execution activities. Figure 6.6 also shows some constituent activities under each

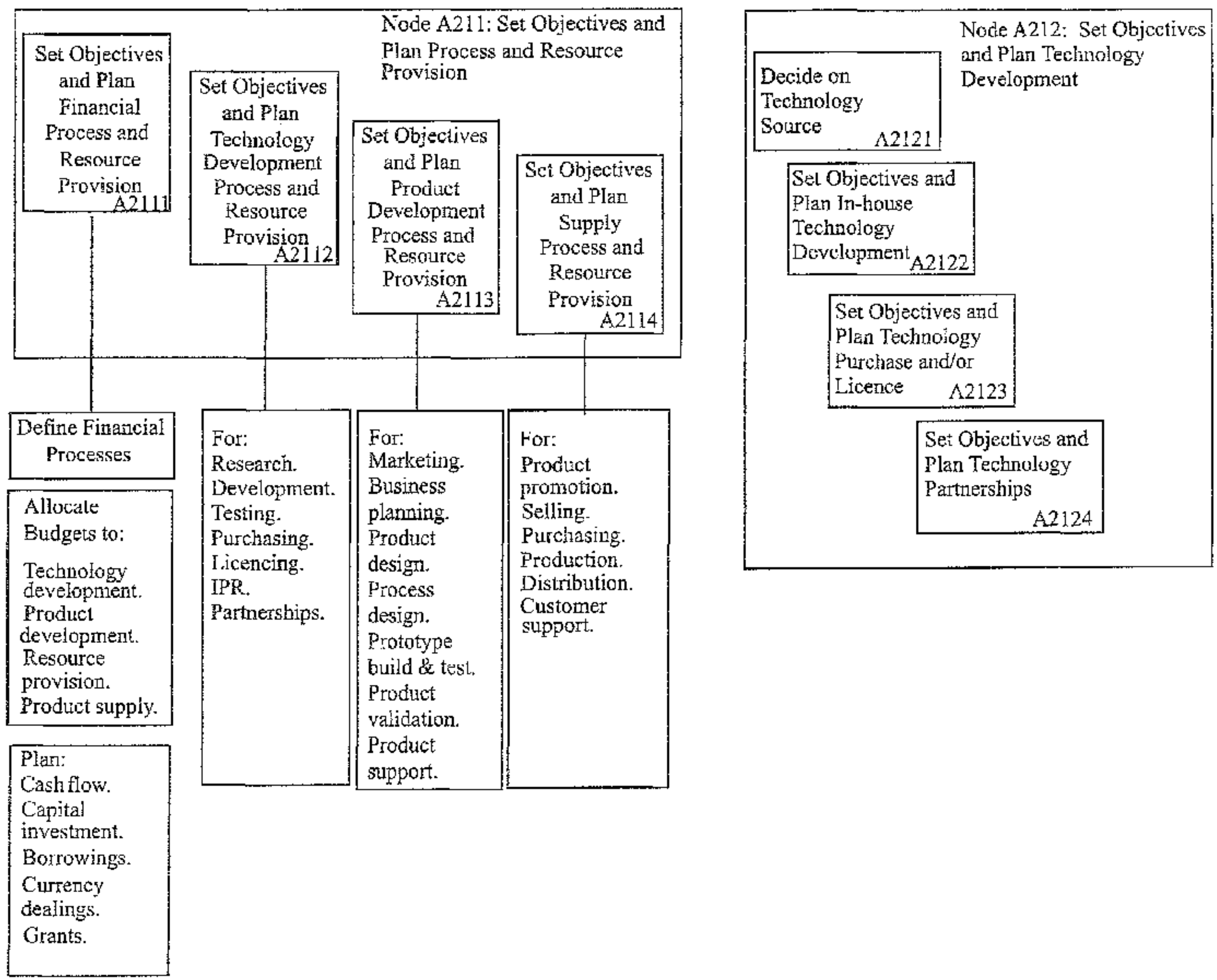


Figure 6.3. Planning Processes

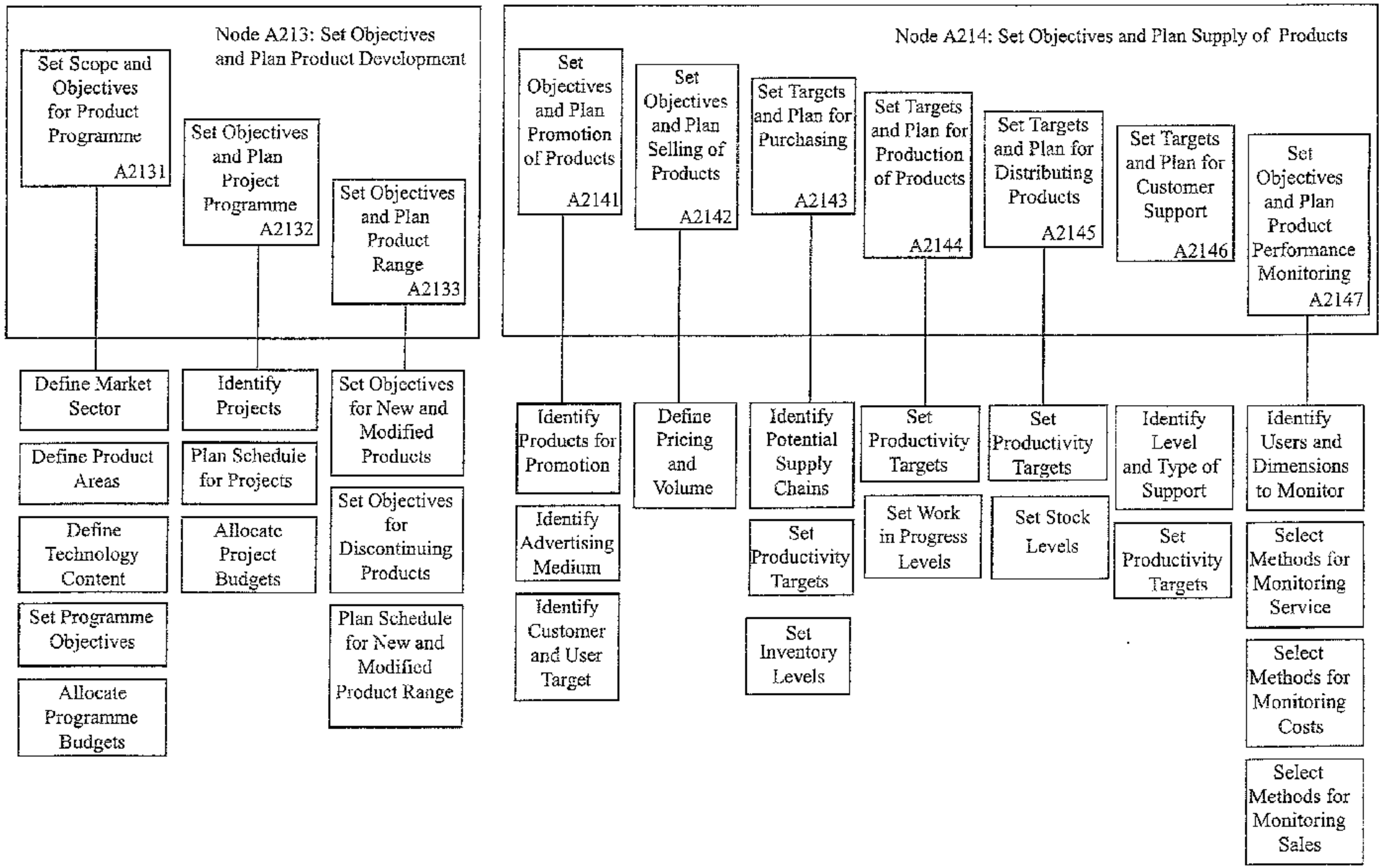


Figure 6.3. Planning Processes (continued)

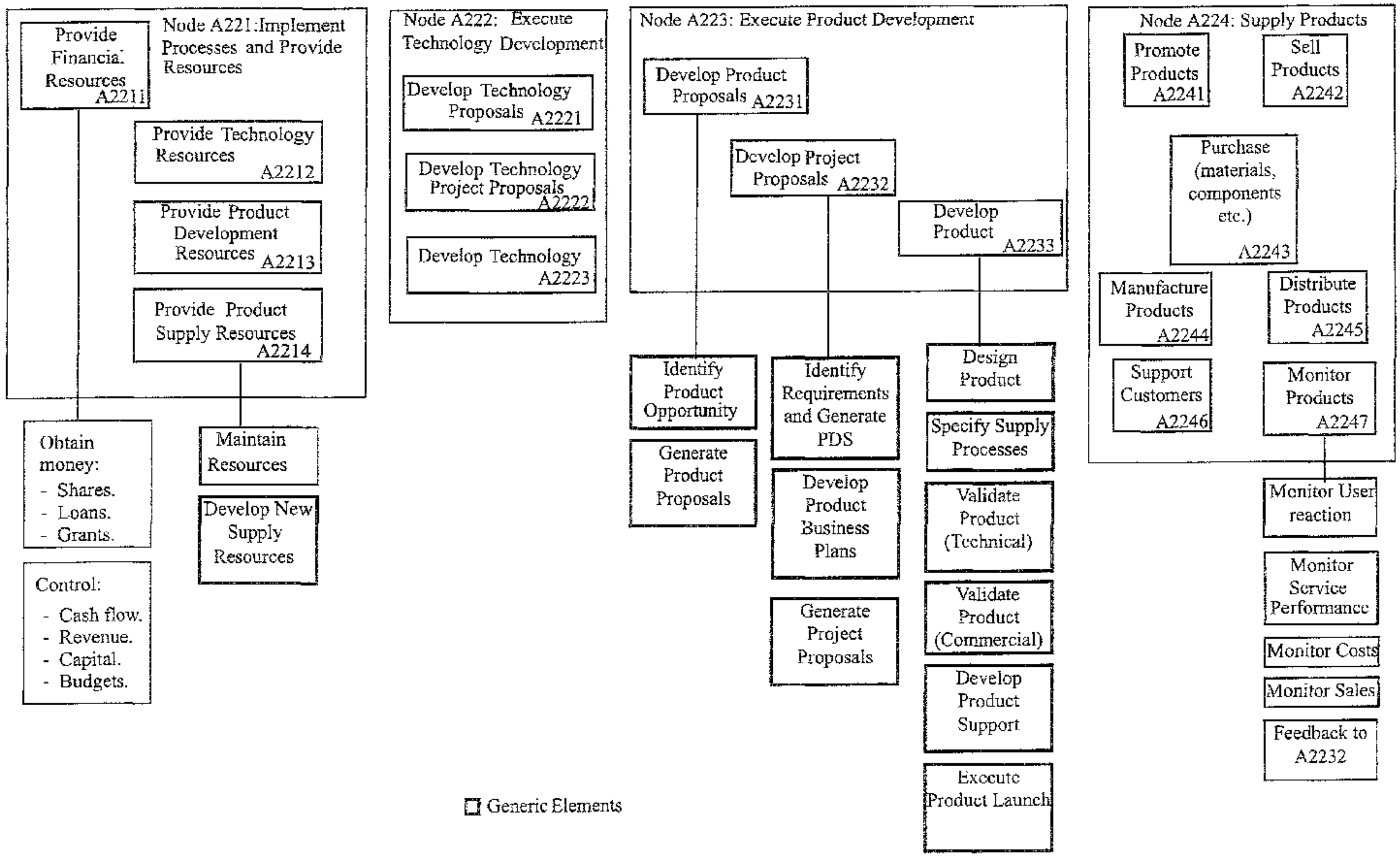


Figure 6.4. Execution Processes

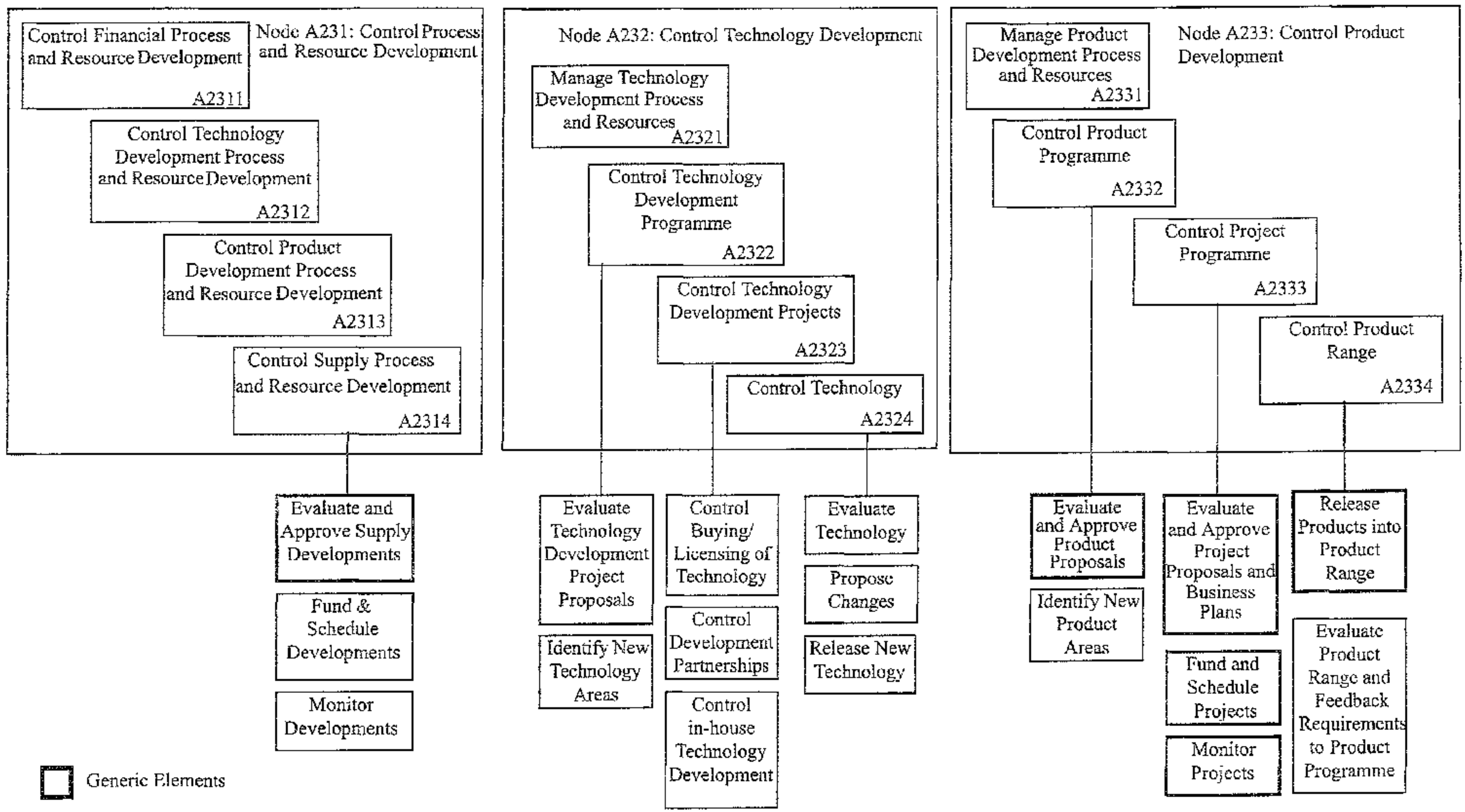


Figure 6.5. Control Processes

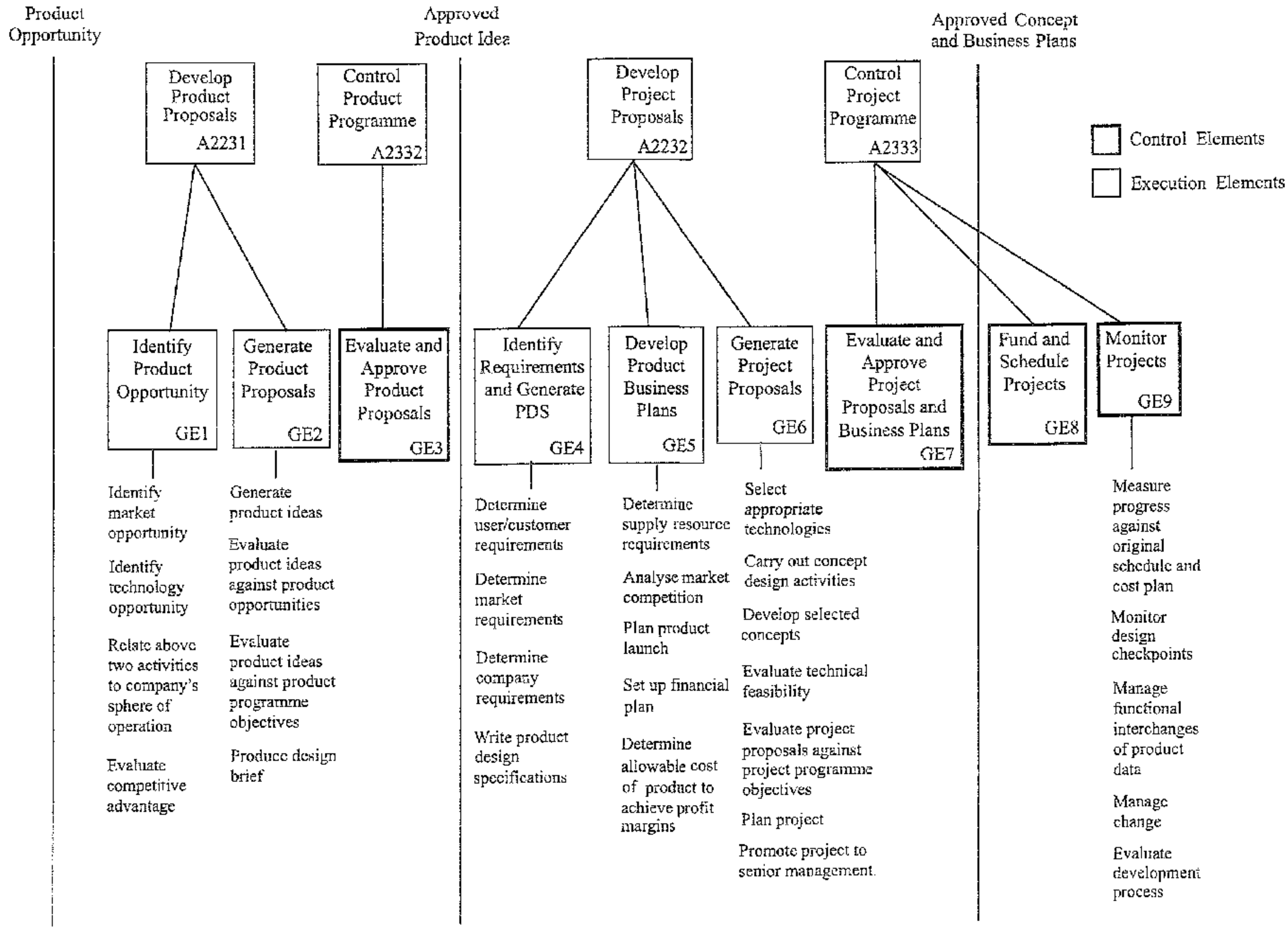


Figure 6.6. The Product Development Process

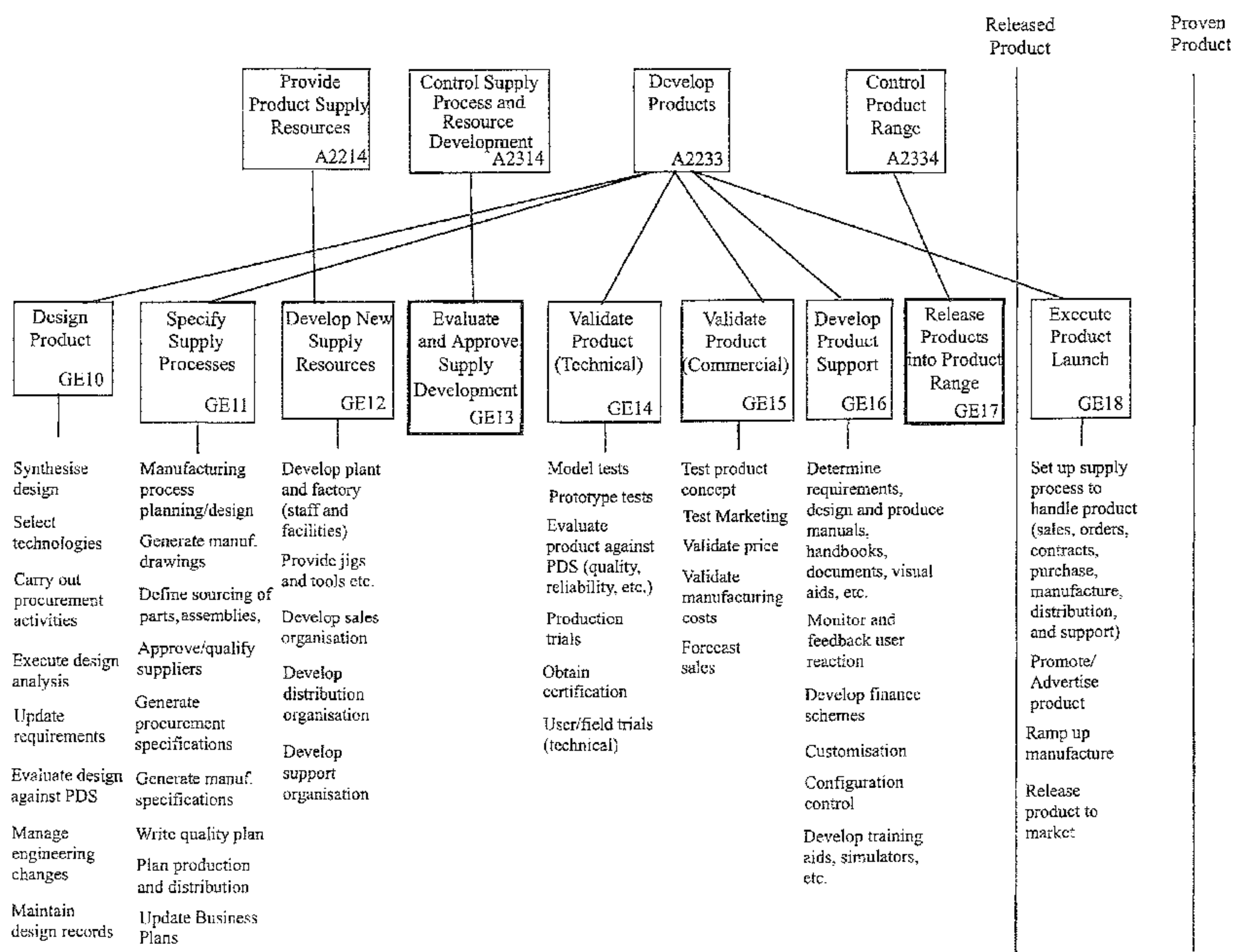


Figure 6.6. The Product Development Process (continued)

GE. These are not intended to be generic, but to act as indicators for identifying company specific activities that implement each generic element, and for comparison with existing models.

To a large extent the model will be self evident from the figures, but some pertinent points are discussed here to give an indication of the reasoning used to generate the model.

Node A21 - Set Objectives and Develop Operational Plan. This is the task of setting long term operational plans in response to the company strategy (A20).

Node A211 - Set Objectives and Plan Process and Resource Provision. This includes financial targets and budget plans (A2111) as well as plans for the type of PDP to be used and the resources to be dedicated to product development (A2113).

Node A212 - Set Objectives and Plan Technology Development. This task sets plans for technologies to become available in the future for incorporation into new products. The ideal is that the company defines technology content in this way rather than responding to technology needs as they arise during product development. The reality may often be that product development activities reveal an immediate need for new technology. The response to such needs is through Node A2322.

Node A213 - Set Objectives and Plan Product Development. This addresses plans to initiate new areas of product development and to bring certain new products to the market.

Node A2131 - Set Scope and Objectives for Product Programme. The objectives for new product ideas in terms of numbers, market and product areas are set. These provide a source of reference for evaluation and approval of product proposals (GE3).

Node A2132 - Set Objectives and Plan Project Programme. These objectives set the criteria for selecting product ideas that will be fully developed into products. The planned programme has a major impact on the budget required for product development.

Node A2133 - Set Objectives and Plan Product Range. The objectives relate to the market needs that the company wishes to satisfy over the planning period. The operational plan sets a schedule for introducing new and modified products, and for discontinuing products. The product programme and the project programme are, in effect, the longer term objectives for the product range.

Node A214 - Set Objectives and Plan Supply of Products. These are plans for the manufacturing operations of the company, and do not impact significantly on the product development tasks.

Node A22 - Execute Company Operations. These are the added value activities that progress the product from state to state (i.e. GEs 1, 2, 4-6, 10, 11, 14-16, 18) and the activities to develop any new resources (factory, plant, tools) required for the supply of the new product (GE12). Supply Products (A224) follows after the release of a new product at the end of the PDP (GE17), but the monitoring of products (A2247) provides important feedback to the PDP.

Node A23 - Control Outcomes of Company Operations. These are important functions that enable senior management to ensure that company objectives are satisfied in the outcomes of the executable functions without getting too closely involved in day to day management of the functions. Sensitive and effective use of the control functions enables empowerment of the operational teams. This process is more evident in Figure 6.6 where, for example, GE7 (evaluate and approve project proposals and business plans) is the controlling function for the outcomes of GE5 (develop product business plans) and GE6 (generate project proposals). Thus it is the proposals and business plans that are controlled (e.g. ensuring all issues have been addressed and results satisfy company objectives), rather than the actual activity of generating the proposal and business plans.

Node A231 - Control Process and Resource Development. This impacts on the PDP first by setting down the nature of the PDP and ensuring that resources (people, tools, information) are available (A2313), and secondly by controlling (A2314/GE13) any requirement to develop new resources for the supply of the new product (GE12).

Node A233 - Control Product Development. This function acts as a stage gate by approving product proposals (GE3) and project proposals (GE7). It initiates (GE8) and monitors (GE9) product development projects, and checks that all requirements are satisfied before releasing the product into the product range (GE17). It also provides feedback on product requirements through activities under A2332 (identify new product areas) and A2334 (evaluate product range and feedback requirements). These activities inform the strategy and planning functions and help to establish the criteria for evaluating product and project proposals, but are not part of the PDP for a particular product and are not therefore included as GEs.

Node A234 – Control Supply of Products. This includes production scheduling as well as ensuring that the broader supply objectives (A214) are realised.

6.6 Tests of the Model

Two methods were used to test the GEs and activities of the PDP given in Figure 6.6. A survey in industry and academia, and a comparison with published models.

6.6.1 Survey

In the first phase of the survey (see Chapter 4) representatives from companies producing earth moving equipment, chemical filtration systems, ship motion control systems, computer systems and components, aerospace systems and industrial machinery were asked to identify an appropriate strength of focus for their company on each GE, and to comment on and suggest changes to the GEs and their associated activities. The model was modified in response to these comments and then circulated to obtain further comment from academic colleagues in engineering and marketing who have experience of product development in industry. The survey questionnaire can be found in Appendix E.

The industry respondents were all able to identify with the GEs, to indicate their strength of focus, and to isolate any GEs that were not appropriate to their type of product development. Comments were almost entirely at the activity level and they show that an individual representation of the PDP is necessary at that level. It can be concluded that the GEs are set at an appropriate LoA. Comments were made on the scope of the model in so far as the development of mature or customised products does not utilise the front end of the process, and a number of suggestions were made regarding links to technology development. Other comments related to the ordering of activities, interactions, costs, timeliness and risk assessments. It is not intended that the model should include these aspects since they are covered by a separate assessment of the effectiveness of the execution of the activities. Some difficulties with the scope and intention of the model, and with semantics, suggest the need for a users manual, and/or a facilitator to help companies to prepare their own models.

Figure 6.6 shows the final model that incorporates the changes made as a result of the survey. These were improvements that could be made by reorganising and adding activities under different GEs, and by making changes to the descriptions of the GEs and the activities. The recommendations from the survey are summarised below under the relevant GE headings. Changes or additions to activities that have been adopted in the model are shown in normal type while other suggestions that have not been included in the model, but would be appropriate for company specific models are shown in Italics.

GE1. IDENTIFY PRODUCT OPPORTUNITY

- Identify market opportunity.
- *Test market need and pricing.*
- *Define optimum timing for maximum profitability.*
- Evaluate competitive advantage.

GE2. GENERATE PRODUCT PROPOSALS

- *Source new product ideas from government laboratories, universities, competitors, consumers, employees, etc.*
- *Screening of ideas.*
- *Identify likely delivery timing vs. optimal timing.*
- Produce design brief.
- *Analyse commercial risk, opportunity cost of capital, time value of money, product life and life cycle.*

GE5. DEVELOP PRODUCT BUSINESS PLANS

- Determine allowable product cost to achieve profit margins.
- *Compile marketing plan – strengths/weaknesses/opportunities/threats; determine marketing mix – product/price/place/promotion; determine time of launch; define marketing objectives – short/medium/long; plan promotion; plan response monitoring.*
- *Sales forecast; cash flow of development forecast; compile profit and loss forecast; specify financial needs – borrowing, equity, grants, timing; raise finance; types of income.*

GE6. GENERATE PROJECT PROPOSALS

- Develop selected concepts.

GE9. MONITOR PROJECTS

- Measure progress against original schedule and cost plan.
- Monitor design checkpoints.
- Manage functional interchange of product data.
- Manage change.
- Evaluate PDP.

GE11. SPECIFY SUPPLY PROCESSES

- Identify sources of materials and parts.
- Approve/qualify suppliers.
- Plan production and distribution.
- Update business plans.
- *Spare parts management; field repair mechanisms; warranty returns and control.*

GE13. EVALUATE AND APPROVE SUPPLY DEVELOPMENT

(This was added as a GE after the survey)

GE14. VALIDATE PRODUCT (TECHNICAL)

- Evaluate product against PDS.
- *Develop customer test (beta) sites.*

GE15. VALIDATE PRODUCT (COMMERCIAL)

- Validate product price.
- Forecast sales.

GE18. LAUNCH PRODUCT

- Set up supply process to handle product (sales, orders, contracts, purchase, manufacture, distribution, and support).
- Ramp up manufacture.
- Release product on market.

6.6.2 Comparison with Published Models

The objective of this test is to ensure that activities that are represented in the literature as important for successful NPD can be mapped onto the generic model. Three comprehensive models of the PDP have been selected as representative of the published work. BS7000 is also included since standards seek to set out an authoritative view. The comparison is presented in Table 6.2 where the activities are mapped against the generic elements. In some cases several tasks are grouped under one activity and these may be divided amongst two or more generic elements. In other cases several tasks are encompassed under a single description whereas they address two or more generic elements. The table shows that all activities can be mapped against one or more generic elements, and requirement 6 in Section 6.3 is satisfied.

6.7 Concluding Remarks

It has been shown that the principal execution and control activities of the PDP can be identified within a more general model of those company processes that impact on product development. This allows the PDP to be represented in terms of eighteen generic elements against which the activities of the PDP of any company can be mapped. Tests of the model show that a range of manufacturing companies could indeed map their PDP onto the generic elements, and also that the activities of the PDP that are presented in the published literature could be mapped onto the generic elements. This provides good confidence that the main objectives for the model have been achieved.

Cooper (1983b) Cooper and Kleinschmidt (1986)	GE No	Song and Montoya-Weiss (1998)	GE No	Wheelwright and Clark (1992)	GE No	BS 7000 (BSI 1997)	GE No
Technically derived idea generation	1	Strategic planning: preliminary assessment and integration of a project's resource requirements, market opportunities, and strategic directives	1, 2, 3, 4	Provide market based input	1, 4	Inception of new or improved product	1
				Propose and investigate product concepts	2, 6		
Market derived idea generation	1					Analysis of opportunities	1, 2
				Propose new technologies	6, 10		
Idea screening	2, 3					Analysis of business concepts and product identification	4, 5
				Develop product ideas	6, 10		
Preliminary market investigation	4, 5						
		Idea development and screening: Generation, elaboration, and evaluation of potential solutions to the identified strategic opportunities	5, 6, 7	Build models and conduct simulations	11, 14		
						Formulation of the project, objectives and strategies	2
Preliminary technical feasibility	6						
				Define target customer's parameters	4		
Market research	4, 5					Preliminary evaluation and approval of the project by the corporate body	3
				Develop estimates of sales and margins	5		
Product design	10, 11						
		Business and market opportunity analysis: Execution of the marketing tasks required for converting new product ideas into well-defined sets of attributes that fulfils consumers' needs and desires.	4, 5				
Preliminary sales forecasting	5			Conduct early interaction with customers	4		
						Planning, research and feasibility studies leading to the formulation of a project proposal	4, 5, 6
Prototype construction	14			Choose components and interact with suppliers	10, 11		
Prototype testing (in-house)	14						
				Build early system prototypes	14		
						Refine characteristics	6
Prototype trials with customer	14, 15			Define product architecture	10		
						Development of a functional specification	6
		Technical development: Designing, engineering, testing, and building the desired physical product entity	10, 11, 12	Conduct customer test of prototypes	14, 15		
Development of marketing plan	5, 11						
				Participate in prototyping evaluation	14	Development of project configuration and work programme	6
Detailed sales forecasting	5, 15						
				Detailed design of product	11		
Trial production	14					Evaluation and sanctioning of project by corporate body and commitment of resources	7, 8
		Product testing: Testing the product itself. As well as individual and integrated components of the marketing and advertising programmes	14, 15	Interact with manufacturing process	11, 12, 17		
Test marketing	15						
Final business analyses	16			Build full scale prototypes and test	14		
						Form multi-disciplinary team of specialists to realise the project	bs
Acquisition of product facilities	12			Plan marketing roll out	5		
				Establish distribution plan	5, 12		
Revision of launch plan	15	Product commercialisation.: Co-ordinating, implementing, and monitoring the new product launch	11, 15, 16, 17, 18				
				Refine details of product design	10, 11	Design concept development	10
Full production	18						
				Evaluate and test pilot unit	10, 14	'Rehearsing' the customer-product experience	4, 10
Market launch	18						
				Solve problems	bs		
						Outline design (embodiment design or General Arrangement)	10, 11
				Prepare for market roll out	16, 18		

(key: bs - beyond scope of the generic model)

Table 6.2. Mapping of Existing Models onto the Generic Elements

				Wheelwright and Clark (1992)	GE No.	BS 7000 (BSI 1997)	GE No.
				Train sales force and field service personnel	16 18	Detailed design	11
						Construction and testing of pre-production model	14
				Prepare order entry/process system	5 18		
				Evaluate field experience with product	bs		
						Finalisation of completed design ready for manufacture	11 12
				Fill distribution channels	18		
				Sell and promote	18		
						Design support for manufacture	11 12
				Interact with key customers	16 18		
				Propose and investigate manufacturing process concepts	11	Provisions for manufacture and delivery.	18
				Develop cost estimates	6 10 15		
						Product launch, introduction, promotion, and on-going customer support	5 16 18
				Define Manufacturing process architecture	11 12		
				Conduct manufacturing process simulation	14		
				Validate suppliers	11	Selling and use	18
				Do detailed design of manufacturing process	11	Monitoring 'in-use' performance for feedback and refining the design as necessary	16
				Design and develop tooling and equipment	12		
				Participate in building full scale product prototypes	14		
						On-going product testing.	14
				Test tooling and equipment	14		
						Project evaluation to identify areas of PDP improvement	9
				Build second phase product prototypes	14		
				Install equipment and bring up new procedures	12	Design support for decommissioning activities	16
				Build pilot units in commercial process	14		
						Formal termination of the project	bs
				Refine process on pilot experience	14		
				Train personnel and verify supply channel	12		
				Ramp up plant to volume target	18		
				Meet target for quality, yield and cost	bs		

Table 6.2. Mapping of Existing Models onto the Generic Elements (continued)

7

Activity Effectiveness Assessment

Summary

A procedure to assess the effectiveness of all constituent activities of the PDP is developed and tested. Activities are described by a number of characteristics that are assessed in response to questions that reflect current NPD best practice. Tests show that the procedure enables effective expression of industrial practitioner knowledge and permits estimates of activity effectiveness to be made.

The procedure is in early stages of evolution and future development, testing and refinements are proposed. Further studies should investigate how company practitioners think about activities, how they process information to arrive at an estimate of activity effectiveness, and the manner in which knowledge is elicited. This will provide a basis to improve the structure of the method and form of the questions.

7.1 Introduction

A key element of the PDP evaluation method developed in this thesis is to be able to quantify the effectiveness of each PDP activity in addressing the issues identified by the DoP. The approach adopted is to assign a number of characteristics (such as setting of objectives, resources made available, input data) to the activities. An expert practitioner then judges the quality of these characteristics in the context of addressing the issue raised by each DoP (or more generally in the context of one dimension, or of the whole product) and on the basis of these judgements makes an estimate of the effectiveness of the activity.

The design and test of a procedure to obtain these estimates of activity effectiveness is reported in this chapter. The requirements that the procedure must meet are identified in Section 7.2. The current literature is reviewed in relation to these requirements in Section 7.3. The procedure is then presented in Section 7.4 and results of industry trials of the procedure are given in Section 7.5, together with a discussion about findings pertaining to the procedure that were obtained during trials of the overall PDP evaluation method, which incorporated lessons learned from the first trials. Finally, concluding remarks are made in Section 7.6.

7.2 Requirements for the Procedure

The procedure to assess the effectiveness of the activities that constitute the PDP must satisfy the following requirements to be consistent with the ethos of the PDP evaluation method, of which the procedure is an integral part.

1. It must have the capability of eliciting expert judgements from industry practitioners.
2. It must permit the quantification of judgements about the effectiveness with which a current or proposed PDP activity is executed.
3. It must permit effectiveness to be assessed in the context of current PDP and NPD management best practice.
4. It must be non-prescriptive i.e. it must permit the effectiveness of the activities from any form of PDP to be assessed in the context of the specific objectives and operations of the company.

7.3 Literature Review

Findings from studies into NPD management and product development, as encapsulated, for example, in TQM (Zairi 1994), Deming's management method (Walton 1991) and total quality development (Clausing 1994), show that it is principally the performance of the development process, and not the productivity of the people, that must be measured and evaluated to improve the likelihood of success. Deming's 85-15 rule holds that 85% of what goes wrong in product development can be attributed to the process, and only 15% to the people. Thus any assessment of activity effectiveness must focus on the detailed aspects of the process rather than the performance of individuals, recognising, of course, that project team selection is part of the process.

Zairi (1994) discusses traditional Performance to Standard (PS) methods, such as work study, critical path analysis, operational research, cost/benefit analysis, job evaluation, statistical manpower planning and management by objectives. He observes that these methods place the emphasis on evaluating people's performance against some pre-set standard, whereas more recent TQM methods focus on the process and the value of people's contribution to the process. Therefore PS methods do not reflect current best practice for this purpose.

TQM based Self-Assessment (SA) methods and tools, such as European Foundation for Quality Management (1997), Malcolm Baldridge National Quality Award (Zairi 1994), European Quality Award (Zairi 1994), RACE (Carter and Baker 1992), and Product Development-Self Assessment (DTI 1995), are designed to assess performance at company and project level rather than the effectiveness of detailed activities. Furthermore, checklist procedures such as those included in typical SA methods and tools are prescriptive and therefore do not satisfy requirement 4.

Slevin and Pinto (1986) report on a procedure called the 'Project Implementation Profile' that can be used to assess project quality in terms of ten factors:

1. Project mission
2. Top management support
3. Project schedule/plan
4. Client consultation
5. Personnel
6. Technical tasks
7. Client acceptance
8. Monitoring and feedback
9. Communication
10. Trouble-shooting

This again is a project level tool and not intended to assess detailed activity effectiveness, but the ten factors are important best practice issues that must be reflected in the assessment procedure.

Szakonyi (1994a, 1994b) determines R&D effectiveness by focusing on what managers intuitively know is important. In this respect Szakonyi's method is similar to the one presented in this thesis. He identifies ten important issues from the literature: selecting R&D projects; planning and managing projects; generating new product ideas; maintaining the quality of the R&D process and methods; motivating technical people; establishing cross-disciplinary teams; co-ordinating R&D and marketing; transferring technology to manufacturing; fostering collaboration between R&D and finance; linking R&D to business planning. To assess effectiveness, the current level of focus on R&D is selected from a six-level scale:

1. Issue is not recognised.
2. Initial efforts are made toward addressing the issue.
3. Right skills are in place.
4. Appropriate methods are used.
5. Responsibilities are clarified.
6. Continuous improvement is underway.

Szakonyi notes the benefits of this method as firstly, that it requires limited qualitative judgement i.e. it only asks whether or not something is in place. Secondly, the logic of the method gives it credibility, and thirdly, it has a track record, having been used in approximately 300 companies. Limitations of the method are that it assumes that each of the ten activities will have an equal impact on R&D effectiveness, so no provision is made for individual companies to express their uniqueness by weighting the relative impact of each activity. The method does not satisfy requirement No. 4, and Szakonyi's list combines both high level activities and the characteristics of activities, whereas the required procedure must separate these. Szakonyi's method cannot therefore be used directly, but the method does have useful features: a descriptive scale that can be used to rate effectiveness of activities, and a generic list of activity attributes.

Ullman (1997) has developed an assessment tool that divides the PDP into five major areas and 18 sub-areas, and uses over 170 yes/no type questions to help engineers and managers to qualitatively determine the company practice at corporate, programme, project and task levels. As with Szakonyi's method, Ullman's areas and sub-areas contain a mix of activities and characteristics. Ullman's tool is both qualitative and prescriptive so that requirements 2 and 4 are not satisfied, but he does identify the need to develop metrics that focus on the characteristics of activities.

The existing assessment methods and tools reviewed here either did not satisfy all of the requirements or they had not been applied at the required level of abstraction of activities. There was much to be drawn on from the literature, but a new method to estimate the effectiveness of activities was needed, which would meet the stated requirements and incorporate best practice.

7.4 Procedure Design

The approach adopted was to assess the effectiveness of an activity by examining its characteristics. The distinction was made that an activity directly impinges on the evolution of the product from state to state (see Chapter 6), while its characteristics indicate the manner and circumstances under which the activity is performed. The GE 'design product' provides a good example. Its constituent activities would be identified for each particular company, but a typical set is:

- Synthesise the design - evolve the description of the product in terms of its geometry, materials and parts.
- Select technologies from those available to be utilised in the product.
- Carry out procurement activities - resolve technical and quality requirements for materials, components and bought-in parts through consultation with suppliers and the technical, purchasing and quality groups in the company.
- Execute design analysis - analyse strength, performance etc. using analytical and computational tools.
- Evaluate design - results of the synthesis and analysis are continually reviewed and evaluated against the requirement of the Product Design Specification, and against good engineering practice, to ensure that the design is developing on a sound basis.
- Manage engineering changes.
- Maintain design records.

The characteristics illustrate the nature of these activities in terms of people employed, resources available, information available, etc. Since there are a variety of characteristics that have different effects on the activity, a framework is required to organise them and to focus attention on a particular aspect of the characteristics at a particular time. In keeping with the PDP evaluation method, the activity assessment procedure must be universally applicable to all activities in the generic PDP model (developed in Chapter 6). It was decided to adopt Softech's (1981) IDEF0 structure (Figure 7.1) to achieved a generic activity profile or template in which a function represents the process activities involved in transforming the inputs to an output, utilising the means and influenced by the controls.

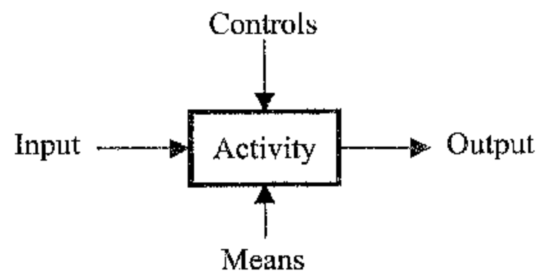


Figure 7.1. IDEF0 Task Structure

The inputs, means and controls provide the framework to classify the characteristics of an activity, which are then used as the units of assessment. Characteristics are assigned as follows:

- **Input** characteristics are data that describe the state of the product e.g. ideas, proposals, specifications, concept sketches, detailed drawings, models, prototypes, launched products, which are added to or transformed by the activity. With this definition, the materials to build a prototype are defined as a 'means' to transform a design from a drawing to a solid artefact, and are not considered as inputs to the activity, as they would be in a manufacturing process.
- **Control** characteristics describe the conditions, circumstances, influences, objectives, instructions, information, monitoring and interaction with related activities that govern the activity and show why, when, to what standards, etc. the activity is to be, and is being, executed. Every activity will have at least one control.
- **Means** are the people, facilities, equipment and materials that are necessary to carry out the activity. The characteristics relate to the identification, availability and quality of these resources.

'Output' is not used to characterise the activity. The output is the consequence of the activity, and the view is taken that high quality output will result when the other characteristics, on which output is dependent, are such as to promote effective execution of the activity. There are many measures of the quality of the output of PDP processes, but these can only provide retrospective information. However, an effective activity will include amongst its 'control' characteristics the notion of monitoring and evaluating the quality of its output. The output of an activity can also be accounted for by assessing it in terms of the quality of input it provides to other activities. The procedure presented in this thesis uses both approaches.

With this method a number of Szakonyi's (1994a, 1994b) activities, for example, would be defined as characteristics. They are: motivating technical people; establishing cross-disciplinary teams; co-ordinating R&D and marketing; fostering collaboration between R&D and finance.

The PDP is evaluated in terms of three dimensions. Namely, solution quality (the quality of achieving the primary activity objective i.e. advancing the state of the product), resource consumption (effective use of resources to achieve the primary activity objective), and timeliness (effective organisation of activities to achieve the schedule objective). Separate DoP are identified for each of these dimensions, so that selecting a DoP effectively selects the dimension against which the activity is assessed (discussed in Chapter 5).

It is fundamental to the developed method that the assessment is done in the context of current NPD best practice, some examples of which are given in Table 7.1. The questions that were derived from these, from discussion with industrial collaborators and academics, and from the experience of the researchers, are listed in Appendix F. The set of questions for the three dimensions was designed to help the user consider the nature of each characteristic of the activity under assessment. The numbers given after some of the questions refer to the index numbers of the best practice issues listed in Table 7.1.

When applying the procedure, the user makes judgements about each characteristic of the activity in response to these questions. An informed estimate of the effectiveness of the activity in addressing a particular DoP is then made by quantifying the quality of each characteristic of the activity and its importance in contributing to the successful execution of the activity.

Index	Best Practice Issues	References
1	Information (use, quality and availability)	Hart (1995), Slevin and Pinto (1986), Szakonyi (1994a, 1994b)
2	Information and data handling procedures (existence and quality thereof)	Hart (1995), Smith and Reinertsen (1995)
3	Continual assessment (measurement and bench marking), learning (feedback and reviews) and improvement (action) of activity execution, and of processes	Griffin (1997), Zairi (1994), Walton (1991), Clausing (1994), Slevin and Pinto (1986), Szakonyi (1994a, 1994b)
4	Communication (internal and external to project)	Hart (1995), Slevin and Pinto (1986), Szakonyi (1994a, 1994b), Cooper (1999), Nihtila (1999)
5	Resource (quality, availability and effective utilisation of people, facilities, tools, time and financial resources)	Slevin and Pinto (1986), Smith and Reinertsen (1995), Cooper (1999)
6	Staff (reward, motivation, training and skills)	Zairi (1994), Walton (1991), Slevin and Pinto (1986), Szakonyi (1994a, 1994b), Smith and Reinertsen (1995), Cooper (1999)
7	Organisation and structure (of company and of project team i.e. multifunctional teams, product champion, team leader, supplier and customer team members, co-location, senior management support)	Hart (1995), Slevin and Pinto (1986), Szakonyi (1994a, 1994b), Smith and Reinertsen (1995), Cooper (1999)
8	Speed, rapid product development and related time to market issues - timeliness of activities (concurrency), and duration of execution.	Hart (1995), Smith and Reinertsen (1995), Backhouse and Brookes (1996), Cooper (1999), Smith (1999)

Table 7.1. NPD Best Practice Issues

An example of the procedure is presented in Table 7.2. Activity effectiveness in addressing a particular DoP (column 3) is calculated by taking the sum of the products of the estimated quality of each characteristic (column 1) and its contribution (correlation) to the effective completion of the activity (column 2). The detail is only shown for the first activity. GE effectiveness (column 5) is calculated by taking the sum of the products of each activity's effectiveness (column 3) and its contribution (correlation) to the GE (column 4). The effectiveness of the PDP in addressing each DoP (column 7) is given by the sum of the products of each GE's effectiveness (column 5) and its contribution (correlation) to resolving the issue represented by the DoP (column 6).

A similar table is completed for each DoP and the final potential for profitable outcomes from the PDP is then given by the sum of the products of the effectiveness of the PDP in addressing each DoP and the correlation of the DoP to profit.

Quality of characteristic	Correlation to the activity	Activity effective-ness	Activity correlation to GE	GE effective-ness	GE correlation to DoP	PDP effectiveness for given DoP
GE1						
Activity 1:						
data = 0.8	0.075					
obj = 0.7	0.145					
info = 0.6	0.053					
exec = 0.8	0.176					
resr = 0.5	0.141					
staff = 0.8	0.251					
fac = 0.7	0.072					
org = 0.5	0.087	$\Sigma = 0.70$	0.40			
Activity 2		$\Sigma = 0.80$	0.35			
Activity 3		$\Sigma = 0.65$	0.25	$\Sigma = 0.723$	0.45	
GE2						
Activity 1		$\Sigma = 0.58$	0.40			
Activity 2		$\Sigma = 0.85$	0.60	$\Sigma = 0.742$	0.25	
GE3						
Activity 1		$\Sigma = 0.90$	0.35			
Activity 2		$\Sigma = 0.83$	0.65	$\Sigma = 0.855$	0.30	$\Sigma = 0.767$

data = product data obj = objectives info = information exec = execution
resr = resources fac = facilities and tools org = organisation and structure

Table 7.2. Example Calculation of Effectiveness to Realise DoP

Three different approaches to implementing the activity assessment procedure were devised and evaluated by trials in industry. These all took the form of questionnaire based interviews with varying degrees of refinement (the questionnaires are given in Appendix G). Only the two more refined approaches utilise the questions presented in Appendix F.

Questionnaire 1 was devised to test whether a simple form of assessment would suffice to give realistic results without using the questions in Appendix F. It required respondents to make broadly based judgements of the degree of focus their PDP gave to the activities, using the following scale.

NA. The activity is not applicable to our product development.
0. We do not execute the activity at all.
1. Some efforts are made towards executing the activity.
2. We have the process in place to execute the activity, but it is not always used.
3. The appropriate methods are used to execute the activity.
4. Execution performance is monitored and continuous improvement is underway.

An effectiveness value for each GE can be determined using activity scores derived from this scale and the correlation factors described earlier. Activities judged as 'not applicable' are omitted from the calculation.

Questionnaire 2 required that respondents first make a 'gut feel' judgement of their company's effectiveness in addressing each characteristic of an activity. This was to provide a basis for comparison with the results of the more detailed assessment, and to see whether exposure to a wide number of issues through the questions would significantly alter their perception.

Respondents were then asked to read all the questions pertinent to each characteristic, and to make an estimate of the effectiveness of the characteristic in the light of the issues raised by the questions. Respondents were free to use either of two scales provided: a verbal scale ranging from low (characteristic is very poorly reflected during execution of the activity), through medium to high (characteristic is strongly reflected during execution of the activity); or a numerical scale from 0 to 10 providing a finer judgement between the same extremes.

Questionnaire 3 also used the questions pertinent to each characteristic, but additionally used a response scale that permitted judgements to be made about frequency (i.e. never, sometimes or always) as well as the manner of handling activities (i.e. formal or informal). This questionnaire also required respondents to make judgements about what they would consider to be a desirable process as well as their actual process. Effectiveness values for activities based on these judgements could then be determined as a ratio of *actual* effectiveness to *desired* effectiveness.

7.5 Industry Trials

Two sets of trials were undertaken. First, the activity effectiveness assessment procedure was tested on its own in relation to the solution quality dimension only, and later on, using all three dimensions, as part of the complete PDP evaluation method, including changes made as a result of the first trial.

7.5.1 Trials of Activity Effectiveness Assessment Procedure

This trial was designed to explore a number of specific issues relating to assessment of activities.

1. How do respondents think about activities, and how does this affect the assessment procedure? Are respondents able to relate to the concept of activity characteristics organised under the structure of inputs, controls, and means?
2. Which of the three questionnaire methods do respondents prefer?
3. Which of the three questionnaire methods enables respondents to best express their knowledge?
4. Can the procedure designed to assess the solution quality dimension also be used to assess the resource and timeliness dimensions?
5. How much time is required to complete the questionnaires?

7.5.1.1 Method

Trials were conducted at three industrial companies using the three different questionnaires to assess the solution quality dimension of their activities. Resource and timeliness dimensions had not been developed at this stage. Respondents were made aware that the primary purpose was to assess the procedure, and as such were encouraged to question, challenge and/or propose changes to any aspect of the procedure. A facilitator was available to explain and clarify. The procedure was evaluated only in relation to the GE 'Design Product', the activities of which have been listed earlier. Responses were recorded (on tape and in writing) and the time taken for the respondents to answer each of the three questionnaires was noted. Respondents were asked to say which questionnaire best enabled them to represent their knowledge.

7.5.1.2 Results

Findings from these trials indicate that the more crude the judgement method the more optimistic the assessment tended to be. 'Gut feel' judgements were generally more optimistic than estimates of effectiveness derived in response to detailed questioning. Respondents found that when they read the questions they became more aware of the issues involved (i.e. best NPD practice), and were able to make progressively more informed judgements.

It was clear that respondents tended to think about activities in a global sense, focusing more on the output than the inputs, controls and means. All respondents found the presentation of best practice issues under these categories new, but insightful, and it helped them to think more specifically about the effectiveness of their activities. It is an important finding that all respondents felt that the procedure permitted them to examine their knowledge of the activities in a meaningful way.

There was no preference for the numerical or verbal scales, but the respondents did prefer to modify a scale so that it suited their own approach. Generally they preferred the procedure used in questionnaire 2, which allowed them to set the scene and review the issues in their own mind, and then to respond in a manner and against a scale that they had chosen.

The third questionnaire produced the most extensive results, but the average response time was approximately 15 minutes for each activity, against about 1 minute and 5 minutes for questionnaires 1 and 2 respectively. Considering that the GE and constituent activities in this trial were assessed for the overall product, and not against the individual DoP, it can be seen that the time required to assess, say 17 GEs against 5 to 10 DoP is considerable. However, evaluating the PDP is no small undertaking, and it may well be that the extra effort is justified by more accurate results. The option to use questionnaire 3 will be retained in future versions of the method.

7.5.1.3 Modifications to the Procedure

As a result of user preference and the shorter time required, questionnaire 2 was used as the basis for the procedure included in the trials of the overall PDP evaluation method. The procedure was modified to enable individual choice of the response scale, and it was decided that the procedure could be extended to include the questions relating to resource and time dimensions, as given in Appendix F.

7.5.2 Trials of the Overall PDP Evaluation Method

These trials were conducted with three industrial collaborators, and enabled the procedure to assess the effectiveness of activities to be tested as an integral part of the overall PDP evaluation method. Only these findings are reported here. Specific issues to be addressed in these trials were:

1. Does the procedure enable respondents to express their knowledge about the effectiveness with which the issues covered by the DoP are addressed by the activities of the PDP?
2. Does the procedure handle cost and time DoP as effectively as solution quality?
3. Does the procedure provide better judgements than are reached informally?
4. Does increased familiarity with the questions result in a faster response?

7.5.2.1 Method

The user of the procedure was in each case an expert company practitioner, and a facilitator was available to clarify any points that arose. The users implemented the procedure by completing a full set of forms provided for recording all evaluation decisions. The facilitator observed how the users exercised their judgements, and noted any points of discussion that arose.

Once again, respondents were asked to make an initial 'gut feel' judgement of the effectiveness of each activity for comparison with the value calculated using the full procedure. The procedure was continually evolved, with each successive trial including corrections, suggestions and improvements from the previous trial. *Cost effectiveness* was re-named *resource consumption effectiveness* before the second trial so as to encapsulate the notion of all resources (people, time, tools, equipment, etc.), and not just money.

7.5.2.2 Discussion

Respondents noted that the procedure (as an integral part of the PDP evaluation method) had enabled them to estimate activity effectiveness and identify important activities with a level of awareness that was not possible when taking a more informal approach (i.e. using gut-feel judgements). In all three cases the respondents elected to assess activity effectiveness with regard to the whole product rather than to each individual DoP. This was mainly due to limited time available for the exercise.

Of interest was the method used by one respondent to estimate the overall effectiveness of each activity. He was originally of the opinion that no activity could be scored higher than its lowest scored characteristic, but later concluded that there were some characteristics that could compensate for shortcomings in others. E.g. good staff could compensate for poor objective setting. Thus his overall estimate for the effectiveness of an activity was not the lowest rating but some intuitive average. An important objective of the procedure was that users should be able to form their own assessment agenda in the context of best practice. The respondents approach to estimating activity effectiveness demonstrates that the procedure meets the objective very well.

One respondent experienced some difficulty in assessing resource consumption. This was partly due to the volume of information that had to be processed, and also due to some lack of experience in making such judgements. Apart from this, respondents had little difficulty relating to the three dimensions of resource, time and solution quality, and in using the questions to set the context for the assessment. It was observed, as expected, that familiarity with the questions resulted in faster responses.

7.6 Concluding Remarks

A procedure to assess activity effectiveness, which satisfies the stated requirements, has been developed and tested. The opinion of expert practitioners is that it allows them to adequately express their knowledge of their company's processes.

Respondents at two companies commented that the procedure had required a substantial mental effort. This is not unexpected as the concept of assessing activity effectiveness to realise identified DoP is new and initially unfamiliar (one respondent had to be prevented from continually assessing the quality of the product as opposed to the quality of the activity). The findings indicate that the procedure forced respondents to think about what they are trying to achieve with their PDP, which was very much an objective.

A significant amount of time was required to exercise the procedure, and this limited the scope of the trials so they could not examine the sensitivity of the process in responding to specific DoP. Further trials will be required to explore this. An evaluation of the PDP is a significant undertaking, to which consultants, for example, would devote several days, if not weeks. It will be necessary to generate sufficient confidence in the method for companies to be prepared to devote the necessary time.

Due to the intensity of working with the questionnaires during evaluation of the procedure, little dialogue was engaged in to determine whether respondents understood all the best practice issues presented in the questions and how they developed their trains of thought. The trials did not therefore clearly reveal which questions had the greatest influence on the response, and whether these questions were the most important to the company's context. Although these were not primary objectives, future trials of the activity assessment procedure should be designed to ensure a greater level of dialogue on these issues between the facilitator and industry expert. This will help identify those best practice issues pertinent to the company context, and to ensure that they are addressed. However, it must be recognised that there will be an accompanying time implication.

The procedure presented is in an early stage of evolution, and it is recognised that the form of the questions, nature of responses, etc. will become more effective as experience accumulates. The questions require refinement, and the way in which knowledge is elicited needs further investigation. The manner in which company practitioners think about activities, and how they process the information to assess effectiveness, also requires further investigation. Future findings should enable improvement of the procedure to reduce the mental effort required and the amount of time to obtain more refined judgements.

8

Correlation Factors

Summary

The Analytic Hierarchy Process (AHP) is presented as a suitable procedure to quantify expert judgement and determine the correlation factors which express the relative importance of relationships between components in the PDP evaluation method.

When there are interactions between DoP, the AHP can not be used directly to determine these correlation factors. A procedure to overcome this has been developed whereby the correlation factors are determined first by assuming independence between alternatives, and then modifying the factors to take account of any interactions. Test results are promising, and further refinements to improve the procedure are suggested.

8.1 Introduction

Figure 5.2 shows the connections between the components of the PDP evaluation method developed in this thesis. The effect that each DoP has on determining the potential for profitable outcomes is represented by a correlation factor that must be estimated when using the evaluation method. The potential for profit from a particular PDP is determined by the effectiveness with which each issue identified as a DoP is resolved. This is a function of the quantified effectiveness of each pertinent GE and its relative contribution to realising that DoP. Thus a further set of correlation factors must be established between the GEs and the DoP which indicate the degree to which the outcome of each DoP is influenced by each set of activities represented by a generic element. Lower level components do not contribute equally to their parent node. The quality of each activity characteristic does not contribute equally to the overall effectiveness of the parent activity. Similarly, the effectiveness of each constituent activity does not contribute equally to the overall effectiveness of the parent GE, and each GE does not contribute equally to the effectiveness with which each DoP is realised. Thus correlation factors must be estimated to explain the relative contribution of each of these components to its parent node.

The topic of this chapter is the procedure adopted to determine these correlation factors. The procedure is described in the context of determining DoP to profit correlation factors because these are the most complex. The procedure has been applied in a similar manner to determine correlation factors between all other components of the method, although interactions are not involved. The application of the procedure has been tested during trials of the evaluation method and found to be successful (see Chapter 9).

The rest of the chapter is structured as follows. Requirements to be met by the procedure are presented in Section 8.2. The AHP is described in Section 8.3 and reviewed against the requirements in Section 8.4. DoP interactions are described in Section 8.5 with their impact on correlation factors and approaches to addressing the issue described in Section 8.6. The issue of DoP threshold values and how they are addressed in the procedure is discussed in Section 8.7. Industry trials of the procedure and findings from these are described in Section 8.8. Concluding remarks are made in Section 8.9.

8.2 Requirements for the Procedure

The procedure must satisfy the following requirements.

1. It must have the capability of eliciting expert judgements from the users of the PDP evaluation method.
2. It must be able to quantify these judgements to determine the relative importance or contribution of components to a common goal.
3. It must accommodate the network system of linked components shown in Figure 5.2.
4. It must accommodate at least 18 alternatives (or components), this being the number of GEs.
5. It must accommodate the fuzziness inherent in expert judgements.
6. It must account for any interactions amongst the DoP.

The basic requirement is to determine the relative contribution of each component. The AHP is an available procedure that readily meets requirements 1 to 4. However, requirement 5 and, in particular, requirement 6 need further consideration.

8.3 The Analytic Hierarchical Process (AHP)

The AHP was developed by Saaty (1977, 1990d) who demonstrated the feasibility of expressing, either verbally or numerically, the importance of one element (or alternative) relative to another with respect to a given criterion. Expert judgement concerning alternatives is elicited using a pair-wise comparison method based on the response to a question such as: "In terms of realising the goal, which of the two alternatives is more important, A or B? Quantify the relative importance of A over B (or vice versa)." The expert first has to judge which alternative is the more important or makes the greater contribution, and then quantify the degree of importance/contribution. Each pair of alternatives is considered in turn using the numerical scale or linguistic responses given by Saaty (Table 8.1). The numerical scale is applied directly as a ratio of importance. That is, 9.0 indicates that one element is nine times as important as the other. Experience has confirmed that a scale of nine units is reasonable and reflects the degree to which humans can quantify relationships among elements. The judgements are recorded in a matrix, which can then be solved for the principal eigenvector. This vector gives the normalised weights for all of the alternatives, which indicate their relative importance.

Saaty (1990d) establishes four axioms that must be true of any hierarchical system if it is to be successfully analysed using the AHP.

1. Reciprocal Comparison. The decision-maker must be able to make comparisons and state the strength of preferences.
2. Homogeneity. The preferences must be representable by means of a bounded scale (e.g. Table 8.1).
3. Independence. Criteria are assumed independent of the properties of the alternatives. i.e. a comparison between one pair of elements is not affected by the properties of any other element.
4. Expectations. For the purpose of making a decision, the system structure is assumed to be complete i.e. all possible alternatives are represented.

The common semantics of the AHP refer to a number of alternatives being evaluated by pair-wise comparisons in order to grade the alternatives. However, in this application, it is not strictly alternatives that are considered but rather components, all of which contribute to the performance of the parent. It is the relative level of contribution that must be determined.

NUMERICAL SCALE	VERBAL SCALE	EXPLANATION
1.0	Equal importance of both elements.	Two elements contribute equally.
3.0	Moderate importance of one element over another.	Experience and judgement favour one element over another.
5.0	Strong importance of one element over another.	An element is strongly favoured.
7.0	Very strong importance of one element over another.	An element is very strongly dominant.
9.0	Extreme importance of one element over another.	An element is favoured by at least an order of magnitude of difference.
2.0, 4.0, 6.0, 8.0	Intermediate value between two adjacent judgements.	Used for compromise between two judgements.
Increments of 0.1	Intermediate values in increments of 0.1	Use for even finer graduations of judgements.

Table 8.1. The Pair-Wise Comparison Scale (Saaty 1990d).

8.4 Review of the AHP against the Requirements

Use of the AHP to obtain component weightings is well established. Two of the AHP validation experiments described by Dyer and Forman (1991) provide examples. In the first, respondents were asked to make judgements about the relative sizes of five geometrical shapes using pair-wise comparison with the verbal criteria given in Table 8.1, but with importance replaced by ratio of size. Analysis of the results using the numerical scale in Table 8.1 shows that verbal judgements can provide quite accurate estimates of the actual numerical ratios. The second experiment was based on judgements of perceived light intensity. The power of the AHP was demonstrated by successfully predicting the inverse square law from verbal judgements of intensity levels. Other relevant work which supports the choice of the AHP for this application includes Forman (1992) who describes the use of the AHP to determine factors of certainty for expert system rules; Dobias (1990) who produces weightings of the relative importance of design criteria for new product development; and Zahedi (1986) who describes the use of the AHP to measure the degree of membership in fuzzy sets.

The review shows that the AHP satisfies items 1 to 5 of the requirements. However requirement 6 is not satisfied because it violates Saaty's third axiom. Interactions exist between DoP, the effect of which must be quantified. It was therefore necessary to find a method of handling interactions if the AHP was to be used.

8.5 DoP Interactions

A scenario can exist where the impact on profit of one DoP may be dependent on first effectively realising one or more related DoP. In the example from Chapter 3, the benefit of selling at an appropriate price is only achieved if the toaster has the specific features and aesthetic appeal expected by customers prepared to pay that price. If these features and aesthetic appeal are not realised to the correct level by the PDP, then the impact of selling price on profit is negated. Thus it can be seen that the impact of one DoP may not be independent of others.

In order to retain the numerical basis of the evaluation method it is necessary to quantify these interactions. This is achieved by taking each DoP in turn and estimating the strength of the interaction effect (SI) on the 'subject' DoP from each of the other 'interacting' DoP. If there is no interaction then SI = 0, and if there is complete interaction, such that no benefit would be gained from the subject DoP if the interacting DoP was not realised effectively, then SI = 1.0. The strength of interaction from each DoP is assumed to be independent and can be estimated either directly by the user of the evaluation method, or the AHP can be applied again. Pair-wise comparisons are executed in response to the question: "Which of the following two DoP [from the interacting set] has the greater negative effect, if not realised effectively, on the subject DoP? Use Saaty's scale to quantify the relative effect." The weights obtained from the AHP provide the values SI_{ij}, which give the strength of interaction of the ith. interacting DoP on the jth. subject DoP. There is an implicit assumption in using the AHP in this way that the strengths of

interaction can be normalised, and that if none of the interacting DoP are realised effectively then the benefit of the subject DoP is entirely negated. These are not good assumptions. A number of interacting DoP might have quite a severe impact if acting on their own and the normalised strength of interaction may underestimate this. The normalised SI values are therefore scaled by the user setting an absolute value to the largest normalised SI in the set, and proportioning all other SI values by the same ratio as the largest. A consequence of this is that the cumulative impact will not be well represented by the sum of the individual strengths of interaction, which may easily exceed 1.0. A procedure is required that will estimate the cumulative impact of several interacting DoP. This must apply the full impact of a single interacting DoP, but progressively reduce the impact of additional interacting DoP so that the total cumulative strength of interaction does not exceed 1.0, or some lesser value ($SImax_j$) that the user may assign if it is felt that some benefit will still derive from the subject DoP, even if all interacting DoP act to negate the benefit. It is logical and necessary that all SI_{ij} should be less than or equal to $SImax_j$. The procedure that has been developed involves the effectiveness measure (η) of the DoP, and the impact of effectiveness must therefore be considered before the procedure is presented.

8.6 Impact of Interactions on Correlation Factors – Role of Effectiveness

A particular feature of DoP interactions is that they only have an impact when DoP are realised with an effectiveness of less than 100%. Saaty's third axiom is therefore satisfied if all the DoP in an interacting set are assumed to be realised with an effectiveness of 100%. The use of the AHP to relate DoP to profit under this constraint was tested successfully in industry. Some initial tests were also conducted to see whether the AHP could be applied in the presence of interactions. These are described in the next section. However, it became apparent that this approach required an unreasonable degree of mental agility, and it was therefore necessary to develop and test a specific procedure, described in Section 8.6.2.

8.6.1 Modification of the Pair-Wise Comparison Question

The objective of this modification was to quantify the effect of interactions amongst a set of DoP. When the interacting DoP are not realised with 100% effectiveness they are described as 'incomplete', and it is only then that the interaction effect comes into play. It was thought that DoP interaction effects could be quantified with the aid of a matrix of correlation factors generated by repeating the full set of pair-wise comparisons in turn assuming that just one interacting DoP was incomplete at a time. Thus a set of normalised weights that reflect each DoP's impact on profit could be derived given that one of the DoP was incomplete. The number of sets of normalised weights for each DoP would be equal to the number of incomplete interacting DoP. These would then be combined to yield a single set of correlation factors reflecting the expert's judgement about the impact of each DoP on profit, in the context of all incomplete interacting DoP.

Clearly, the first step was to ensure that an industrial expert could relate to a modified knowledge elicitation procedure i.e. adding an extra proviso to the standard AHP question. The question was re-phrased to read: "Relative to the goal of maximising the profit potential of the product, which of the following DoP is more important, A or B given that C is incomplete? Use Saaty's scale to quantify the relative importance."

The expert experienced difficulty in answering this form of question. Although he was able to complete the pair-wise comparison matrix, he found it virtually impossible to consider the 'ranking' question with the proviso of incomplete DoP, and when the incomplete DoP had a strong correlation to profit, he found it meaningless to try to compare two less strongly correlated features.

It was concluded that it was not practical to include interaction effects within pair-wise comparison judgements, and that an alternative approach was required.

8.6.2 Procedure to Calculate Interaction Effects (Decoupling the DoP Interactions)

It has already been established a) that interacting DoP can be de-coupled by assuming that the PDP is 100% effective in realising appropriate outcomes (i.e. all DoP are complete), and b) that industry experts are comfortable using the AHP to estimate the correlation factors under this constraint. This provides the basis for the approach described in this section in which the 'complete' correlation to profit of each subject DoP is modified to take account of all incomplete interacting DoP.

The modification to the correlation factor is determined by the degree of impact (DI_{ij}) that each incomplete interacting DoP (suffix i) has on the potential for profit that stems from realising the subject DoP (suffix j) 100% effectively. Each DI depends on the strength of the interaction (SI_{ij}) and on the effectiveness (η_i) with which the interacting DoP is realised. Each interacting DoP with $\eta_i < 1.0$ will compound the cumulative negative effect on the potential benefit to profit of realising the subject DoP. The subject DoP's correlation factor to profit (w_j), calculated by assuming that all the DoP are complete, is adjusted by this cumulative interaction effect before its effectiveness η_j is applied.

A DoP that is realised with 100% effectiveness ($\eta_i = 1.0$) has no interaction effect on any other DoP. DI_{ij} is therefore zero for all j (i.e. for all subject DoP). It follows therefore that the degree of impact of an interacting DoP on the subject DoP is only high when its strength of interaction is high *and* it is realised with a low effectiveness. If the strength of interaction is low, or if the effectiveness is high, then the degree of impact will be low. The set of possibilities is illustrated in Table 8.2. These are boundary conditions that represent high/low cases only.

Effectiveness (η)	Strength of Interaction (SI)	Degree of Impact (DI)	Vertex Co-ordinates
high	high	low	1;1;0
low	high	high	0;1;1
high	low	low	1;0;0
low	low	low	0;0;0

Table 8.2. Relationship between Effectiveness, Strength of Interaction, and Degree of Impact.

By equating high to the numeral 1.0, and low to the numeral 0, the results in Table 8.2 can be represented graphically as the vertex points of two intersecting planes in a three dimensional space, as shown in Figure 8.1. The four points can define two alternative pairs of planes. The first pair is shown hatched, while the second pair is shown by heavy lines and takes the form of two faces of a pyramid. These alternative planes provide two linear boundaries to the space that probably contains the best estimate of DI as a function of SI and η. At this early stage in the development of the procedure it was decided to use the linear function defined by one pair of planes, and intuitively the hatched planes are more appropriate since they indicate that there is no significant interaction effect provided that the effectiveness of the process is reasonably good. The value of DI can be obtained from Figure 8.1 as the intersection of the normal through the point (SI,η) with the planes. This can be expressed algebraically to provide a simple algorithm for the degree of impact.

$$DI_{ij} = SI_{ij} - \eta_i \qquad \text{for } SI_{ij} > \eta_i$$

and $$DI_{ij} = 0 \qquad \text{for } SI_{ij} \leq \eta_i$$

In the absence of evidence to the contrary, the algorithm to modify the correlation factor is based on linear relationships. It is a subject for future research to determine these relationships more exactly. On this basis the modification to the correlation factor w_j due to the ith. interacting DoP is given by $w'_j = w_j\,(1\text{-}DI_{ij})$. Thus a high DI will have a large negative effect on the potential of the subject DoP to maximise profit. The modification to w_j due to the accumulated effect of several interacting DoP is obtained by applying each successive DI_{ij} to the progressively reducing difference between the accumulating DI and $SImax_j$. By this means the accumulated total degree of impact DIt_j becomes asymptotic to $SImax_j$ if there are a large number of interacting DoP. This gives:

$$w'_j = w_j.(1.0 - DIt_j)$$

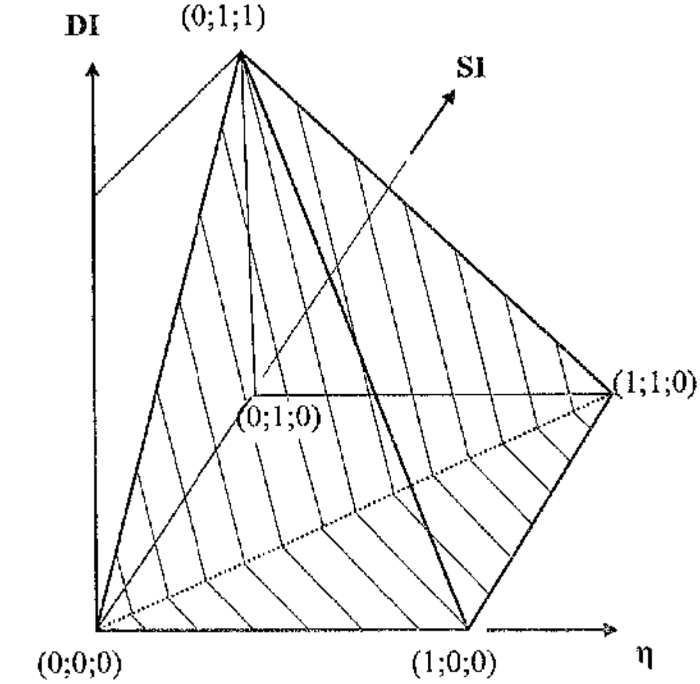


Figure 8.1. Relationship Between Effectiveness (η), Strength of Interaction (SI), and Degree of Impact (DI)

Where

$$\mathrm{DIt}_j = \mathrm{SImax}_j\left(1.0 - \prod_{i=1}^{n}\left(1.0 - \frac{\mathrm{DI}_{ij}}{\mathrm{SImax}_j}\right)\right)$$

The derivation of this equation is given in Appendix H.

Example

n	Subject DoP	w	η	SI			DI			DIt	w'	η.w'
				1	2	3	1	2	3			
1	Price	.45	.8	-	.5	.7	-	.1	.3	.367	.285	.228
2	Aesthetic	.3	.4	0	-	0	0	-	0	0	.3	.12
3	Features	.25	.4	0	0	-	0	0	-	0	.25	.1
											PMP' = .448	

Table 8.3. Example of the Evaluation Analysis. ($\mathrm{SImax}_i = 0.9$)

Table 8.3 gives some typical values from the evaluation of the PDP for an electric toaster. The correlation to profit of the DoP 'price' is judged to be dependent on two interacting DoP (aesthetics and features). The effect of the interaction is to reduce the potential for maximising profit (PMP) from 0.58 to the calculated value of 0.448.

8.7 Threshold Effectiveness Values

A further issue was raised during the tests in industry of the procedure to account for DoP interactions. It was observed that there would be little point in producing a product unless certain DoP were satisfactorily realised by the PDP. For example, a mechanical handling device that did not meet minimum statutory safety requirements would be a non-starter. The evaluation method is only meaningful if the PDP has the potential to deliver viable (i.e fit for purpose) products.

For a 'safety' DoP, an effective PDP must not only correctly identify the appropriate level of safety but must also ensure that the product meets this requirement. As the PDP becomes less effective there is less assurance that the optimum requirement will be met, even though the product may still be viable. A PDP that does not address safety at all (i.e. $\eta = 0$) is clearly not viable. There must therefore be at least a notional threshold value of effectiveness (η_{th}) below which the PDP is not viable, and therefore has no potential for successful outcomes. Thus the first step for a company must be to ensure that they have a viable PDP, and only then can they use the evaluation method to benchmark the process.

Clearly then, minimum targets must be achieved for some critical DoP. However it is a fundamental tenet of the evaluation method that DoP do not set target values. Rather it is the function of the PDP to set these values when realising the DoP. The evaluation method should not be dependent on what these values are *per se*. Thus the procedure requires the user to identify threshold values of effectiveness without first assigning target specification values. It was accepted that some crude judgements would have to be made, but they are necessary to avoid spurious results from the evaluation method by ensuring that a zero potential to maximise profit will be returned if the effectiveness value of any critical DoP lies below its threshold.

During tests in industry it was discovered that it could be difficult to make an absolute estimate of low levels of effectiveness, and that it could also be useful to use threshold values of effectiveness with non-critical DoP. In this case the effectiveness of any DoP that was evaluated as being below the threshold would be recorded as zero, and its degree of impact (DI) would then be equal to the full strength of the interaction (SI) and used as such to modify the subject DoP correlation factors.

8.8 Industry Trials

The evaluation method has been tested with a number of collaborating manufacturing companies. The researcher acted as facilitator to assist the company expert with interpretation of the judgements to be made. The DoP were identified first, and then the sets of interacting DoP were identified by asking the expert "In order to gain the benefit of getting this issue (subject DoP) right, what other issues (interacting DoP) must be got right as well?" The next step was to estimate the strengths of interaction. Tables 8.4 and 8.5 show the results for the hi-fi systems manufacturer who followed the procedure as described in this chapter. No threshold values were set since all DoP were judged to be realised at a high level of effectiveness and the interactions had no influence on the resulting PMP. The PMP was very high and reflects the success of the product produced using the evaluated process. For the purposes of illustrating the procedure, the effectiveness values in Table 8.5 have been reduced a little to show the impact that interactions might have on a basically successful process. These figures give a complete PMP of 0.817, which reduces to 0.705 when the effect of interactions is included.

		Interacting DoP					
n	**Subject DoP**	**1**	**2**	**3**	**4**	**5**	**6**
1	Aesthetics	-	0.5	0.9	0.1	0.7	0.1
2	Technical compatibility	0.7	-	0.9	0.1	0.7	0.1
3	Performance	0.7	0.3	-	0.1	0.9	0.1
4	Reliability	0.5	0.3	0.9	-	0.7	0.1
5	Perceived value	0.7	0.3	0.9	0.1	-	0.1
6	Launch date	0.5	0.3	0.9	0.1	0.7	-

Table 8.4. DoP Strength of Interaction (SI) Values (Hi-fi Systems Manufacturer)

n	**Subject DoP**	**w**	η	η.w	**DIt**	**w'**	η.w'
1	Aesthetics	0.15	0.95	0.142	0.1	0.135	0.128
2	Technical compatibility	0.1	0.98	0.098	0.1	0.09	0.088
3	Performance	0.36	0.8	0.288	0.2	0.288	0.23
4	Reliability	0.03	0.95	0.029	0.1	0.027	0.026
5	Perceived value	0.31	0.7	0.217	0.1	0.279	0.195
6	Launch date	0.05	0.85	0.043	0.1	0.045	0.038
			PMP =	**0.817**		**PMP'** =	**0.705**

Table 8.5. Estimated and Modified Subject DoP Correlation Factors (Hi-fi Systems Manufacturer)

The expert at the computer components manufacturer did not feel able to make close estimates of the strengths of interaction in the time available, so the procedure was modified to simply identify the existence of interactions, and then to apply DI = 0 if the effectiveness of the interacting DoP was above the threshold value and DI = 1.0 if it was below. It was judged that none of the DoP was critical. Tables 8.6 and 8.7 show these results, and the impact of not achieving threshold levels of effectiveness is clearly shown by the low PMP.

		Interacting DoP						
n	**Subject DoP**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	PC card standard	-					x	x
2	Store/power performance		-					x
3	Environment performance		x	-				x
4	MTBF		x		-			x
5	Aesthetics					-		
6	Plug and play	x					-	
7	Product road map	x	x	x	x	x	x	-

Table 8.6. DoP Interaction Matrix (Computer Components Manufacturer)

n	**Subject DoP**	**w**	η_{th}	η	η.w	**DIt**	**w'**	η.w'
1	PC card standard	0.16	0.8	0.9	0.144	0	0.16	0.144
2	Store/power perform.	0.3	0.8	low	0	0	0	0
3	Environment perform.	0.21	0.6	low	0	1.0	0	0
4	MTBF	0.15	0.6	low	0	1.0	0	0
5	Aesthetics	0.04	0.6	0.75	0.03	0	0.04	0.03
6	Plug and play	0.1	0.8	0.85	0.085	0	0.1	0.085
7	Product road map	0.04	0.6	0.7	0.028	1.0	0	0
				PMP =	**0.287**		**PMP' =**	**0.259**

Table 8.7. Estimated and Modified Subject DoP Correlation Factors (Computer Components Manufacturer)

The company experts (technical directors in both these examples) were satisfied that although their judgements were subjective, and even crude in some cases, the procedure did allow them to represent their knowledge of their product and their PDP, and that the results of the evaluation provided a fair reflection of the capability of the evaluated process. They felt the judgements they were asked to make were insightful and focused their attention on some issues that had largely been handled by default.

8.9 Concluding Remarks

It has been shown that the AHP can be applied to quantify many subjective judgements that must be made to evaluate the PDP in a manufacturing company, and in particular to determine the correlation of important product issues (DoP) with the likelihood of successful product outcomes. It is shown that interactions can exist between the DoP, and this violates Saaty's third axiom for the AHP. Tests show that it is indeed very difficult to apply the AHP if interactions exist, but a procedure has been developed whereby the correlation factors are first estimated using the AHP with the assumption of no interactions, and are then modified to reflect any interaction effects.

Results of tests in some manufacturing companies show that the AHP is effective in this application, with company experts satisfied that it provides a realistic quantification of their subjective judgements about their products and their PDP. Further work is required to refine the evaluation method to enable company experts to express their knowledge and judgement with increasing accuracy and to interpret the results so as to enable improvements to the PDP. At this stage many relationships have been assumed to follow a simple linear form, but as more field data is generated it will be possible to refine these relationships to provide increasingly accurate and useful feedback to company management.

9

Assembly and Implementation of the Evaluation Method

Summary

Incorporation into the PDP evaluation method of solutions to the research issues discussed in Chapters 4 to 8 and trials of the full implementation of the method at three industrial sites are described.

An important finding is that the method returns analysis results that are realistic, and that practitioners felt that the method brought to the fore important issues often taken for granted. Findings also indicate that the method has sufficient flexibility to accommodate a certain amount of simplification, should practitioners need to reduce time commitment. However it is recognised that this incurs a loss of rigour and information.

Other findings include: the importance of the facilitator's role; the importance of the user having an appropriate level of management experience; the need to investigate the effect of single user subjectivity; and finally, that the current assessment sequence is close to optimum but can be changed to accommodate each unique situation.

9.1 Introduction

A number of issues that were raised about the PDP evaluation method described in Chapter 3 have been examined in Chapters 4 to 8. Procedures and findings of that research are now integrated into the evaluation method and tested. The assembly, implementation and trials of the method as a whole are the topics of this chapter.

The chapter is structured as follows. The assembly of the overall evaluation method is described in Section 9.2. The implementation of the method is discussed in Section 9.3. Trials of the method, with findings, discussion and modifications are presented in Section

9.4. A detailed presentation and discussion of the current structure of the evaluation method is given in Section 9.5. Finally, concluding remarks are made in Section 9.6.

9.2 Assembly of the Evaluation Method

9.2.1 Literature Inputs

An important directive from Meyer and Booker (1991) is that the evaluation method should not lead people to present untrue or poor judgements. It is important that the method be assembled in such a way as to avoid this, whilst simultaneously facilitating the elicitation of knowledge that is accurate and true.

9.2.2 User Interface

The evaluation method will ultimately be implemented as a computer based tool with practitioners interacting and responding to on-screen prompts. This is beyond the scope of this thesis. The evaluation method has, instead, been implemented as a paper based tool (see Appendix I) for the trials described in Section 9.4. In this a user makes judgements and quantifies estimates in response to questions that are presented in questionnaire form. A facilitator assists the user in his/her responses, which are recorded on the supplied record sheets.

9.2.3 Sequence

The process to assemble and implement the evaluation method was to think about it rationally and place the steps of the method in an initial order, which is given in Table 9.1. The first of the three trials described in Section 9.4 was conducted in accordance with that sequence. The sequence was designed to be logical, to draw the user slowly into the method, and to allow the user to become familiar with the concepts in a manner that permits knowledge to be elicited effectively and in an organised fashion. Findings from the first trial regarding sequence were incorporated and lead to the current sequence shown in Table 9.1.

9.3 Implementation of the Evaluation Method

9.3.1 The User

9.3.1.1 Single, Multiple or Team

The evaluation method may be implemented within a company using a single expert, several experts independently, or a team of experts. There are advantages and disadvantages for each.

Single User

Advantages of having a single user are that less time commitment is required and that knowledge is unlikely to be 'lost' or omitted due to lack of communication between individuals. The prime disadvantage is that the degree of subjectivity of the data (an issue raised by Brookes and Backhouse 1998) and any errors in judgement are not immediately obvious.

Multiple Users

The greatest advantage of multiple users is that the potential exists to identify subjective and erroneous judgements. Contradictory judgements can be investigated and consensus reached. Also, individuals can be selected who have expert knowledge about specific areas of the company's products and PDP. In this manner concerns regarding subjectivity of performance measurement systems can be addressed to some degree. A disadvantage of this approach is that a significant commitment of company time will be required.

A Team of Users

The main advantage of a team of users is that consensus can be reached on judgements through immediate discussion (thus reducing the effects of subjectivity) and that the maximum amount of knowledge is exposed at one time (assuming the team is well chosen and co-located). This can result in mutual stimulation amongst team members to reveal important issues that may have otherwise remained hidden. Disadvantages of this approach are that it is less likely to be applied successfully (i.e. achieve significant levels of advantage) when company culture is not sympathetic to such an approach, and that a significant time commitment will be required.

9.3.1.2 Seniority

Analysis of industry survey results in Chapter 4 and trial results described in Section 9.4 show that the user/s must be of sufficient seniority to have knowledge of all aspects of the company and its products addressed by the evaluation method. Failure in this regard results in erroneous judgements, in excessive time taken to execute the method due to users having to source information from others, and in a lack of ownership of the evaluation findings that may result in recommendations not being carried out.

9.3.2 Role of the Facilitator

As mentioned previously, it is envisaged that the evaluation method will ultimately be computer based. This was outside the scope of this research project, so a facilitator was used for the implementation trials described in Section 9.4.

The role of the facilitator was to introduce the method and its various, often new and unfamiliar, concepts to each practitioner. Thus the facilitator can be viewed as an ES whose role can be summarised as follows:

- Explain terminology and the logic of the evaluation method.
- Explain unfamiliar concepts e.g. DoP, interactions, threshold effectiveness values.
- Explain scope of the activities in the generic PDP model.
- Aid judgements by, for example, ensuring that the practitioner understands all the concepts he/she is using at any given point in the evaluation.
- Guide effectiveness assessments e.g. reiterate that it is activities that are being assessed and not the product.
- Review the specific tools and techniques known to impact positively on NPD success e.g. QFD, FMEA, Taguchi methods, SPC, TQM.

It is evident that the greatest advantage of using a facilitator is that he/she can interpret and respond to any question or situation that may arise, whereas it is difficult to programme a computer to address all potential issues and to answer all questions. A disadvantage is that a facilitator may find it difficult to remain impartial, and can be tempted to lead users to respond in the manner desired by the facilitator.

9.3.3 Computations

Using the quantified data obtained from the forms completed by the user, the PMP value for the PDP under evaluation is computed (by the facilitator) as a function of activity effectiveness and the correlation factors. The relevant equations, given in Appendix J, have been implemented as a computer based spreadsheet using the Microsoft Excel software. The spreadsheet was also used to perform a sensitivity analysis to identify PDP activities most in need of improvement i.e. those having low effectiveness and high impact on profit.

9.4 Trials

9.4.1 Introduction

The objectives of the trials were:

1. To provide a further opportunity to test the solutions to the research issues discussed in Chapters 4 to 8.
2. To test the assembly and implementation of the evaluation method as a whole.

Findings from the trials about individual research issues have been presented earlier in the relevant chapters. Findings about the evaluation method as a whole are presented and discussed in this section.

9.4.2 Method

The evaluation method was applied at three industrial sites: a ship motion control system manufacturer; a computer components manufacturer; and a hi-fi systems manufacturer. In each case a past (as opposed to an existing or proposed) PDP was evaluated in relation to a realised product currently in the market. The purpose being to provide a comparison between the results of the evaluation (i.e. the estimated degree of PDP effectiveness) and performance of the product in the market. The evaluation method must estimate high PMP to coincide with successful product outcomes and low PMP for a product having poor market performance.

It was thought initially that the whole method could be applied during the course of a single day. However, the marine practitioner found that this was tedious, which effected his judgement. The method was therefore applied at the other two sites over the course of two consecutive mornings.

Each practitioner made comments (as time allowed) in response to questions included at the end of each section of the method (see Appendix I). The facilitator recorded (in writing and on tape) responses to knowledge elicitation questions and comments regarding the method.

9.4.3 Findings, Discussion and Modifications

9.4.3.1 Individual Research Issues

Although some of the findings given here relate to the specific research issues of chapters 4 to 8 they have been included because they also relate to the assembly and implementation of the whole method.

<u>Correlation Factors</u>

In a number of instances where the AHP should have been used to elicit judgements and determine correlation factors, practitioners opted to use a simple scale to quantify their judgements. For example, the marine practitioner used a scale of 1 to 5 to quantify the relative contribution of each GE to realise each DoP. The reason for this was to reduce the time commitment required.

It is relatively straightforward to determine correlation factors from quantified judgements based on a scale. However, it must be recognised that the rigour of these judgements is questionable due to the limitations of short-term memory identified in the literature (Dyer and Forman 1991). This may result in reduced accuracy and reduce the value of the findings, an issue that is addressed by using the AHP.

DoP

To reduce the time commitment required, all three practitioners elected to assess activity effectiveness to realise the product as a whole rather than to realise each individual DoP.

The most rigorous way of evaluating the PDP is as described in Chapter 3. However, it is recognised that to evaluate the PDP at this level of detail is not always practical because of the significant time commitment required. It is a feature of the method that it can accommodate grouping of DoP. However, there is a penalty in loss of information. The analysis of activity effectiveness (and therefore PDP effectiveness) becomes insensitive to the influence of the individual DoP.

GEs and Activities

Each practitioner chose to group activities and GEs in some manner during evaluation. Two of them combined similar activities and made a single assessment of their effectiveness (using judgements at characteristic level), with the same quantified value being assigned to each activity in the group. The third practitioner chose to make judgements about effectiveness at GE level. GEs were assessed by using activity characteristics and being aware of the constituent activities of the GE. This significantly reduced the time commitment as the practitioner had also consolidated the GEs of the generic model into 7 company-specific equivalents. The practitioner also suggested that when the analysis indicates a problem with a particular GE, that GE can then be analysed in greater detail by evaluating the effectiveness of each constituent activity. However, the same observation about the rigour of the evaluation made in relation to grouping of DoP, also applies to this case. That is, the method can accommodate evaluation of effectiveness at a high LoA (i.e. GE level) but there is a penalty in loss of information and accuracy. It is unlikely that evaluating effectiveness at GE level will expose all pertinent issues of best practice. Thus, it is possible that a poor PDP may be judged as being effective when assessed in this manner because some issues only visible at more detailed low LoA (activity level) or unique to some activities at that level, may not be considered.

The danger of this approach was highlighted by findings from the third trial where the PDP was estimated as having an effectiveness (PMP value) of approximately 99%. However, the PDP was known to be ineffective in that the manufacturing resource had not been identified timeously. This omission resulted in a missed launch date. The discrepancy between the estimated and actual effectiveness can be directly attributed to the approach used whereby effectiveness was evaluated at too high a LoA.[1] It cannot be assumed, therefore, that a process is effective unless it has been exposed to detailed evaluation at the appropriate activity level.

It can be seen that the combined effect that grouping both DoP and activities/GEs has on the rigour and volume of useful information obtained can be significant.

<u>Dimensions</u>

The computer practitioner was the only one to identify a time dimension DoP. The marine practitioner thought their PDP and DoP did not have a time dimension as they develop products in isolation from the market. That is, their product development occurs independently and prior to any orders and/or sales. Thus their development process is not constrained by any specific time scale (other than to optimise resource consumption). The practitioner did concede however that it is possible that their products would be sold earlier if available. This indicates that the marine practitioner should have been encouraged to evaluate the PDP with regard to a time-to-market (and associated time dimension) DoP. Although the hi-fi practitioner identified 'launch date' as a DoP, the DoP was assigned to the solution quality dimension. Failure to identify an appropriate time dimension DoP had a significant effect on the evaluation results. This is discussed in the next section under the heading 'Product Success'.

[1] In this case the LoA was even higher than the GE level of the generic model. The hi-fi practitioner had evaluated the effectiveness of 7 company equivalents, where each was a consolidation of a number of GEs of the generic model.

9.4.3.2 Assessment of the Evaluation Method

An important finding is that the evaluation method returned appropriate results. All practitioners thought that the results reflected accurately the capabilities of the respective PDPs.

The computer practitioner observed more than once that the evaluation method had encouraged him to think about issues that he would normally take for granted. For example, consistently low effectiveness scores identified the 'execution' characteristic as a weak area in activities. The hi-fi practitioner observed that he found the PDP model to be 'very comprehensive' and noted that it helped him to crystallise what is generally done but not usually thought about.

<u>The User (Single, Multiple and Team)</u>

The computer practitioner suggested that for the sake of thoroughness obtaining inputs from others in the company could help identify DoP. He also observed that it would improve rigour if inputs and judgements were made by a number of personnel considered to be experts in their particular function (marketing, design, management, etc.). The advantages and disadvantages of a multi-user approach have been discussed. It is left to future work to assess the impact and practicality of implementing the evaluation method with multiple users and/or teams.

<u>The User (Seniority)</u>

During the first trial the marine practitioner's limited knowledge of the business and marketing aspects of the PDP were noticeable. This was due to the practitioner not having access to all the information required to effectively assess the PDP, particularly with regard to business and marketing activities. This was not the case during the second and third trials, both of these practitioners being Technical Directors. Care must be taken in the future to ensure that users are at a sufficient level within the management hierarchy to make informed judgements. This would also be true for multiple user scenarios.

The Facilitator

Due to a desire to press ahead with the evaluation, the hi-fi practitioner did not immediately become acquainted with the terminology and concepts used in the method. The facilitator was repeatedly asked to remind the practitioner of the meaning of terminology and syntax, to explain complexity, and to explain the underlying philosophy of the method. The practitioner also required frequent explanations about the activity assessment procedure (i.e. the concept of each activity having characteristics and therefore an activity can be assessed in accordance with those characteristics).

At present the evaluation method allows each practitioner to respond directly to the activity assessment questions. The facilitator only provides assistance when required. More informed judgements could be elicited and thoroughness of judgements could be improved using an interview approach. Here the facilitator would ask questions and the expert make estimates after a thorough consideration, through dialogue, of the best practice issues involved. This would add rigour to the method by ensuring that questions are more carefully considered than they may have been during the trials. It is recognised that this approach incurs another increase in the time required to complete the evaluation.

Timing of Implementation

The marine practitioner noted that he had found it useful to have the opportunity to identify DoP a number of weeks prior to the overall evaluation. This gave time to assimilate the new concept and meant that sufficient time was available to make informed judgements to identify DoP. He thought that it would be advisable to apply the same approach to the generic PDP model (i.e. make the questionnaire available to practitioners at least a week before executing an evaluation of the process). The practitioner felt that he would have experienced greater difficulty had he been required to undertake the evaluation with no prior knowledge.

This practitioner also recommended that because the intensity of the evaluation process gave rise to a risk of tedium and exhaustion, exposure time should be limited to shorter periods over a number of days rather than the full day taken for the first trial. Assessment could occur over a number of mornings (for example) rather than continuously. In response to this finding the subsequent trials took place during two half-day periods at each site. In spite of this adjustment the hi-fi practitioner still commented on the high degree of cerebral intensity required by the method.

Time Commitment

The time taken to complete the trials was approximately 6.25 hours for the first, 6.5 hours for the second and 6.5 for the third. However, significant sections of the evaluation method were not used. Activity effectiveness was not assessed for all three dimensions in any of the trials. Nor was it assessed in relation to every DoP, nor did the practitioners assess all activities. Evaluating the PDP at the level of detail of the method presented in Chapter 3 will require a significant time commitment. The results will, however, be more rigorous.

Product Success

It was found that for the purpose of testing the evaluation method, evaluating the PDP in relation to a successful product may not be as helpful as for an unsuccessful one because a scenario then exists where a product may be successful without the company knowing why. This can be seen in the instance where the hi-fi practitioner rated the 'reliability' DoP as having a low impact on profit. This surprising judgement may be due to the relative ease with which the company achieves high reliability. The question to ask is what would happen if product reliability were not achieved to the correct level? In a market where reliability is highly valued by customers, a strong negative reaction would occur if product reliability were not achieved to the level of customer expectation. Because the company achieves high reliability with relative ease, the consequences of not achieving the correct level of reliability were overlooked. A second perspective is that for this product type reliability is not an issue with customers because all products exhibit high reliability. However, if the product's reliability was significantly lower than that of the competition, then warranty claims would increase and customers would be lost.

This is a good example of a critical enabling DoP. Reliability has low impact when correct levels are attained, but its interaction with other DoP i.e. its effect on profit when reliability is *not achieved*, must be strong. Low DoP interaction judgements in this instance can be ascribed to complacency on behalf of the hi-fi practitioner because the product produced by the PDP under review had been judged a success. Users must be guided by the facilitator or ES to recognise critical enabling DoP. This will ensure that the PDP is evaluated in relation to all appropriate DoP, even though the company may have a history of addressing many of them effectively. It cannot be assumed that DoP addressed effectively in the past will be addressed effectively by a proposed PDP.

PDP Success (Correlation between Trial Estimates and Reality)

The calculated PMP values for the ship motion control systems manufacturer, the computer components manufacturer, and the hi-fi systems manufacturer, were 0.65, 0.26 and 0.99 respectively. The marine practitioner noted that their products are subject to a significant number of warranty claims. This is an indication that all is not well with the process, an observation that is supported by the PMP value, which indicates a process of average effectiveness. The process at the computer component manufacturer has required significant improvements to attain the levels of product success desired by the company. To achieve this the company has appointed specialists in areas of the process identified as critical to success. There was, therefore, good correlation between the estimated effectiveness of the PDP, using the evaluation method, and the actual effectiveness of the process in terms of product performance in the market. Although the product that was used as the basis for the evaluation of the hi-fi systems manufacturer's process is very successful, the PMP value of 0.99 is felt to overestimate the quality of the PDP.

The hi-fi systems manufacturer arrived at a point in the development of their product where they realised that they could not produce the product in-house and still achieve their financial objectives. They therefore made a decision to out-source the manufacturing. This necessitated rework that resulted in a missed launch date (an annual exhibition) and the company had to wait until the following year to launch the product. In spite of this, the product success exceeded expectations. However, a PDP that resulted in a missed launch date should not have rated as high as 0.99.

The reason that the method did not identify a weakness in the process is because no DoP to indicate the importance of overall development time was in place.[2] Had the practitioner identified a 'time-to-market' DoP the time dimension would have been critical and the late selection of the manufacturing resource would have been interpreted as a weakness in the process (depending on the strength of correlation of the time DoP to profit). Instead the potential for success was high because, although the constituent activities of the GE 'specify supply processes' (GE11 in Figure 6.6) were not executed early enough, this GE was not judged to have a strong impact on any of the chosen DoP.

The reason the practitioner did not identify the appropriate DoP was because he deemed it important only that the product should be launched on the correct day in the year (an annual exhibition). It was not critical to the success of the product that launch was postponed by a year. This is a surprising comment.

It is important that the evaluation method should reveal these and similar issues. The above problem arose because the hi-fi practitioner was permitted to assess effectiveness at too high a LoA, and because he was permitted to evaluate the PDP in the absence of an appropriate time dimension DoP. The quality of evaluation is dependent on quality input data via expert judgement. It is therefore necessary to ensure that users of the evaluation method are given better guidance (by a facilitator or ES) and encouraged to consider these and similar issues discussed above (i.e. reliability, time dimension DoP, and effectiveness assessment at appropriate LoA). Only then will the method estimate low PDP effectiveness even though a user may have judged a product to be successful.

This raises the following question: assuming the hi-fi practitioner *had* identified 'time-to-market' as a strong DoP, how would the method have estimated a lower PMP value due to a late consideration of the manufacturing resource?

Assessment of the PDP in relation to a 'time-to-market' DoP would return a low effectiveness estimate because late consideration of the manufacturing resource would have a knock-on effect to cause a schedule overrun that results in a missed launch date. Thus the time-to-market DoP is not realised effectively and, because it is strongly

[2] The other reason has been discussed earlier i.e. effectiveness was assessed at too high a LoA.

correlated to profit, results in driving the PMP value lower. Further, a strong time dimension DoP is likely to interact with other DoP and negatively effect their impact on profit, which again results in a lower PMP value.

Sequence

The marine practitioner experienced difficulty in refocusing his thoughts to make judgements about DoP impact on profit when required to do so toward the end of the evaluation. He noted that it would be better if he had made these judgements immediately after the DoP were identified. This would have allowed the relative importance of DoP to be uppermost in his mind and so would have assisted him to make better informed judgements. It was considered that this observation merited a change to the sequence. This change, and others discussed below, can be found in Table 9.1.

The same practitioner experienced similar difficulty in making judgements about the relative contribution of each GE to the PDP for each DoP when required to do so early on in the evaluation method (see 'Initial Sequence' Item 5 in Table 9.1). He believed his judgements would have been more informed had he made them with the experience of having assessed activity effectiveness. The sequence was therefore altered to accommodate this observation, with judgements about the relative contribution of each GE to the PDP for each DoP being moved to follow activity effectiveness assessment.

The sequence of the method was changed after the trial at the marine engineering company and prior to the subsequent two trials. The initial and current sequences can be found in Table 9.1, where it can be seen that:

- Assessment of the relative importance of DoP to profit (via the three dimensions) ('Current Sequence' Item 7 in Table 9.1) now takes place immediately after reviewing DoP.
- Assessments to determine the relative contribution of GEs to the PDP for each DoP (Item 16) occur after assessment of activity effectiveness (Items 8 to 15).

The appropriateness of these changes can be illustrated by the fact that at the subsequent two trials both practitioners were comfortable with the new sequence.

9.5 State and Enhancement of the Evaluation Method

9.5.1 Current Structure and Implementation

The structure of the evaluation method has evolved during the industrial trails described in the previous section to its current form, which is presented below. (Note: Unless stated otherwise all data recording sheets, forms or questionnaires referred to below can be found in Appendix I.)

1. A questionnaire (given in Appendix E) regarding the company's PDP is forwarded to the user approximately a week prior to the evaluation.

   The objective of forwarding the questionnaire in advance is to allow the user time to map the company's PDP activities onto the generic model in advance of full implementation of the evaluation method at the company, and aids familiarisation with the model and its constituent activities.

2. A questionnaire (given in Appendix C) regarding DoP is forwarded to the user at least one week before full implementation of the PDP evaluation method at the company. DoP appropriate for a chosen product are identified by the user in response to the questionnaire.

   The objective of forwarding the questionnaire in advance is to introduce users to the (possibly new) concept of DoP and to allow them time to assimilate the concept.

3. On the day of the evaluation the user is given a bound copy of the data sheets (see Appendix I). The facilitator then introduces the user to the full evaluation method, the approach underlying the method and its structure and sequence.

   It is important that users understand that the method is a vehicle for NPD best practice, that it is not prescriptive, and that the approach adopted is that they themselves are the experts regarding company processes, culture, context, products, etc. Thus users must grasp the fact that the method will not tell them what they should be doing, rather, it will allow them to judge for themselves whether they should be executing certain activities and if they are, how effectively they are doing so. The method will not only give an overall indication of the effectiveness of the company's PDP but also permit them to identify activities that require attention.

Initial Sequence	Current Sequence
1. Day of evaluation – present bound copy of data sheets to user and introduce full method. 2. Map company's PDP onto model and make 'gut feel' judgements about activity effectiveness. 3. Identify DoP. 4. Define fuzzy numerical values of linguistic variables. 5. Estimate the relative contribution of each GE to the PDP for each DoP in the three dimensional groups. 6. Estimate solution quality (SQ) effectiveness of PDP activities (in relation to each characteristic) to realise SQ dimension DoP. 7. Estimate relative contribution of each SQ activity characteristic to its activity for each SQ DoP. 8. Estimate relative contribution of each SQ activity to its GE for each SQ DoP. 9. Estimate resource consumption effectiveness of PDP activities to realise RC dimension DoP. 10. Estimate relative contribution of each RC activity to its GE for each RC DoP. 11. Estimate time effectiveness of PDP activities (in relation to duration and timeliness) to realise time dimension DoP. 12. Estimate relative contribution of duration and timeliness to their activity for each time DoP. 13. Estimate relative contribution of each activity to its GE for each time dimension DoP. 14. Identify DoP interactions (includes: judgements of threshold effectiveness). 15. Estimate relative contribution of each DoP to profit and of each dimensional group of DoP to profit.	1. Forward PDP questionnaire to user prior to evaluation at the company. User maps company PDP onto model. 2. Forward DoP questionnaire to user prior to evaluation at the company. User identifies DoP. 3. Day of evaluation – present bound copy of data sheets to user and introduce full method. 4. Review company specific PDP model. 5. User makes 'gut feel' judgements about activity effectiveness 6. Review DoP and assign dimensions. 7. Estimate relative contribution of each DoP to profit and of each dimensional group of DoP to profit. 8. Estimate solution quality (SQ) effectiveness of PDP activities (in relation to each characteristic) to realise SQ dimension DoP. 9. Estimate relative contribution of each SQ activity characteristic to its activity for each SQ DoP. 10. Estimate relative contribution of each SQ activity to its GE for each SQ DoP. 11. Estimate resource consumption effectiveness of PDP activities to realise RC dimension DoP. 12. Estimate relative contribution of each RC activity to its GE for each RC DoP. 13. Estimate time effectiveness of PDP activities (in relation to duration and timeliness) to realise time dimension DoP. 14. Estimate relative contribution of duration and timeliness to their activity for each time DoP. 15. Estimate relative contribution of each activity to its GE for each time dimension DoP. 16. Estimate the relative contribution of each GE to the PDP for each DoP in the three dimensional groups. 17. Estimate threshold effectiveness to realise DoP 18. Make judgements about DoP interactions

Table 9.1. Initial and Current Knowledge Elicitation Sequence

4. The facilitator reviews the model, and if required, modifies data sheet 5.1 to reflect the activities and structure of the company specific model.

5. The user is asked to make quantified 'gut-feel' judgements (using a scale of his/her choice) about the effectiveness of each activity in the company specific model. These judgements are recorded on data sheet 5.1.

   This gets the user thinking about the process, the activities involved and the effectiveness with which those activities are executed in the company's PDP. The 'gut-feel' judgements are later used for comparison with the *informed* judgements made using the method to take into account all issues and best practice.

   The user may select any scale to quantify judgements. E.g. scales may be verbal (i.e. low, low/medium, medium, medium/high, high) or numerical (1 to 10).

6. The facilitator reviews the choice of DoP with the user and consensus is reached to ensure that the DoP are appropriate for use in the evaluation method. Using the guidelines presented in Chapter 5, the DoP are modified (if required) by renaming, expansion and/or consolidation. The DoP and their appropriate dimension (i.e. solution quality, resource consumption arc time) are recorded on data sheet 5.2

   Through discussion the facilitator is able to ensure that the user understands the concept of DoP and that the identified DoP are appropriate for use in the evaluation method.

7. The user makes judgements concerning the relative contribution and impact of each DoP to profit, and the correlation of each dimensional group of DoP to profit. The pair-wise comparison method of the AHP is used to elicit judgements, which are recorded on sheets 5.3 to 5.6.

   These judgements are included at this point to allow the user to maintain a train of thought about DoP.

The facilitator uses the AHP to quantify these judgements (where linguistic judgements have been made) and to determine the correlation factors that will be required to calculate the PMP value and perform sensitivity analyses (once all the data has been obtained from the user). Quantifying these judgements at this point gives an opportunity for the user to comment on the appropriateness of the correlation values.

8. The user makes estimates of the effectiveness of each activity (in relation to each characteristic) to realise each of the relevant DoP in the solution quality dimensional group. Estimates are recorded on data sheet 5.8.

9. The user makes judgements about the relative contribution of each activity characteristic to the execution of the activity for each solution quality DoP (recorded on data sheet 5.9)

10. The user makes judgements about the relative contribution of each activity to its GE for each solution quality DoP (recorded on data sheet 5.10).

    Issues relevant to the particular dimension are still uppermost in the user's mind, which assists him/her to make these judgements most effectively. Isolating each dimension (i.e. determining effectiveness and correlation values for solution quality, then resource consumption, and finally time) allows users to focus on the issues concerning one dimension at a time.

11. The user makes estimates of the effectiveness of each activity to realise each of the relevant DoP in the resource consumption dimensional group. Estimates are recorded on data sheet 5.11.

12. The user makes judgements about the relative contribution of each activity to its GE for each resource consumption DoP. Estimates are recorded on data sheet 5.12.

13. The user makes estimates of the effectiveness of each activity (in relation to duration and timeliness) to realise each of the relevant DoP in the time dimensional group. Estimates are recorded on data sheet 5.13.

14. The user makes judgements about the relative contribution of duration and timeliness to the execution of the activity for each time DoP (recorded on data sheet 5.14).

15. The user makes judgements about the relative contribution of each activity to its GE for each time DoP (recorded on data sheet 5.15).

    It can be seen that for Items 8 to 15 the focus is first on solution quality (Items 8 to 10), then resource consumption (11 and 12) and finally, time (13 to 15). Including Items 8 to 15 (which focus on effectiveness) at this point in the sequence enables the user to focus on estimates of the effectiveness with which each activity is executed to realise each of the DoP for a specific dimension.

    The user has the choice of whether to assess each activity for each DoP in turn or vice versa. That is, the user can focus on the activity and think about all the things to which the activity contributes, or focus on the DoP and think about everything that must happen in order to realise each DoP.

16. The user makes judgements about the relative contribution of each GE to the PDP for each DoP in each of the three dimensional groups. These judgements are recorded on sheets 5.16 (solution quality), 5.17 (resource consumption) and 5.18 (time).

    At this point the main issues are still uppermost in the user's mind, which aids him/her to make these judgements.

17. The user estimates all threshold DoP effectiveness values, which are recorded on data sheet 5.19.

    The reason for including this section at this point is that the user has a good grasp of pertinent issues regarding activity effectiveness to realise each DoP and should be able to make more informed judgements concerning this rather abstract issue.

18. Finally, judgements about DoP interactions are made and recorded on data sheet 5.20.

This item is last because by this time the user should have a good understanding of the DoP and be able to make an informed judgement. Another reason for making these judgements at this point is that some issues may arise from judgements about threshold effectiveness values that could assist in making informed judgements. In fact quantifying DoP interactions using the go/no go gate approach requires knowledge about threshold effectiveness values.

A case can be made to have users make these judgements when identifying DoP under Item 5. It can be argued that to do so will prevent the user from being distracted throughout the rest of the evaluation by the fact that interactions exist but have not been addressed. However, the trials show that practitioners were comfortable with the position of this item in the sequence.

9.5.2 The Use of Fuzzy Logic

The use of fuzzy logic has been considered, but implementing the method as a full fuzzy system was not realistic in the time scale of this research project. However, some degree of fuzziness can be incorporated into the AHP (Ruoning and Xiaoyan 1992, Weck *et al* 1997) and the activity effectiveness assessment. Also, a procedure similar to that described by Tsaur *et al* (1997), who permit the user to define fuzzy numbers for each verbal judgement and then execute the analysis using these numbers, can be followed. Fuzzy mathematics as described by, amongst others, Klir and Folger (1988) is used to perform the appropriate computations. The final fuzzy PMP value can be 'defuzzified' using for example, one of the methods described by Gulley and Jang (1995).

During trials of the full implementation of the evaluation method users were given the opportunity to assign fuzzy numbers to linguistic judgements (i.e. low, low/medium, medium, medium/high, and high) (see data sheet 5.7 in Appendix I). Fuzzy linguistic judgements would have been immediately de-fuzzified to yield a 'crisp' number for each verbal judgement using the centroid method described by Gulley and Jang (1995). The 'crisp' numbers would then have been used to compute PMP values. However, all three users preferred to work with either numerical judgements or 'crisp' numbers assigned directly to linguistic judgements.

9.6 Concluding Remarks

The research issues identified in Chapters 4 to 8 have been assembled and implemented successfully as a complete PDP evaluation method. Test findings indicate that the final method sequence is close to optimum and that the method returns appropriate results if applied correctly, but care is needed to interpret issues correctly. It has been shown that successful application of the method is potentially compromised by short cuts.

Further trials are needed with a greater number of companies and with time spent evaluating each PDP. The fact that all of the practitioners chose to simplify the activity effectiveness assessments in some manner can be ascribed to time pressure. Practitioners were looking for ways to fit the assessment into the available time, or for ways to keep the expended time to a minimum. As has been discussed, this simplification reduces the effectiveness of the evaluation. More interaction with the facilitator (something that was kept to a minimum during the three trials to attempt to simulate an ES) should allow the value of applying the full method to be pointed out to practitioners. It is important to impress upon practitioners that proper evaluation requires an extensive time commitment. Working the evaluation method up into a computer based ES should prevent practitioners from easily abbreviating assessments, and make clear the loss of value that will result.

Another issue that must be investigated is the effect of multi-users. The three practitioners each observed that the method should utilise inputs from other personnel in the company to reduce subjectivity and to give more rigorous and relevant results.

Lastly, trials of the evaluation method where the focus is on past PDPs only gives a limited amount of information about the validity of this method. Full and complete evaluation of the method requires further trials that focus on proposed processes. These trials will be long term. Measures of process performance in terms of product outcomes will be needed that can be assessed and monitored to determine the impact of the evaluation method.

10

Future Work

Summary

Development of the constructs of the evaluation method, and tests of these, highlighted areas for future work. These areas include: DoP interactions and threshold values; extending the method for implementation in the service sector; refining knowledge elicitation techniques and questions to assess activity effectiveness; and reducing subjectivity and increasing accuracy when determining correlation factors and activity effectiveness.

Other areas for future work were also identified from the trials of the complete evaluation method. These include: use of multiple experts to reduce subjectivity and increase accuracy; assessing activity effectiveness in relation to each DoP; benchmarking PMP values; comparative trials on successful and unsuccessful products; evaluation of proposed PDPs; and incorporation of the method into an interactive computer based ES.

10.1 Introduction

Solutions to the research issues identified in Chapter 3 have been developed and tested through trials at industrial sites. The complete evaluation method, into which the solutions have been integrated, was also tested by trials. Requirements for future work can be identified from the findings of these trials, and from issues identified during the development of solutions to some of the research issues. Future work identified in previous chapters has also been included here for ease of reference.

10.2 Research Issues

10.2.1 DoP

1. Investigate more fully the nature of the relationships between degree of impact (DI), strength of influence (SI) and PDP effectiveness to realise DoP (η) for interacting DoP. In the thesis these relationships have been viewed as linear, but it is probable that they will be more complex and non-linear in nature.

2. Extend the concept of DoP to include any measure of success e.g. number of sales, market share, return on investment. DoP could be renamed determinants of success (DoS). An advantage is that it requires less mental effort for industrial practitioners to understand how the concept reflects their own product agenda.

3. It was accepted that some crude judgements about DoP threshold values would have to be made to avoid spurious results from the evaluation method. Further investigation may enable a procedure to be developed to facilitate more refined judgements about these values.

10.2.2 Generic PDP Model

It is likely that the evaluation method can be developed to represent the PDP for service industry products. A service sector model can be achieved by either modifying the current generic model described in Chapter 6 or by using the IDEF approach to develop a new model for the service sector.

10.2.3 Activity Effectiveness Assessment

1. The manner in which company practitioners think about activities, and how they process the information to evaluate effectiveness, requires further investigation. The objectives should be to refine the procedure to reduce the mental effort and the amount of time required, and to obtain more refined judgements.

2. The way in which knowledge is elicited needs further investigation. For example, the 'best practice' questions may require refinement.

3. Future trials of the activity assessment procedure should be designed to ensure a greater level of dialogue on best practice issues between the facilitator and industry expert. This will help identify those issues pertinent to the company's context and to ensure that they are addressed.

10.2.4 Correlation Factors

To overcome subjectivity when using the AHP, statistical methods can be applied to pair-wise comparison judgements elicited from teams or a number of individuals. This is known as data triangulation (Easterby-Smith *et al* 1991). Alternatively, a correlation factor can be determined from the pair-wise comparison judgements of each individual in a group or team. These values are then 'averaged' to obtain a less subjective input.

10.3 PDP Evaluation Method

1. Trials of the method should be conducted with a user team and with a group of individual users who are experts in their designated functional areas (marketing, design, etc.). Each will perform an assessment of activity effectiveness, or provide inputs to facilitate such assessments. This approach should yield data that is less subjective and more accurate. However, implementing the evaluation method with multiple users will increase the time commitment.

2. Further trials are required to explore the sensitivity of the evaluation method to assess the PDP's response to specific DoP. This was not achieved during implementation trials of the complete evaluation method due to time limitations. Practitioners chose to assess the effectiveness of PDP activities in relation to realising the overall product as opposed to individual DoP.

3. The impact on the accuracy of PDP effectiveness estimates when users abbreviate the evaluation method should be investigated and quantified. Abbreviations can include the following.

- Evaluation of the PDP in relation to the whole product (or groups of DoP) as opposed to each DoP. This has been discussed in Chapter 5.
- Evaluation of the PDP at a high LoA e.g. at GE level as opposed to activity level. It has already been shown in Chapter 9, however, that significant errors can occur in this case.
- Determining correlation factors from quantified judgements using simple scales, rather than using the AHP. That is, instead of making pair-wise comparisons about the relative contribution of components to their parent, users simply rate the contribution using a scale e.g. 1 to 10. These values are then used to calculate normalised weights that are the correlation factors of each component to its parent.

4. A range of benchmark PMP values for successful products, failed products, etc. should be determined from extensive application of the method to a large sample of companies. This will enable the correlation between PMP values and success in a range of industry sectors to be established,

5. It has been stated that the PDP as defined in this thesis interacts with technology development activities but does not incorporate them. For some companies it will be important that the evaluation method has the facility to apply similar criteria (i.e. activity characteristics) to evaluate a PDP that includes the technology development process. It is likely that the method can be refined to do this. To achieve this refinement, DoP should be identified against which to measure the outcomes of technology development (it is recognised that this may no longer include the notion of profit). The effectiveness of the technology development activities that interact with the PDP (or are included in the PDP) can then be determined in relation to the identified DoP.

6. Future work should investigate whether the method can be used to evaluate the development of service sector products e.g. mortgages. A generic model that reflects the development process associated with this type of product would have to be developed. Further, best practice issues relating to the service sector should be

researched. The model and the best practice issues would then be integrated into the evaluation method.

7. Further work can be undertaken to determine whether the method can be used to evaluate the effectiveness of a company to develop its product programme. The generic model would need to be extended to incorporate programme level processes that cover strategic and planning issues. Further, best practice issues pertinent to the development of a product range will have to be researched. The model and best practice issues could then be integrated into the evaluation method.

8. Extensive trials should be conducted to gain confidence in the ability of the evaluation method to differentiate between effective and ineffective PDPs. This should be achieved by evaluating PDPs used to create existing products where the degree of market success is known.

9. Extensive trials to assess whether the evaluation method can be used to predict the degree of product success should be undertaken. This can be achieved by evaluating a statistically significant number of proposed PDPs and monitoring the performance of the products realised by those processes. However, it is recognised that to do so requires that data be gathered over the duration of the product life cycle to fully determine the degree of success of each product.

10. The method can be modified to include the use of fuzzy linguistic judgements. This has been introduced in Section 9.5.2. The potential advantage of this refinement (as argued by Gulley and Jang 1995) is that the evaluation method would be easier to use and give more accurate results. However, it must be ascertained whether any real benefit would be derived from taking this approach.

11. Finally, the evaluation method can be incorporated in a stand-alone interactive ES that negates the need for a facilitator. The system should be designed to minimise the risk that users will take short cuts, some of which have already been shown to jeopardise the effectiveness of the evaluation.

11

Conclusion

Summary

Findings indicate that the development of the PDP evaluation method has achieved the primary objective. Findings also demonstrate the usefulness of the method to industry.

Novelty of the method is demonstrated in that it addresses all the criteria identified in a recent review paper by Brookes and Backhouse (1998) as having been omitted to some degree in current methods. The new method boasts a set of features not present in any current method, and addresses an identified need for work in this area.

A new PDP evaluation method has been developed that enables companies to assess for themselves the effectiveness of their current or proposed PDP. The method has been evaluated during trials at a number of industrial sites. Findings indicate that success has been achieved with regard to attaining the primary objective set out in Chapter 1. Findings also indicate that as well as being useful in manufactured product development, the method has potential to be applied in other areas.

11.1 Degree of Success

The objective of the research project described in this thesis is stated in Chapter 1: "…to provide companies with a method to enable them to assess for themselves the effectiveness of their current or proposed PDP. This is to be a quantified method so that they are forced to think about issues, and so that results of the assessment can be used effectively as the basis of argument for change. The method is to be non-prescriptive, is to account for the uniqueness of each company, and is to draw out and utilise company knowledge within a framework of current best practice in engineering management."

Although the evaluation method was tested using a facilitator to prompt practitioners and explain concepts, issues, etc. where necessary, the method has been successfully designed to be implemented in-house by industrial practitioners themselves. Also, the method utilises company knowledge about its products, processes and procedures by facilitating the creation of a company specific PDP model. The method does not prescribe, but provides structure for the organisation of activities, which allows judgements to be made in the context of best practice issues.

The method has been successfully designed to evaluated current and proposed PDPs. This is achieved because the method is not restricted by historical data that may only become available at the end of the product life cycle.

Fundamental to the method is that it incorporates current NPD best practice, which is integral to the activity effectiveness assessment procedure. Company experts are required to think about best practice issues when assessing activity effectiveness. Also foundational is that although the expert is faced with best practice issues and a list of PDP generic elements, these are only used insofar as they relate to the company's particular product, context, culture, etc. The objective to develop a non-prescriptive method that allows company uniqueness to be expressed has thus been achieved.

It is concluded that the developed PDP evaluation method is successful in meeting the primary objective.

11.2 Usefulness

The method provides quantified data that can be used effectively as the basis of justification for change to a company's PDP. The method provides industry practitioners with a procedure to identify PDP activities most in need of improvement i.e. those that have low effectiveness and high impact on product success.

The method can also be used to build up a picture, from activity characteristics, of general NPD areas in need of change. This is achieved by analysis of the data to highlight consistently low effectiveness scores of particular activity characteristics. They in turn point to the NPD best practice issues that must be addressed. For example, examination of activity effectiveness scores may reveal that timeliness characteristics have scored consistently low, which in turn indicates that concurrency issues may require attention.

The evaluation method can be applied more generally to any process that can be defined in terms of DoP, GEs and activities.

11.3 Novelty

Innovation and novelty is demonstrated by the following.

- The concept of DoP and their use as criteria against which the effectiveness of the PDP is evaluated.
- The new PDP model is the only model to meet all the requirements identified in Chapter 6. It is novel in the way it is structured (i.e. activities and GEs at like LoA) and the purpose it serves in the evaluation method i.e. to provide a non-prescriptive model, which acts as a framework onto which the particular PDP activities of a company can be mapped to produce a company specific PDP model.
- The manner in which activity effectiveness is assessed i.e. by making judgements, in the knowledge of NPD best practice, about the quality of activity characteristics in the context of realising each DoP.
- The manner in which the AHP is used to determine DoP impact on profit whilst accounting for DoP interactions.

Innovation and novelty is claimed for the evaluation method as a whole in that it addresses a gap in this field of work. No method or evaluation framework exists that is non-prescriptive in nature and which allows proposed processes to be evaluated by quantified assessment of PDP activity effectiveness in relation to execution quality, resource consumption and time dimensions of important product issues (DoP). Further, as demonstrated in Chapter 3, none of the current methods reviewed has all the features of the new PDP evaluation method.

From their case study experience Brookes and Backhouse (1998 p7) suggest that in order to create effective and practical performance measurement mechanisms the following issues should be addressed:

- The lack of an effective quality measurement mechanism (where the quality of a process is perceived as the extent to which the output of that process matches customer expectations).
- Difficulties in making comparisons across projects owing to system problems (e.g. lack of computer automation, data inaccuracies) or comparisons perceived as lacking meaning.

The new evaluation method has novel features that address both of these problems, the first of which is addressed by an assessment of PDP quality to realise each DoP that include customer expectations. The second problem is addressed through calculation of a benchmark PMP value for each project, which allows the performance of the PDP across projects to be compared. Also, the profile of each activity provided by evaluation of its characteristics with regard to best practice provides another means of comparison across projects.

Finally, the new evaluation method meets or is capable of meeting the following criteria for effective performance measurement identified by Brookes and Backhouse (1998). (How the new evaluation method meets the criteria is shown in bracketed italic type):

1. The level of the performance measurement - mechanisms should give results at the 'whole process' level. *(The evaluation method gives results at this level because the developed generic PDP model accounts for the whole process.)*
2. The balance of performance measurement - mechanisms should incorporate measurement of lead-time, resource and quality. *(The DoP are identified and activity effectiveness to realise each DoP is assessed in the context of three dimensions that reflect lead-time, resource and quality.)*
3. Ease of comparison of performance measurement - mechanisms should facilitate comparison across different product introductions. *(The calculated PMP value serves as a benchmark that facilitates comparison of the PDP across different product introductions. Activity characteristic effectiveness profiles can provide a similar facility.)*

The above illustrates how the research area of methods and tools to assess the performance of the PDP has been advanced by the work presented in this thesis.

APPENDICES

Appendix A

Evolution of the PDP Evaluation Method

The purpose of this Appendix is to show the process whereby the evaluation method has evolved. This occurred in two phases: (1) The evolution of a model to relate the PDP and profit; and (2) the evolution of the evaluation method itself, as an extension of the PDP/profit model.

1 Evolution of the PDP/Profit Model

The diagram in Figure A.1 illustrates the final model that evolved out of a desire to determine the links between the following elements: a) a high level general management system that considers company strategy, culture, organisation, management style, control, and resources, b) the PDP, c) the product requirements (internal and external to the company), and d) profit derived from the sale and support of the product.

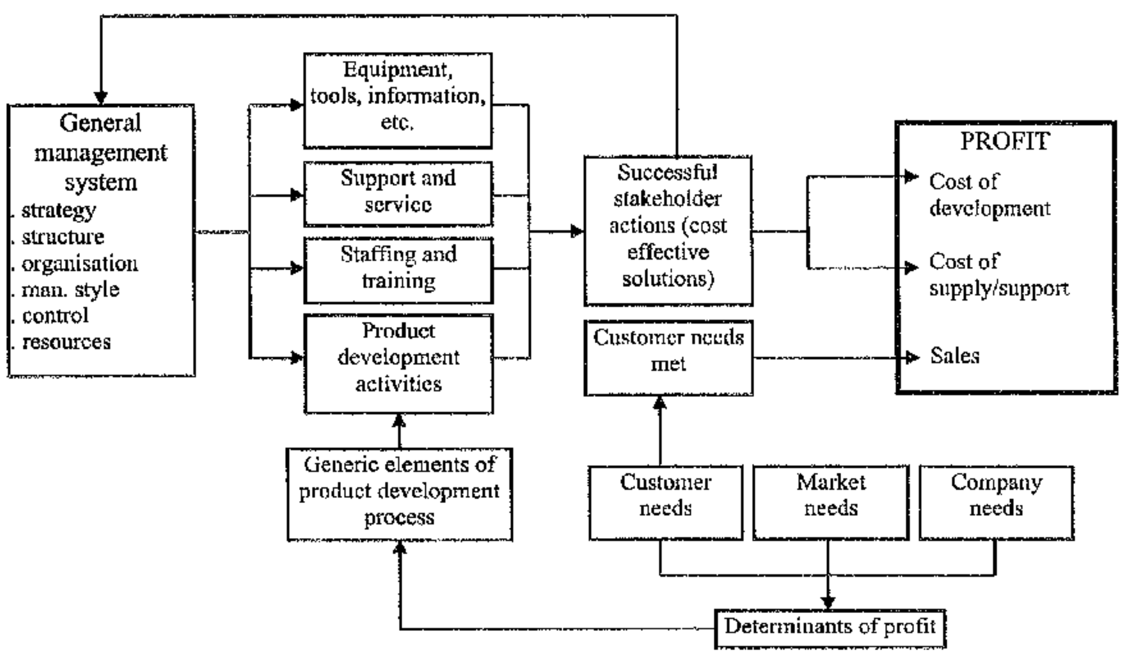


Figure A.1. The PDP and Profit

The first stage of evolution of this model can be seen in Figure A.2, which began from the viewpoint that a company makes products for profit. It is considered that there must be certain issues that will determine the profit a company derives from the sale and supply of a product. These issues are called 'determinants of profit' (DoP). Profit is expressed as the income from sales of the product less the costs of development, supply and support of the product. Sales of a product depend on meeting customer needs e.g. price, quality, quantity. Cost of development is determined by the cost of activities such as market research, concept and detail design, prototype manufacture and testing. Thus these activities must encompass the effective utilisation of time, money, human and technological resources. The Figure also illustrates how 'management' is thought to impact on 'process' (i.e. the PDP). The 'process' is linked to 'activities' (of the process), which in turn effect 'costs' and 'productivity' or 'successful stakeholder (those executing the activities) performance'. 'Successful stakeholder performance' in turn impacts on cost and profit.

It was felt at this point that the model did not yet represent the elements and their relationships in a manner that was usable as a basis for a generic evaluation method.

The second stage in the evolution of the model can be seen in Figure A.3. The model depicts how, through the DoP, the elements are related to, and impact on, profit. The DoP are viewed as a function of 'cost of sales of product' i.e. cost of development and cost of supply/support, and, 'sales of product' i.e. income from sales derived from meeting customer needs.

Two problems had to be addressed; first, how to link the PDP to the other elements, and second, what are determinants of profit? E.g. activities, processes, management (i.e. capabilities, teams, resources, structures, etc.), successful stakeholder action? It was thought that answering this question would identify the links. This however proved not to be the case.

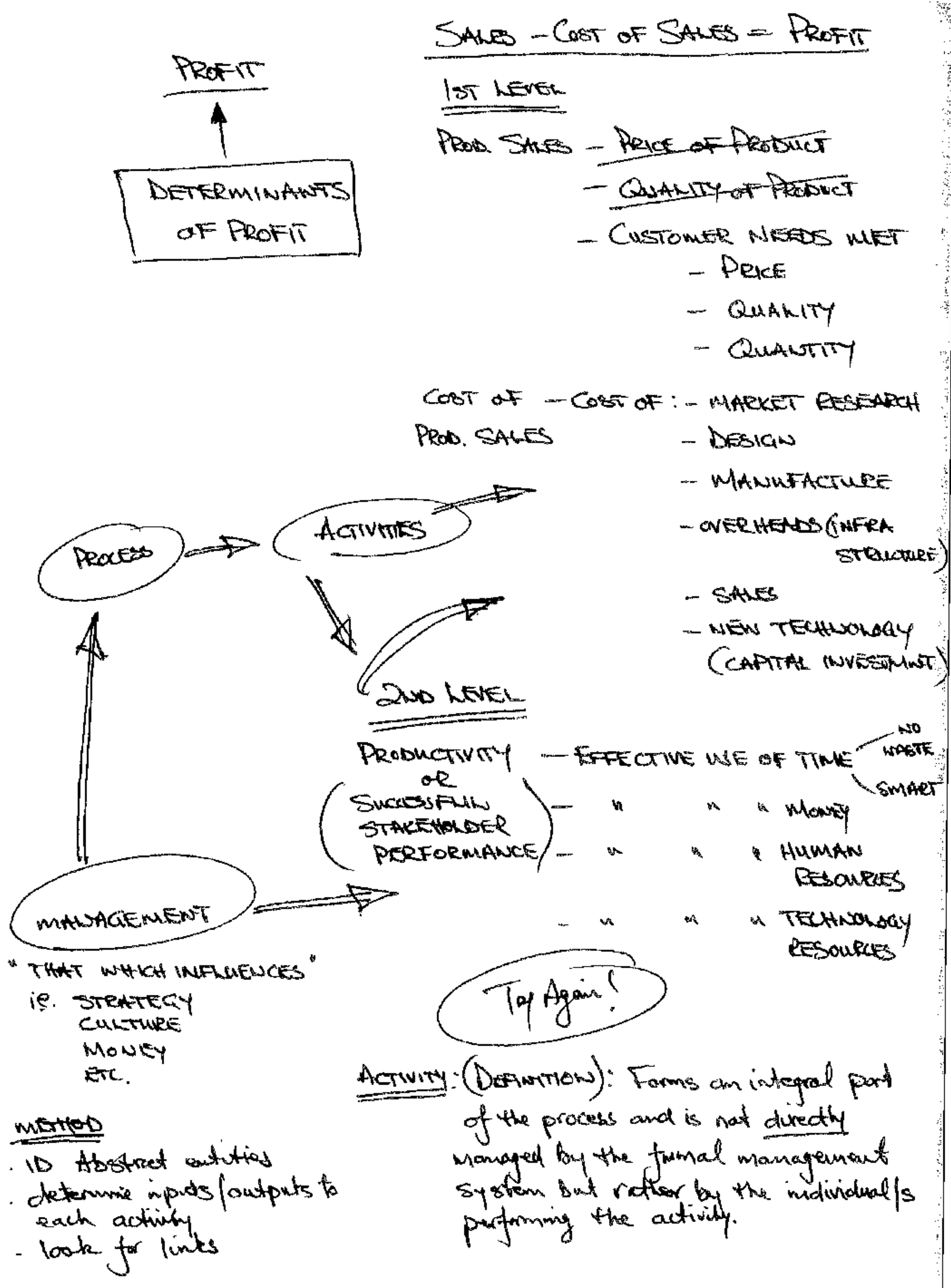


Figure A.2. Evolution of PDP and Profit Model: Stage 1

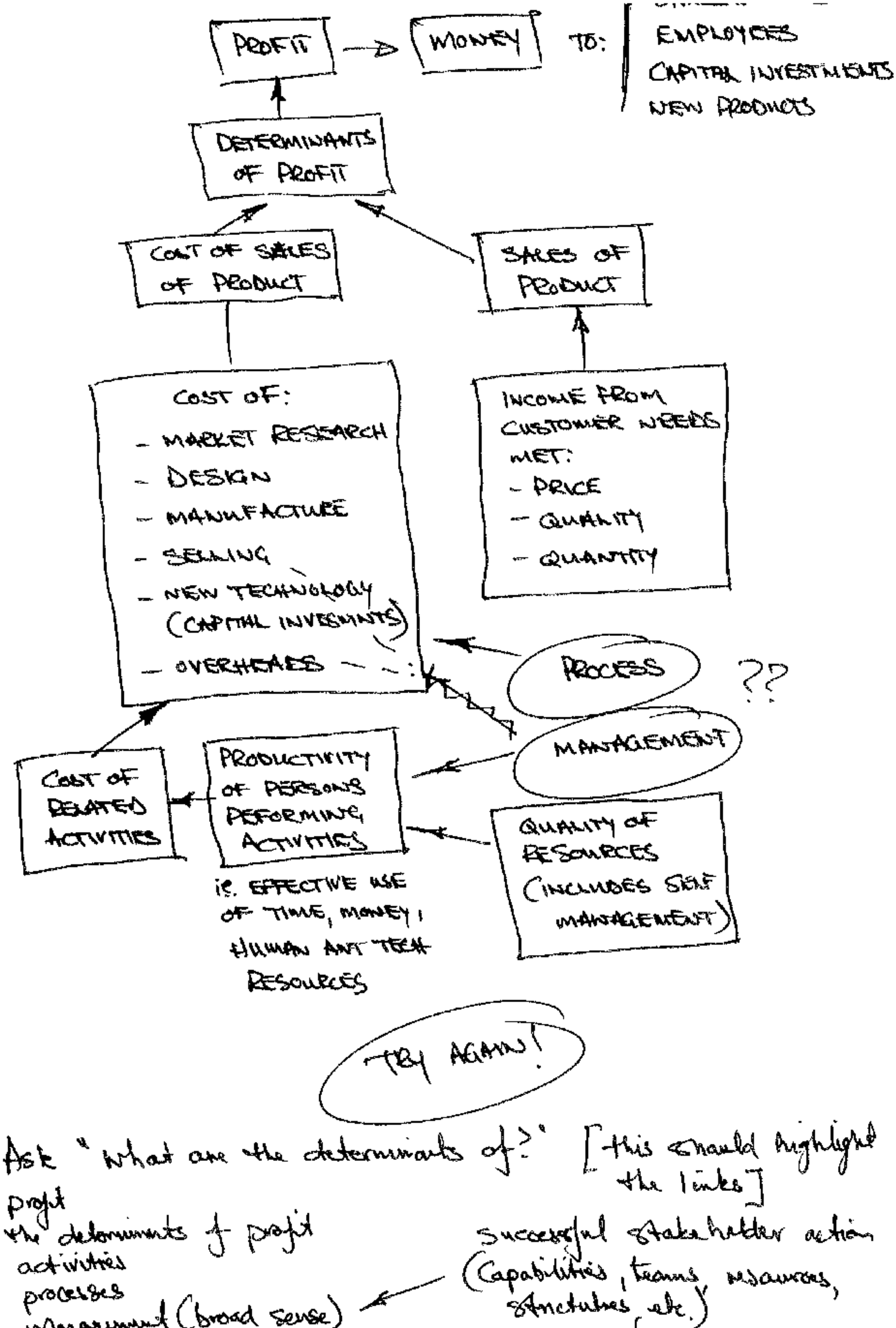


Figure A.3. Evolution of PDP and Profit Model: Stage 2

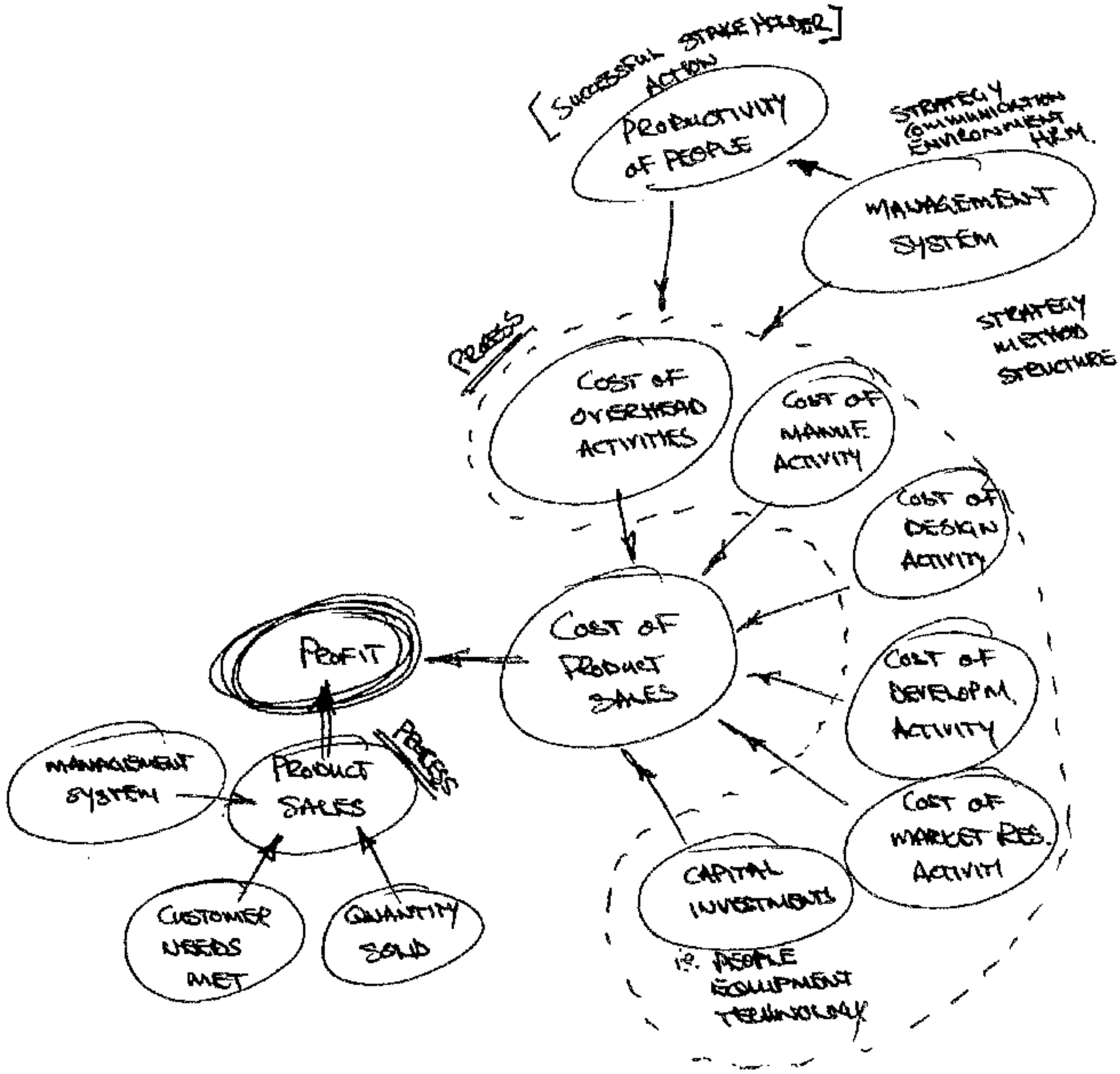
The third evolution stage of the model is depicted in Figure A.4. Here the focus is on how the 'management system' relates to elements contributing to both sides of the profit equation. The management system is viewed on the one hand as being linked to the 'process' and to 'productivity of people' (Productivity of people ensures successful stakeholder actions). These two effect the cost of the product. On the other hand the management system impacts on sales of the product, which effects income from the product. (Management system relationships with process, process activities, and effectiveness of people actions are shown in more detail in Figure A.5).

'Determinants of profit' are no longer visible in Figure A.4, however, a 'company needs' element is identified in terms of 'quantity of product sold'. Further, and more importantly, meeting customer needs is identified as an important element. Almost all NPD literature (the development of Sony Walkman being an often cited exception) identifies meeting customer needs as critical to new product success (hence the rise of QFD (Hauser and Clausing 1988; Griffin 1992; Powers *et al* 1997; Verma *et al* 1998)).

This fourth evolution stage model is shown in Figure A.6. The view here is that the 'general management system' impacts on most of the other elements. However, this impact is now shown to be restricted to the 'cost' side of the profit equation. This stage in the evolution of the model shows a link for the first time, between the 'cost' and 'income' parts of the model. Activities within the process are seen to impact on 'customer needs met' and 'identifying customer needs' (rather than the other way around). Determinants of profit are still not visible, however.

The fifth stage of evolution of the model can be seen in Figure A.7. A number of important considerations that ultimately shaped the PDP evaluation method can be seen at this stage. They are:

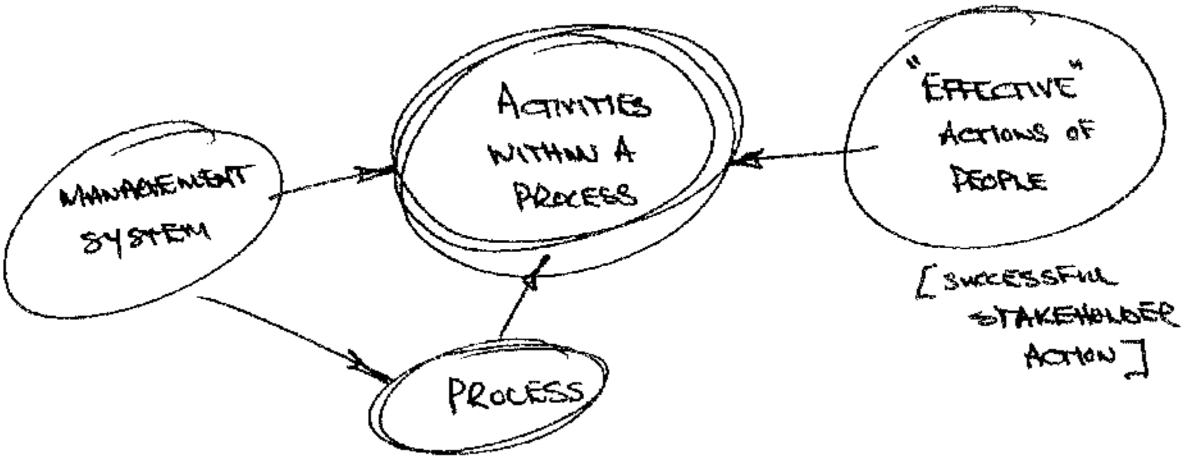
- Determinants of profit are visible again, but are now thought of in terms of "what do you have to get right to make a profit?" i.e. what are the important issues. Determinants are also thought to be linked to outcomes of the process.
- The importance of DoP to *both* sides of the profit equation should be measured.



Question: Are the activities indicated not also processes? ✓
By our definition processes controlled by management
(broadest sense) – activities are not! (Is this true
though?)

NO!

Figure A.4. Evolution of PDP and Profit Model: Stage 3



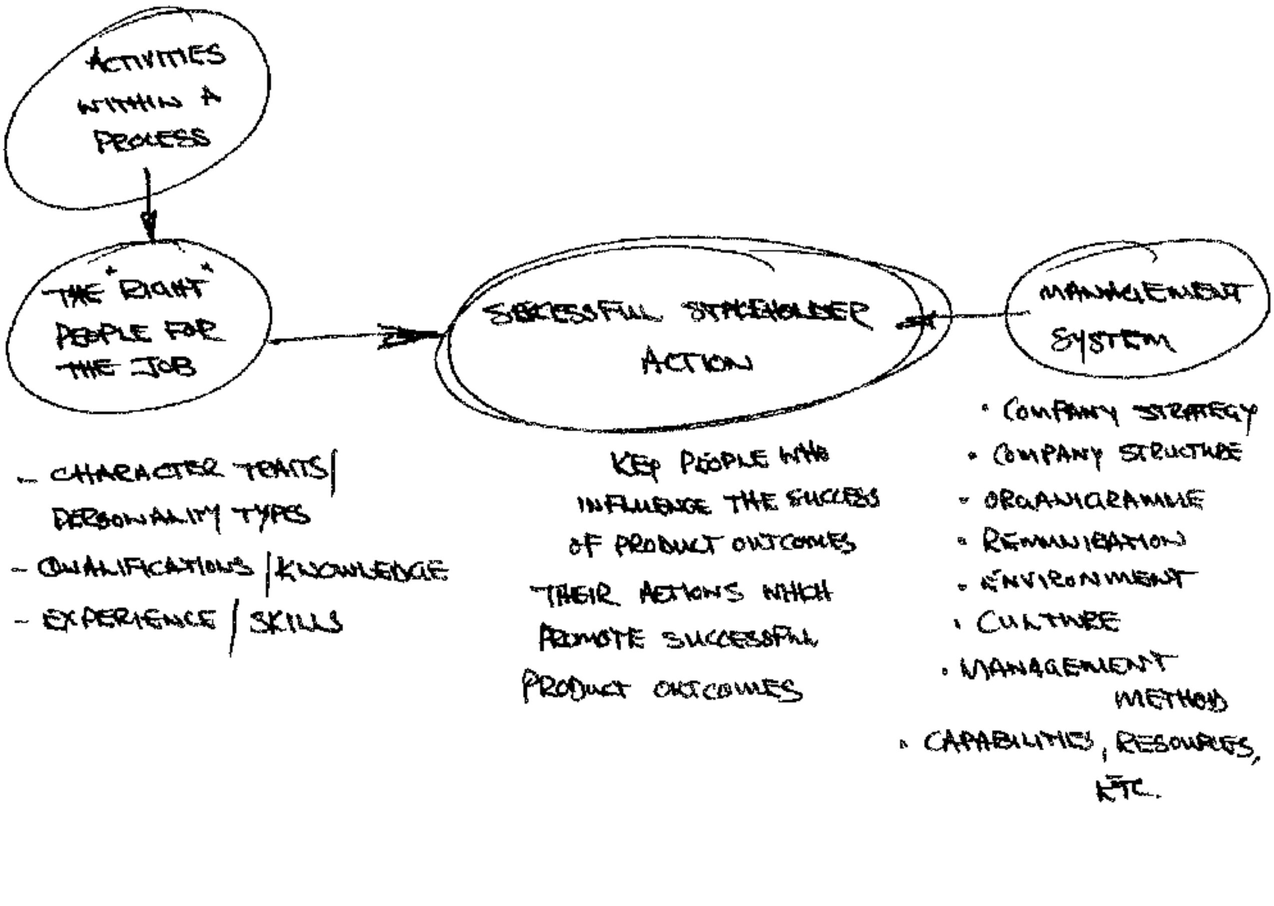
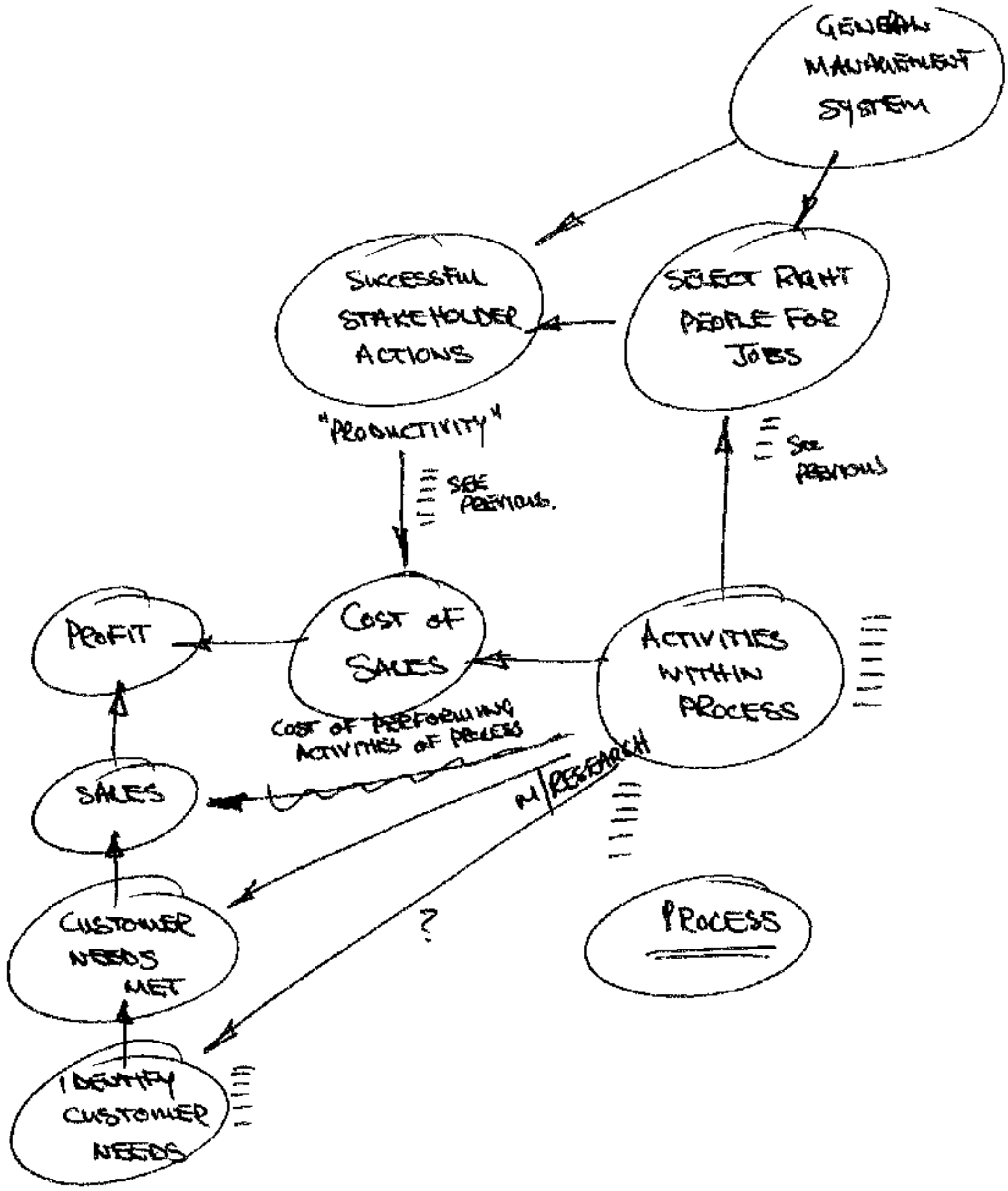
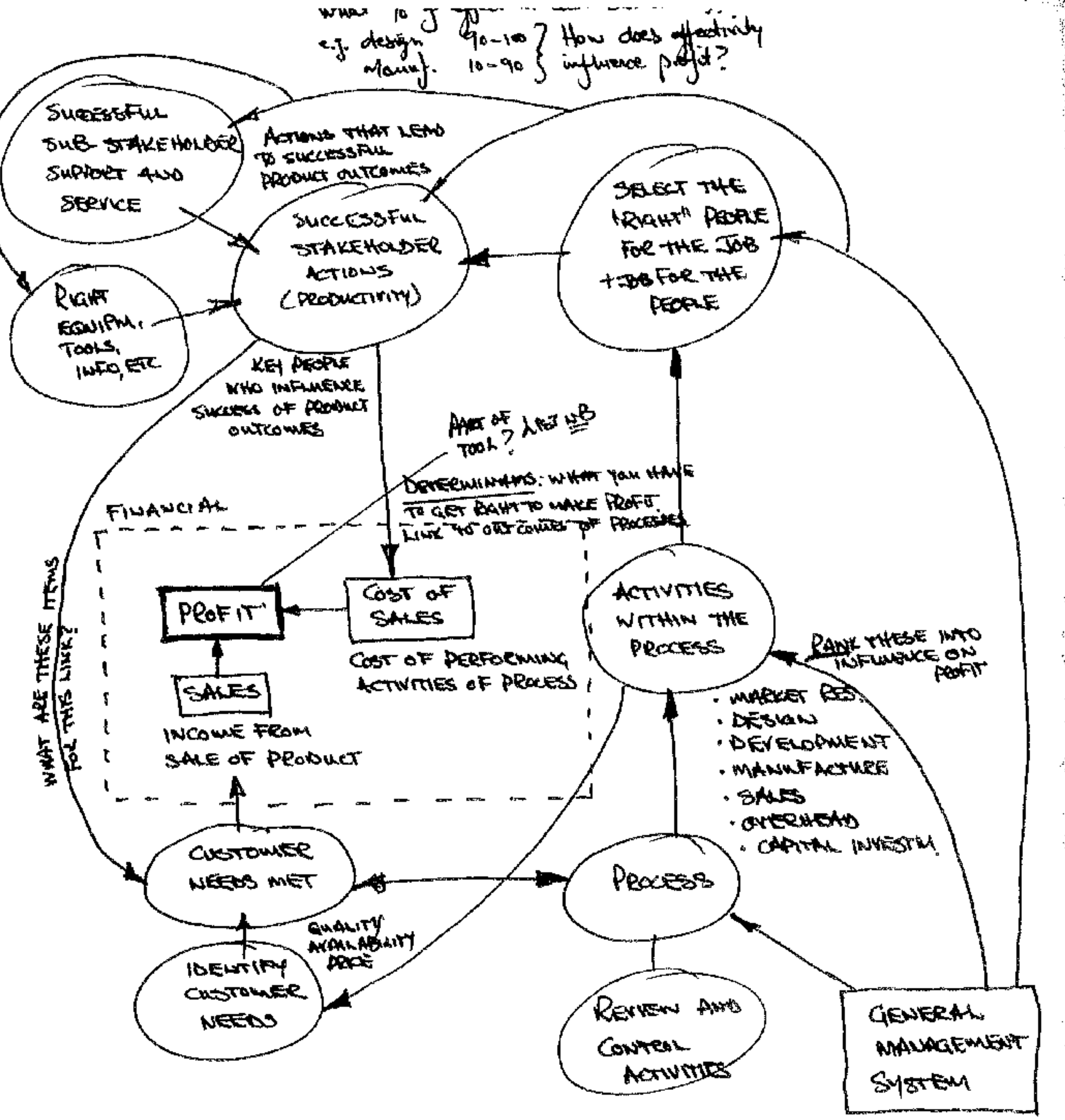


Figure A.5. Management System Relationships



Process meets needs
not activities?!

Figure A.6. Evolution of PDP and Profit Model: Stage 4



- Measure of NB of determinants to two sides of profit equation.
- what affects performance of stakeholders in achieving determinants successfully?

Expand these into each of the boxes they influence

COMPANY STRATEGY
STRUCTURE (FUNCTIONAL, ETC)
ORGANIZATION
CULTURE
ENVIRONMENT
MANAG. STYLE (CONTROL)
CAPABILITIES, RESOURCES
REWARDS

Figure A.7. Evolution of PDP and Profit Model: Stage 5

- Activities within the process e.g. market research, design, development, manufacture, and sales are to be *ranked* in terms of their influence on profit (which is due to the fact that PDP activities do not necessarily have an equal impact on profit. For example business development and detail design are both important to successful product outcomes. However, it can be argued that good detail design may be important for some companies than good business plan development).

The sixth evolution stage of the model is represented in Figure A.8 and depicts updates to, and a rearrangement of, Figure A.7. Three important modifications occur at this point. First, activities within the process are thought to impact on *both* sides of the profit equation and not only 'cost'. Second, 'identify customer needs' is now included as an activity in the process. Thirdly, 'activities within the process' (i.e. market research, design, development, manufacture, sales, overhead, and procurement) are reallocated to new defined 'sub-processes'. However, it is noted that 'sub-processes' and 'process' required greater clarity.

Previous considerations are taken up in the final stage of the model's evolution, which is represented in Figure A.1. Evident in this model is how sub-processes (now generic elements - GE) of the PDP (and their constituent activities) are related to DoP. Also, GEs and DoP effect *both* sides of the profit equation. 'Customer needs' has been expanded to show market and company needs. Lastly, the element, 'successful stakeholder actions', feeds back to impact on the 'general management system'.

It was felt that this representation of the elements and their inter-relationship could be used as the basis for the development of a PDP evaluation method, which would be implemented and tested in industry.

Look at this again

Updated 27/9/96

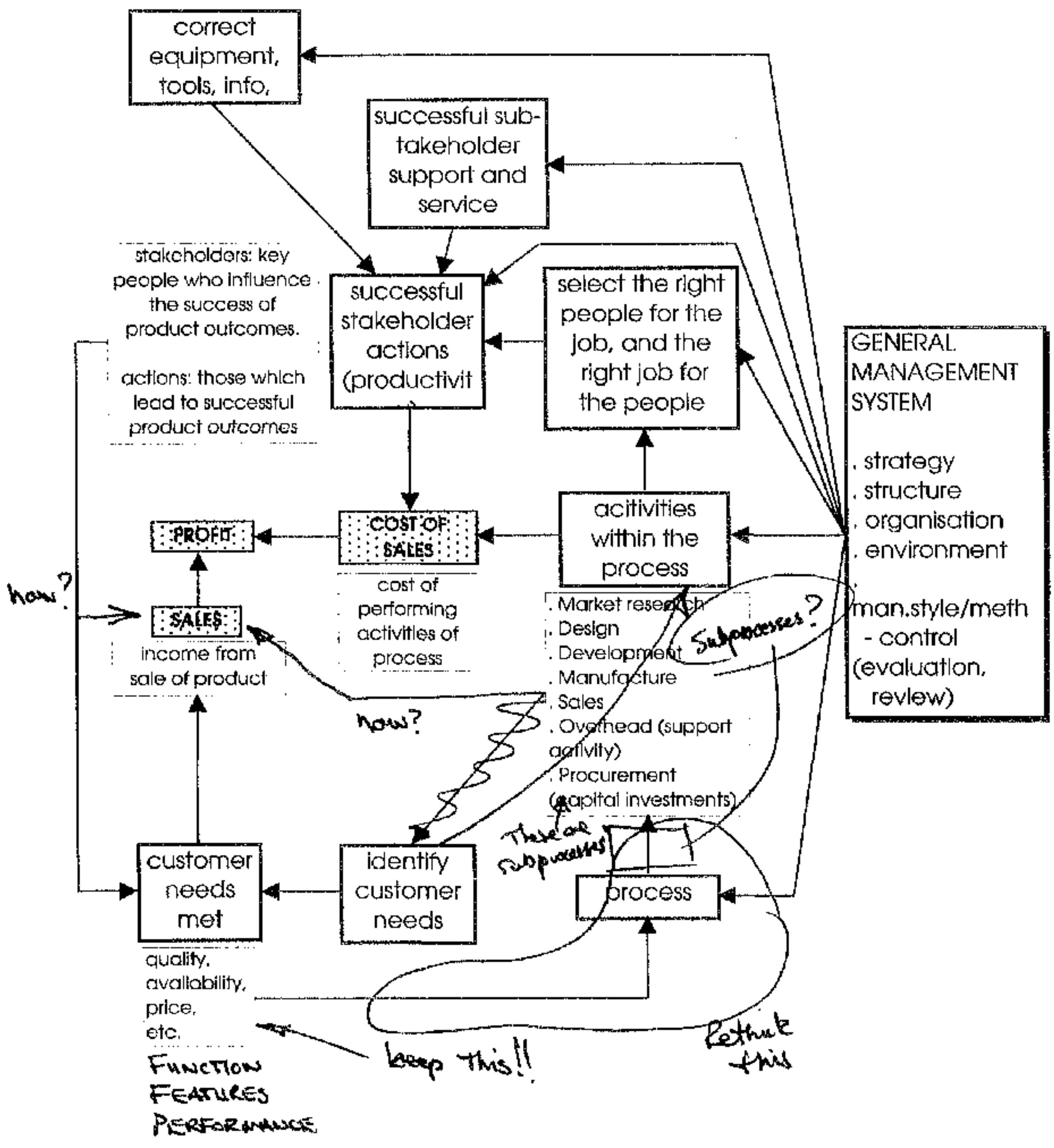


Figure A.8. Evolution of PDP and Profit Model: Stage 6

2 Evolution of the PDP Evaluation Method

The current state of the PDP evaluation method, illustrated by the flow diagram in Figure 3.2 (see Chapter 3), evolved out of the PDP and profit model described above. The first stage of evolution of the PDP evaluation method is shown in Figure A.9, where the method and its interaction with a company's management system and PDP can be seen. Elements at this stage of evolution are:

- Identify DoP.
- Apportion an assessed quantified contribution of each DoP to profit.
- Relate GEs of the PDP to the specific PDP of the company.
- Relate DoP to GEs of the PDP i.e. which GEs influence which DoP.
- Make a quantified assessment of the effectiveness of the company's PDP in fulfilling the generic PDP requirements.
- Use the *two* quantified elements to derive a probability of successful product outcomes.

A number of issues were under consideration at this stage in the evolution of the evaluation method:

- *Management system*: The management system is integral to the process that carries out the generic requirements that must exist in the PDP. The manner in which a company achieves this has to be judged against a particular generic activity that must be executed. Management actions that set up and support the process must be distinguished from those that are part of the process. (This distinction is handled in the generic PDP model the development of which is described in Chapter 6).

- *DoP*: These are issues about the product that cause the sale of the product, and will vary from company to company. (DoP are discussed in greater detail in Chapters 4 and 5).

- *GEs*: These are the 'things' that have to be done in the PDP in order to realise the DoP. These are important for the company if a company wants to develop successful new products. (GEs are discussed in greater detail in Chapters 4 and 6).

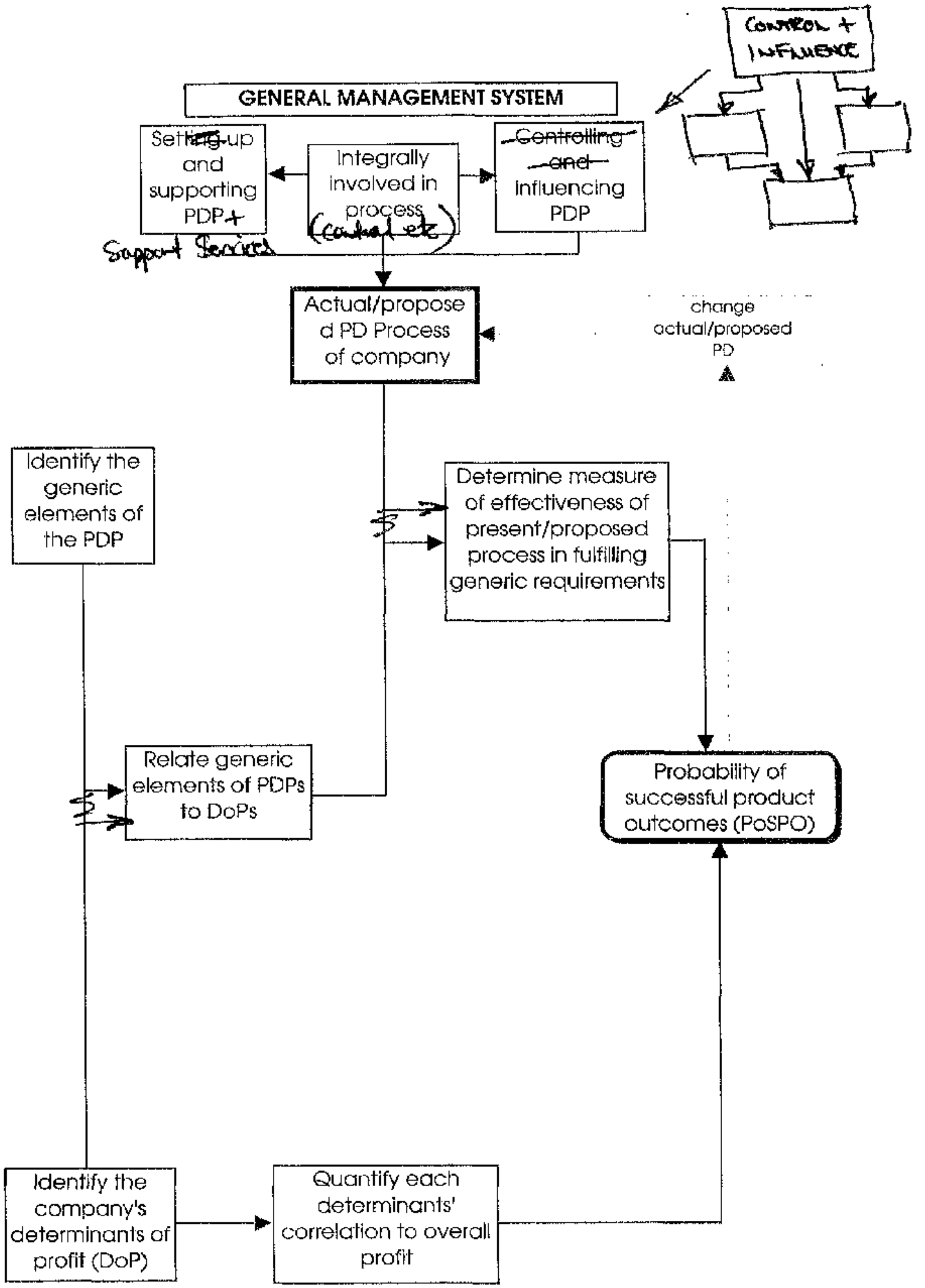


Figure A.9. Evolution of the PDP Evaluation Method: Stage 1

- *Probability of Successful Product Outcomes*: This value is determined by two factors: the DoP and how effective the actual process is in handling the GEs. Thus to have a good probability of success the PDP (actual or proposed) must realise important DoP with a high degree of effectiveness. This implies that a company does not have to execute all GEs with a high degree of effectiveness, only those that are strongly correlated to important DoP.

At this point the method was considered too nebulous to be implemented as an evaluation tool.

The second evolution stage is depicted in Figure A.10, and illustrates an extra element in the method i.e. 'Quantify importance of each GE for every DoP', which provides a third quantifier from which a value for the probability of successful product outcomes may be derived.

The third stage in the evolution of the evaluation method is illustrated in Figure A.11. Apart from a decision to combine two elements (illustrated) the major consideration at this point was the issue of uncertainty that may exist due to limited confidence in judgements, limited predictability of factors external to the company (e.g. market and customer requirements), and the extent to which judgements (e.g. regarding relative importance of GEs to realise DoP) are affected by factors external and/or internal to the company.

It can be seen in the Figure that various facets of the issue and ways to account for them, are explored. For example, identifying the uncertainty in the identified DoP. Further, what is the exact nature of uncertainty, what causes it and how does it impact on development? How should the issues be reflected in the developed evaluation method?

The fourth stage in the method's evolution is depicted in Figure A.12 in which an element to assign a DoP predictability value has been included. This element, and the element to determine a measure of effectiveness of the PDP, is used to determine a dynamic effectiveness value for the PDP, which is a measure of how well the PDP is able to deal with uncertainty and unpredictability of factors internal and external to the company.

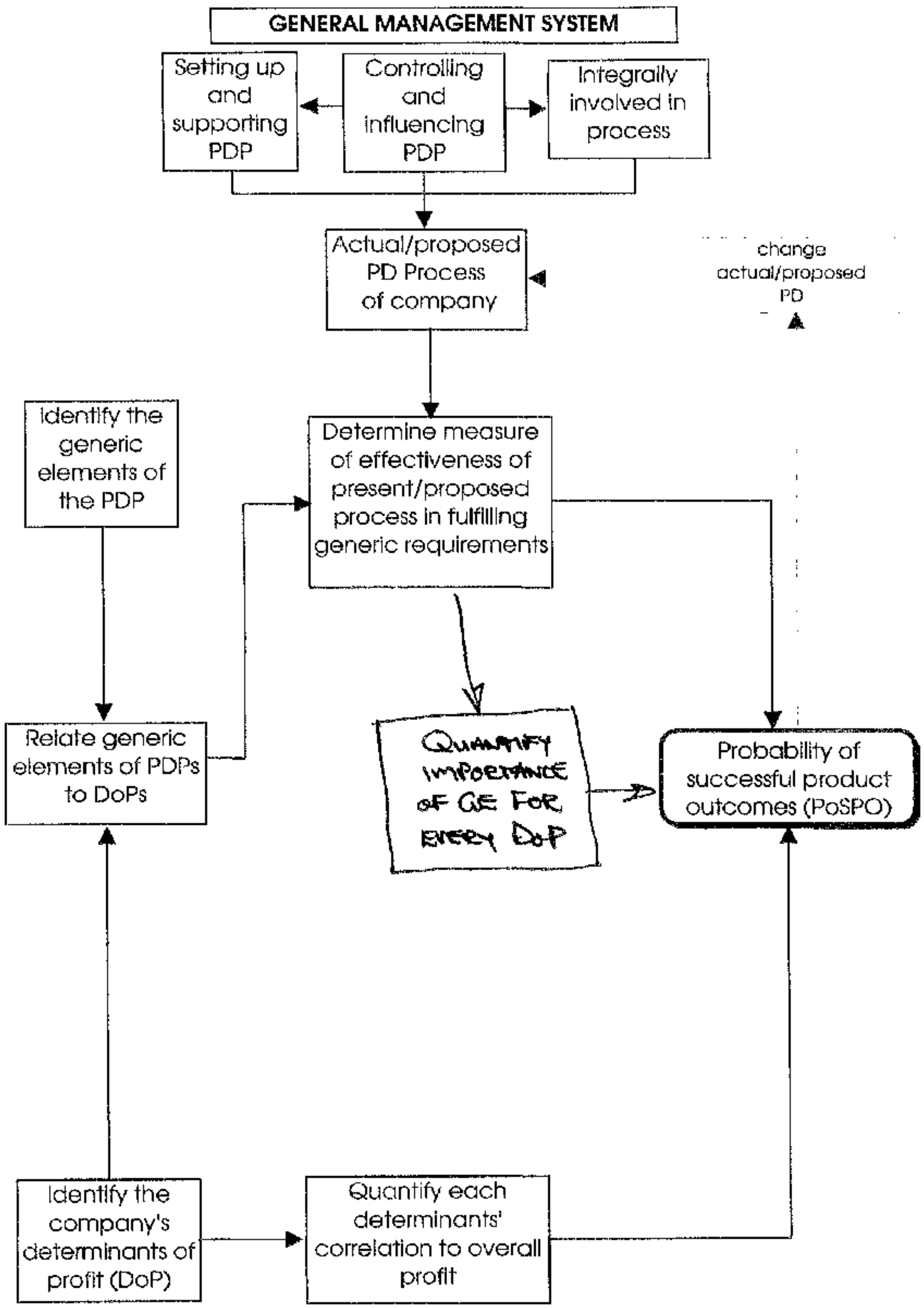


Figure A.10. Evolution of the PDP Evaluation Method: Stage 2

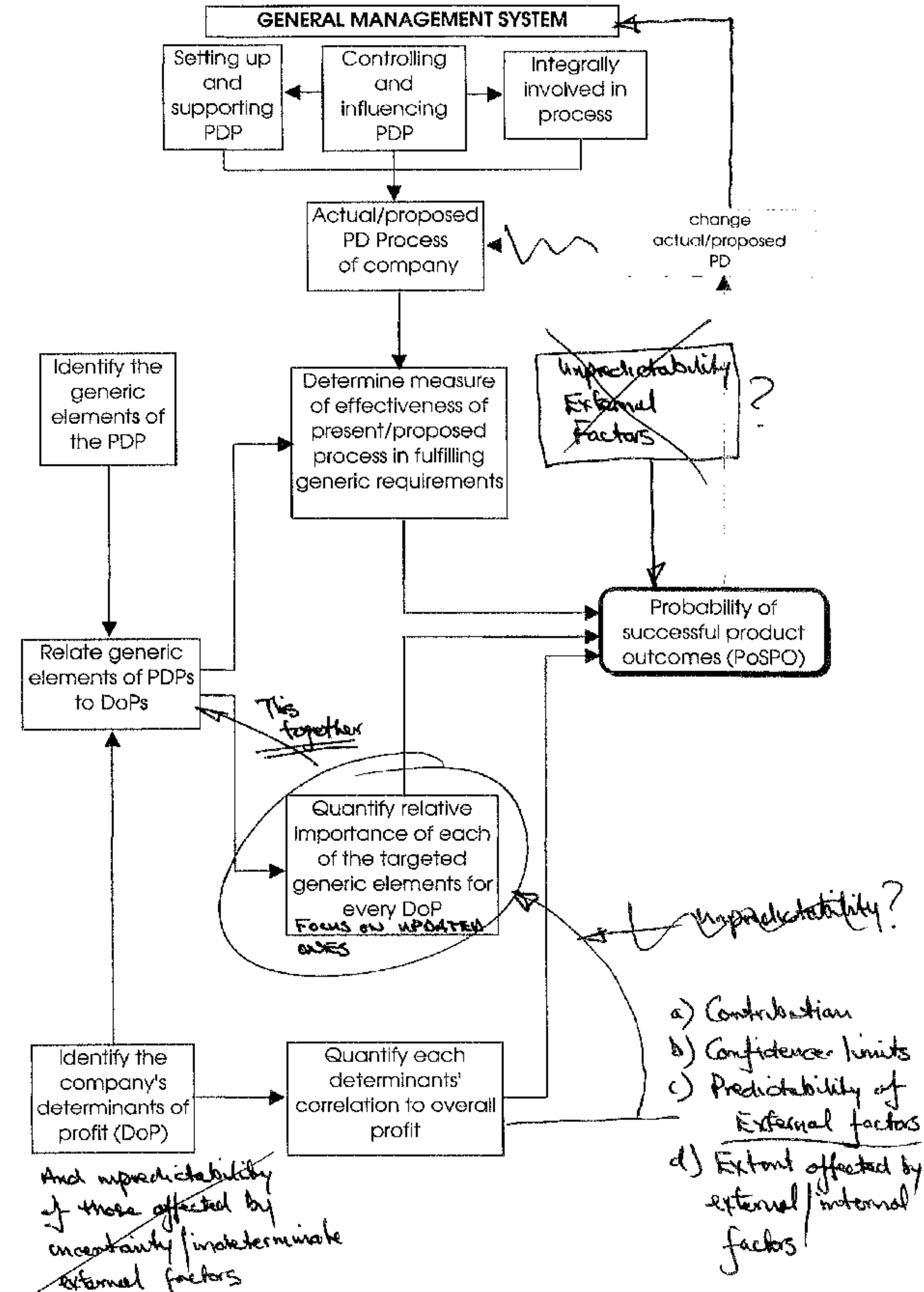


Figure A.11. Evolution of the PDP Evaluation Method: Stage 3

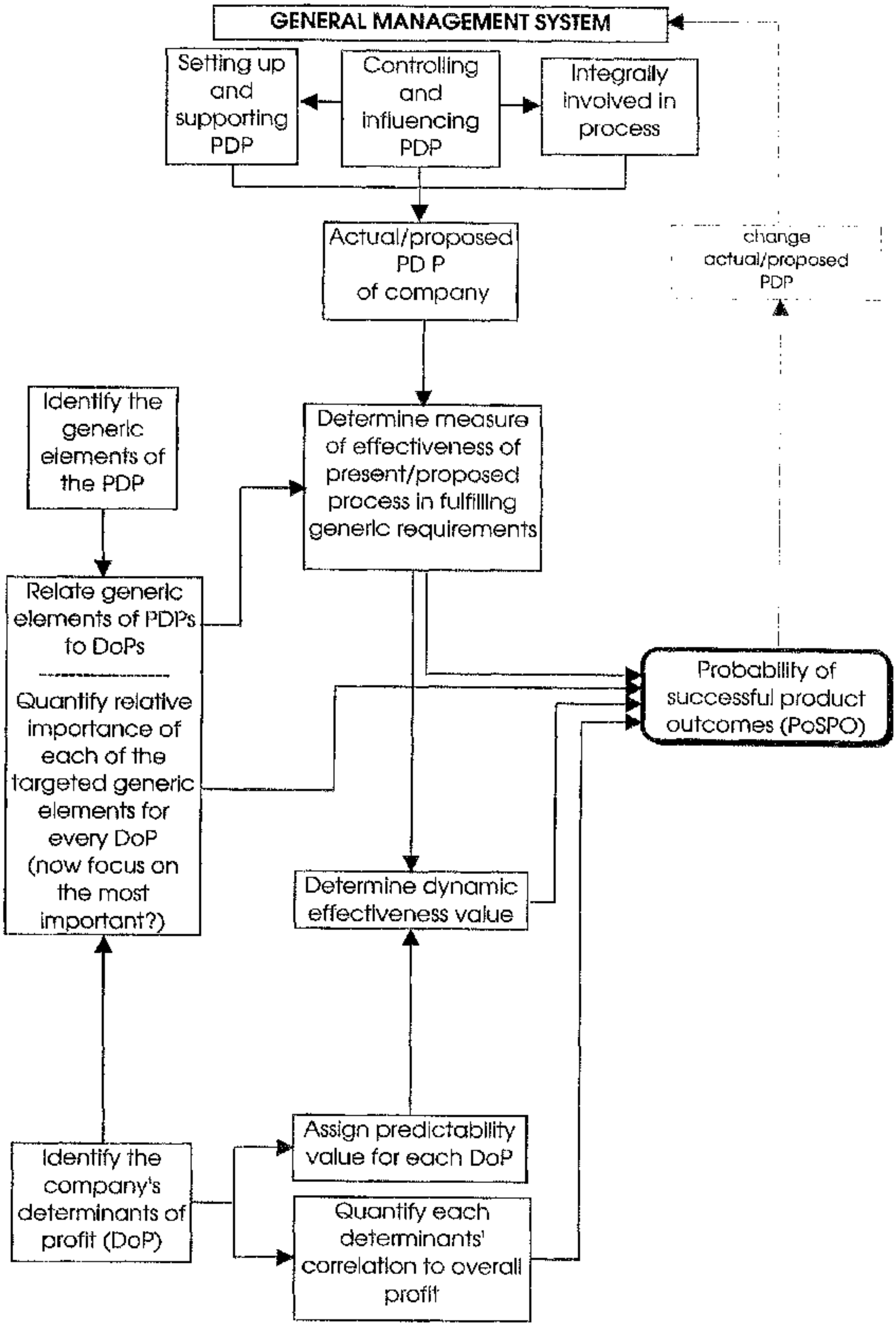


Figure A.12. Evolution of the PDP Evaluation Method: Stage 4

The quantified value 'probability of successful product outcomes' (PoSPO)[1] is now a function of four quantifiers: PDP effectiveness; dynamic effectiveness of the PDP; importance of each GE in relation to each DoP; and, contribution of each DoP to profit.

The fifth stage in the evolution of the method is presented in Figure A.13, and is essentially a rearrangement of the elements of the previous stage. However, the method's interaction with the company's management system and PDP, has been omitted for the sake of brevity. A 'dynamic qualifier' is assigned and dynamic effectiveness is now calculated as part of determining the PoSPO value. Further, PDP activities that correspond to the GEs are identified and their correlation to their parent GE is quantified.

It was felt that at this point the method could be implemented.

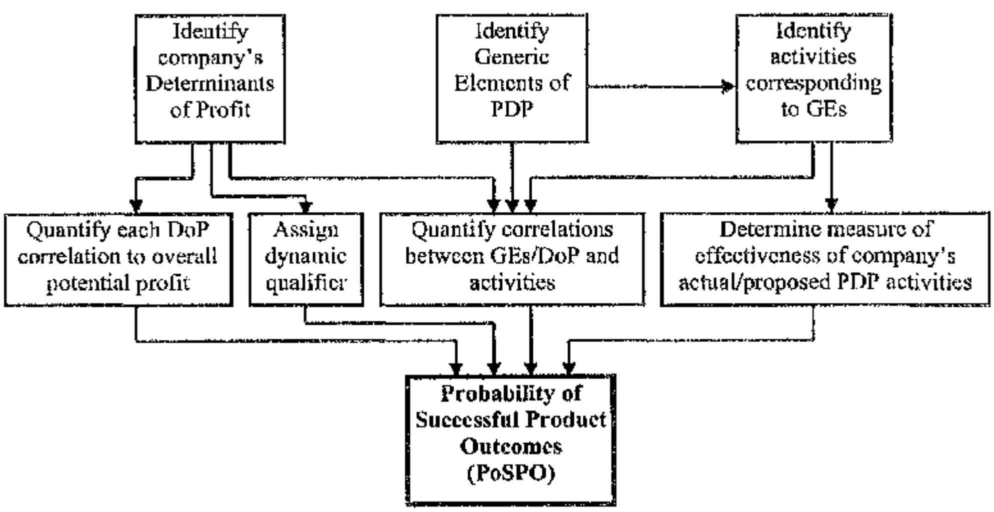


Figure A.13. Implemented PDP Evaluation Method

It can be seen that the method as described in Chapter 3 (Figure 3.2) has evolved further than described here. This evolution occurred during trials of parts of the method designed to address research issues (discussed in Chapters 4 to 8) and implementation of the complete evaluation method (Chapter 9). For example, one consideration that was of some concern was how to represent a process that was able to respond to change rapidly. In the early stages of evolution it was felt that this consideration could be accounted for as a

[1]This was later changed to 'potential for maximising profit' (PMP).

qualifier or factor (hence the dynamic qualifier in Figure A.13). However, with the final method to assess the effectiveness of the process, the time dimension was introduced that accounted for this consideration (see Chapter 7).

Appendix B

Pilot Survey Questionnaire

QUESTIONNAIRE REGARDING

A PRODUCT DEVELOPMENT PROCESS ASSESSMENT METHOD

Objective

The objective of this questionnaire is to determine whether internal company knowledge about products and product development processes can be efficiently "captured" and used within a method that evaluates proposed changes to the process.

We believe that an important element of this knowledge is an understanding of which product and service factors primarily determine the potential for profit (called the "determinants of profit") and the primary "generic elements" of the process that ensures that these factors are optimised for the product.

Who should fill this in?

The person who has the most knowledge and insight into how your company functions, the processes it employs and the products it produces.

Background

This section provides some background information to place the survey questions in context.

For the purposes of this exercise success of product development is measured by profit calculated using the equation:

profit = income from sales - cost of development - cost of supply and support

The profit equation identifies two primary requirements. First to satisfy customer needs so as to maximise selling price and sales, and second to control costs. These two requirements must pervade the whole product development process.

At a more detailed level, for every product there are a number of factors that largely determine the manufacturers profit through their effect on the profit equation e.g. for a household toaster some factors may be number of slices of bread toasted, size, ruggedness, choice of materials, manufacturing methods. These factors are viewed as 'determinants of profit'.

The determinants of profit establish the issues that must be addressed by the product development process. The successful execution of the various activities that constitute the product development process must ensure that these issues are resolved so as to optimise the potential for profit. Thus market research must establish the optimum size of the toaster, the number of slices of bread accommodated, and, in conjunction with detail design and process engineering, the optimum materials.

Amongst the determinants of profit will be those factors deemed to be of importance to the customer. However the determinants must extend beyond this to include every factor that is important to the success of the product and which may be influenced by the product development process. The basis of the proposed assessment method is to estimate how important each factor is to success, and then to evaluate the effectiveness of the product development process in optimising the product in respect to that factor. If important factors are handled effectively then the probability of product success should be high.

For the purpose of evaluation, the activities that constitute the product development process can be classified according to their contribution to a number of abstractions of the process, which are referred to as the generic elements of the process e.g. market research, conceptual design, detail design, procurement, business planning, product promotion.

A. Determinants of Profit

1. Please select a typical product from your company's product range and identify under each heading in the following list some "factors" that you would view as determinants of profit for the product.

   Please grade these "factors" for importance in determining the potential for profit on a scale of 1 (low importance) to 5 (high importance).

   Name of product..

Form of product e.g. colour, shape, etc.

determinant	Grade
....	...
....	...
....	...
....	...
....	...
....	...

Functionality of product e.g. user friendliness, extra features, etc.

determinant	Grade
....	...
....	...
....	...
....	...
....	...
....	...

Performance of product e.g. size, weight, speed, accuracy, etc.

determinant	Grade
....	...
....	...
....	...
....	...
....	...

Customer perception of product e.g. advertising etc.

determinant	Grade
....	...
....	...
....	...
....	...
....	...

Quality

determinant	Grade
....	...
....	...
....	...
....	...
....	...

Safety

determinant	Grade
....	...
....	...
....	...
....	...
....	...

Other (please specify)

	determinant	Grade
....	....	...
....	....	...
....	....	...
....	....	...
....	....	...
....	....	...

2. How easily were you able to do this?

- very easily ☐
- easily ☐
- with some difficulty ☐
- with great difficulty ☐

3. If you did not answer "easily" or "very easily" please attempt to explain the difficulty.
....
....
....
....
....

B. Generic Elements of the Product Development Process

For the product and its determinants of profit that you identified please answer the following questions about generic elements of the product development process;

1. Identify from the following list the generic elements of the product development process which are present in your own company. Please rate on a scale of 1 to 5 how strongly your own activities focus on each generic element.

(1 = low focus 5 = high focus)

- market research ☐
- business development ☐
- support services to product development process ☐
- conceptual design of product ☐
- concept testing and modifications ☐
- detail design of product ☐
- design of product support and documentation ☐
- design of promotion of product ☐
- modifications/change procedures ☐
- management of;
    - time to market ☐
    - change ☐
    - overall cost of development ☐
- manufacturing process planning ☐
- procurement (technical and quality requirements of bought-in components and materials) ☐
- prototype manufacture ☐
- testing and qualification ☐
- Other (please specify)

.... ☐
.... ☐
.... ☐
.... ☐
.... ☐
.... ☐

2. Please indicate how easily were you able to answer question 1.

- very easily ☐
- easily ☐
- with some difficulty ☐
- with great difficulty ☐

3. If you did not answer "easily" or "very easily" please attempt to explain the difficulty.
....
....
....
....
....
....
....
....
....

C. General questions regarding this questionnaire.

1. Approximately how long did it take you to complete this questionnaire?
   ......minutes

2. To what extent do you consider that this questionnaire has allowed you to express your knowledge about your chosen product (regarding determinants of profit and generic elements)?

   - very well ☐
   - well ☐
   - satisfactory ☐
   - poorly ☐
   - very poorly ☐

3. If you are able to do so please make suggestions about improvements that should be made to this questionnaire which would allow you to express your knowledge more effectively.
....
....
....
....
....
....

4. Please include here any other comments that you would like to make regarding this questionnaire.

....
....
....
....
....

D. General questions regarding you and your company

1. Please state your position in the company..

2. Please select the industry sector in which your company resides

High volume consumer products ☐
Low volume consumer products ☐
Capital products ☐
High technology products ☐
Fashion products ☐
High volume industrial products ☐
Low volume industrial products ☐
Other (please specify)

....
....
....

3.Approximate number of personnel in your company.

....

4. Approximate turnover per annum.

....

5. Which of the following statements would best describe your opinion of your company's product development process? (You may select more than one).

Formal ☐
Informal ☐
Mature ☐
New ☐
Structured ☐
Organic ☐
Static ☐
Dynamic ☐
Reactive ☐
Proactive ☐
Efficient ☐

Other (please specify)

....

....

....

....

....

....

....

....

....

6. If you would be willing to assist us with future research or would like to be kept informed of results please fill in your name, your company's name and telephone number. (NOTE: ALL RETURNS WILL BE KEPT CONFIDENTIAL)

Name...
Company name...
Telephone number...............................

Appendix C

<u>**Extensive Survey Questionnaire**</u>

QUESTIONNAIRE REGARDING

A PRODUCT DEVELOPMENT PROCESS ASSESSMENT METHOD

Objective

The objective of this questionnaire is to determine whether internal company knowledge about products and product development processes can be efficiently "captured" and used within a method that evaluates proposed changes to the process.

We believe that an important element of this knowledge is an understanding of which product and service factors primarily determine the potential for profit (called the "determinants of profit") and the primary "generic elements" of the process that ensures that these factors are optimised for the product.

Who should fill this in?

The person who has the most knowledge and insight into how your company functions, the processes it employs and the products it produces.

Background

This section provides some background information to place the survey questions in context.

For the purposes of this exercise success of product development is measured by profit calculated using the equation:

profit = income from sales - cost of development - cost of supply and support

The profit equation identifies two primary requirements. First to satisfy customer needs and establish a competitivie advantage (i.e. create a preference for the product) so as to maximise selling price and sales, and second to control costs. These two requirements must pervade the whole product development process.

At a more detailed level, for every product there are a number of factors that largely determine the manufacturers profit through their effect on the profit equation e.g. for a household toaster some factors may be number of slices of bread toasted, size, ruggedness, choice of materials, manufacturing methods. These factors are viewed as 'determinants of profit'.

The determinants of profit establish the issues that must be addressed by the product development process. The successful execution of the various activities that constitute the product development process must ensure that these issues are resolved so as to optimise the potential for profit. Thus market research must establish the optimum size of the toaster, the number of slices of bread accommodated, and, in conjunction with detail design and process engineering, the optimum materials.

Amongst the determinants of profit will be those factors deemed to be of importance to the customer. However the determinants must extend beyond this to include every factor that is important to the success of the product and which may be influenced by the product development process. The basis of the proposed assessment method is to estimate how important each factor is to success, and then to evaluate the effectiveness of the product development process in optimising the product in respect to that factor. If important factors are handled effectively then the probability of product success should be high.

For the purpose of evaluation, the activities that constitute the product development process can be classified according to their contribution to a number of abstractions of the process, which are referred to as the generic elements of the process e.g. market research, concept development, detail design, procurement, business development, product promotion, etc.

A. Determinants of Profit

1. Please select a typical product from your company's product range and identify "factors that you would view as determinats of profit for the product. The headings in the following list may be used as a guide. (**Note**: you do not have to respond to all of the following, only to those that you feel are relevant.)

   Please grade these "factors" for importance in determining the potential for profit on a scale of 1 (low importance) to 5 (high importance).

   Name of product...

Form of product e.g. colour, shape, finish, style, etc.

determinant	Grade
....	...
....	...
....	...
....	...
....	...
....	...

Functionality of product e.g. user friendliness, extra features, etc.

determinant	Grade
....	...
....	...
....	...
....	...
....	...
....	...

Performance of product e.g. size, weight, speed, accuracy, etc.

determinant	Grade
....	...
....	...
....	...
....	...
....	...

Customer perception of product e.g. fashion item?, necessity?, image?, etc.

determinant	Grade
....	...
....	...
....	...
....	...
....	...

Quality e.g. level of quality, level of reliability, etc.

determinant	Grade
....	...
....	...
....	...
....	...
....	...

Safety

determinant	Grade
....	...
....	...
....	...
....	...
....	...

Operation e.g. level of operational ease, alternate use, etc.

	determinant	Grade
....	....	...
....	....	...
....	....	...
....	....	...
....	....	...
....	....	...

Life costs e.g. finance costs, service costs, running costs, etc.

	determinant	Grade
....	....	...
....	....	...
....	....	...
....	....	...
....	....	...
....	....	...

Other (please specify)

	determinant	Grade
....	....	...
....	....	...
....	....	...
....	....	...
....	....	...
....	....	...

2. How easily were you able to do this?

- very easily ☐
- easily ☐
- with some difficulty ☐
- with great difficulty ☐

3. If you did not answer "easily" or "very easily" please attempt to explain the difficulty.

....
....
....
....
....

B. Generic Elements of the Product Development Process

For the product and its determinants of profit that you identified please answer the following questions about generic elements of the product development process;

1. Identify from the following list the generic elements of the product development process which are present in your own company. Please rate on a scale of 1 to 5 how strongly your own activities focus on each generic element.

   (1 = low focus   5 = high focus)

- market research (determine customer requirements) ☐

- concept generation ☐
- concept evaluaiton ☐
- concept development ☐
- business development ☐
  (market analysis, commercial feasibility, business plans, etc.)
- detail design of product ☐
- perfomrance evaluation (throughout development) ☐
- safety evaluation (throughout development) ☐
- reliability evaluation (throughout development) ☐
- cost evaluaiton of product (throughout development) ☐
- testing and modifications of detail design ☐
- procurement (determine technical and quality requirements of bought-in components and materials, and source these) ☐
- manufacturing process planning ☐
- prototype manufacture ☐
- testing and qualification of prototype ☐
- customer/client trials ☐
- support services to product development process ☐
  (personnel, equipment, information, etc.)
- design of product support and documentation ☐
- design of promotion of product (launch, advertising, etc.) ☐
- management of;
  - time to market ☐
  - change (of product, personnel, process, etc.) ☐
  - overall cost of development ☐
- Other (please specify)

.... ☐
.... ☐
.... ☐
.... ☐

2. Please indicate how easily were you able to answer question 1.

- very easily ☐
- easily ☐
- with some difficulty ☐
- with great difficulty ☐

3. If you did not answer "easily" or "very easily" please attempt to explain the difficulty.
....
....
....
....
....

C. General questions regarding this questionnaire.

1. Approximately how long did it take you to complete this questionnaire?
......minutes

2. To what extent do you consider that this questionnaire has allowed you to express your knowledge about your chosen product (regarding determinants of profit and generic elements)?

- very well ☐
- well ☐
- satisfactory ☐
- poorly ☐
- very poorly ☐

3. If you are able to do so please make suggestions about improvements that should be made to this questionnaire which would allow you to express your knowledge more effectively.
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4. Please include here any other comments that you would like to make regarding this questionnaire.
....
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....

D. General questions regarding you and your company

1. Please state your position in the company……………………………………………

2. Please select the industry sector in which your company resides

High volume consumer products ☐
Low volume consumer products ☐
Capital products ☐
High technology products ☐
Fashion products ☐
High volume industrial products ☐
Low volume industrial products ☐
Other (please specify)
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

3.Approximate number of personnel in your company. …………………………………………

4. Approximate turnover per annum. ……………………………………………………………

5. Which of the following statements would best describe your opinion of your company's product development process? (You may select more than one).

Formal ☐
Informal ☐
Mature ☐
New ☐
Structured ☐
Organic ☐
Static ☐
Dynamic ☐
Reactive ☐
Proactive ☐
Efficient ☐
Other (please specify)
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

6. If you would be willing to assist us with future research or would like to be kept informed of results please fill in your name, your company's name and telephone number. (NOTE: ALL RETURNS WILL BE KEPT CONFIDENTIAL)

Name...................................... Position ....
Company name..
Telephone number................................

Appendix D

Determinants of Profit

Summary of all responses

Please select a typical product from your company's product range and identify under each heading in the following list some "factors" that you would view as determinants of profit for the product.

Please grade these "factors" for importance in determining the potential for profit on a scale of 1 (low importance) to 5 (high importance).

Determinant	Grade
Form of product e.g. colour, shape	
Appearance	5
"	4
"	4
" (robust)	4
" (rugged)	4
" (integrated and well engineered)	4
" (reflect technical quality of product)	3
Shape	5
"	3
"	4
"	4
" (clean)	5
Finish	4
"	3
"	4
Style	4
"	4
" (sexy)	3
Colour	4
"	3
"	1
"	3
Extra features – differentiation	3
Unique features	5
Match competitor's features	5
Comply with standard sizes etc.	5
"	5
Conform to image of product range	2
Functionality of product e.g. user friendliness, extra features	
Room compatibility	3
System compatibility	5
"	5
"	3
"	5
Withstand harsh treatment	5

Handling	3
Rigidity	3
Ease of customisation	4
"	4
"	4
"	5
Upgradability	4
Adaptable to different configurations	4
Easy access	4
Security	5
Interface with user	5
Self adjusting	3
Rugged	5
Robust	3
Wide range of options	4
Versatile	4
"	3
"	4
Alternate uses	5
User friendly software	5
Manuals etc. available in range of languages	2
Comply with standards	5
Extra features – differentiation	4
Compatible with alternatives	5
"	5
Plug and play	5

<u>Performance of product</u> e.g. size, weight, speed, accuracy

Audio sound quality	5
Weight	5
"	3
"	4
"	2
"	4
"	3
"	5
"	5
"	3
"	2
Fuel consumption	4
Thrust growth (i.e. platform for future development)	5
Noise	4
Emissions	4
Filtration efficiency	5
Size	2
"	2
"	5
"	3
"	5
Lifting capacity	5

Speed of lift	5
Accuracy	4
Outperform competitors	5
Smooth operation	5
Fast cycle time	5
"	5
Able to offer required lift capability from a range	5
Good resistance to environment	4
Storage capacity	3
Low power consumption	4
Meets or beats specification	5
Specification exceeds best of competition	4
Meets customer requirements/expectations	5
Accessibility	4
Stability of structure	4
Speed range	4
Pulling capacity	5
Good endurance between replenishment	4
Clarity of display	5
Degree of water tightness	5
High power output	5
"	5
Low speed capability	4
Accuracy	4
Consistency	4
Quiet	3
Small base size	4
Performance / size ratio	4
Guaranteed performance	5
Meet industry standards & statutory requirements	5
"	5
Compatible with alternatives	5
<u>Customer perception</u> of product e.g. advertising	
Luxury system	3
Status symbol	4
Inspire confidence	3
Simplicity	3
Value	5
"	4
Highly rated by experts	5
Reputation of company	4
"	4
Reputation for good field support	5
Reputation of product	4
"	5
Track record	5
"	4
"	5
Environmentally friendly	2

Innovative design	4
Viewed as state of the art	4
Value for money	5
Ease of modification	2
A necessary item	5
"	5
"	4
A necessary item	5
"	5
" (to meet legislation)	4
" (to meet legislation)	5
Differentiate from competition	5
Quality materials and finish	3
"	4
A viable alternative to market leaders	5
<u>Quality</u>	
Reliability	5
"	4
"	5
"	5
"	4
"	5
"	5
"	4
"	5
"	5
"	5
"	5
Satisfy customer requirements	5
"	5
Good MTBF	5
"	4
"	5
Zero defects at installation	5
ISO 9000	2
Finish and appearance	4
"	5
"	4
Low down time and maintenance cost	5
"	5
Maintainability	3
Extensively tested	5
Fit for purpose	5
Good engineering backup	5
Resists wear	5
Resists soiling, vandalism	5
365 day per year availability	5
Low MTTR	5
Low frequency of critical failures	5

High build quality	5
Quality of image produced	5
Resists noise interference	4
<u>Safety</u>	
Comply with regulations	5
"	3
"	2
"	5
"	5
"	5
"	5
"	5
"	5
"	5
"	3
Exceeds national regulations	5
Stability	4
Low fire risk	4
Proven design	3
Good safety record	3
Safety certification	3
COSHH assessment	4
No risk from high voltages	5
"	5
No sharp edges	5
Lockable	4
No accessible parts	5
Explosion proof	4
Safe for under water operation	4
Minimise risk of injury	4
Control acoustic power levels	3
<u>Operation</u>	
Ease of operation	4
"	4
"	5
"	3
"	4
"	4
" (plug and play)	5
Ease of connection	4
Ease of mounting	4
Ease of installation	5
"	4
"	5
"	4
"	4
Ability to replace worn elements	2
Ease of repair and upgrade	4

Easy fault diagnostics and resolution	5
Good operator environment	4
Good operator interface	2
"	4
Ease of transportation	5
Low level of operator training	4
Easily reconfigured	4
Through life support	3
Ease of handling	4
Ease of control	5
Ease of fault diagnosis	4
In-built diagnostic aids	4
Ease of maintenance	5
"	4
"	3
Ease of access for repair/upgrade	5
Parts availability	5
Technical back up	4
"	3
"	5
Good spares availability	5
Withstand all environment conditions	5
Versatility in location	5
<u>Life Costs</u>	
Financing deals	5
Manufacturability	4
Low cost of manufacture / supply	5
"	5
"	5
Good manufacturing process for volume manufacture	5
Low overheads	5
Low development cost	5
Cost of ownership	4
Competitive price	5
"	4
"	5
"	5
"	5
"	5
Good warranty and repair process	3
"	5
Cost of engineering	5
Long service life	4
Durability	4
Low service cost	5
"	3
"	2
"	3
Low downtime	3

Ease of manufacture	4
Ease of assembly	4
Low running cost	3
"	4
"	5
"	3
Low maintenance cost	5
Low requirement for consumables	3
Low financing costs	4

<u>Other</u> (please specify)

Match with many types of equipment	3
Competitive with alternative technologies	5
Simple design	5
Ease of manufacture	5
Basis for follow on products	4
Available on short delivery	4
Effective supplier outlets	5
Credibility in a new market	4
Low environmental impact	5
Good delivery performance	5
Quality & presentation of support documentation	5
Low warranty costs	3

Appendix E

PDP Model Survey Questionnaire

QUESTIONNAIRE REGARDING

PRODUCT DEVELOPMENT PROCESS ACTIVITIES

Thank you for agreeing to fill in this questionnaire. Your experience and insight in the field of product development is invaluable to this research.

Objective

A method is being developed that will allow companies to evaluate their product development processes.

The method relies on addressing actual activities and the efficiency with which companies carry them out. One step in doing this is to understand how companies view their activities.

The objective of this questionnaire is

- To determine whether you can relate to the presented list of product development activities
- To identify any areas of activities that are not adequately represented by these lists.
- To expand the list

Background

For the purpose of this questionnaire a particular view of company operations has been adopted. The model in Figure E.1 represents this view. This high-level control model recognises three product states. vis. approved idea, approved concept and released product (also indicated at the foot of Figure E.3). The 'product programme' contains those approved ideas for which concept designs and project plans will be prepared. The 'project programme' contains approved concepts that will be worked up into products and become part of the 'product range'.

It is recognised that this is not the only view possible and it is appreciated that this may differ from your own experience. However adopting ***a*** view is necessary in order to arrive at a set of product development activities while simultaneously attempting to prevent omissions. This questionnaire will test this approach.

Also according to this view the steps necessary to operate a company are; 1) develop strategy, 2) prepare operational plans, 3) execute operations and 4) control the output of the operations. These steps can be viewed as dimensions of the process as presented in diagrammatic form in Figure E.2.

In Figure E.3 Nodes A223 (Control Product Development), A231 (Provide and Develop Resources) and A233 (Execute Product Development) have been expanded. This expansion creates a set of activities that we refer to as the 'generic elements' of the product development process (PDP). These are a generalised set of activities that together represent the full process irrespective of the type of product. Listed below each generic element is a set of constituent activities.

At the product development level (Figure E.3) 'control' and 'execution' should still be separately visible. 'Control' activities evaluate the outcomes of the 'execution' activities against objectives, and make progress decisions. In Figure E.3 white and dark boxes distinguish 'control' and 'execution' activities respectively.

It should be noted that technology development is not the focus of this survey. Technology development is considered to be a parallel process that provides inputs to product development as necessary.

Definitions of product states and other terms are given.

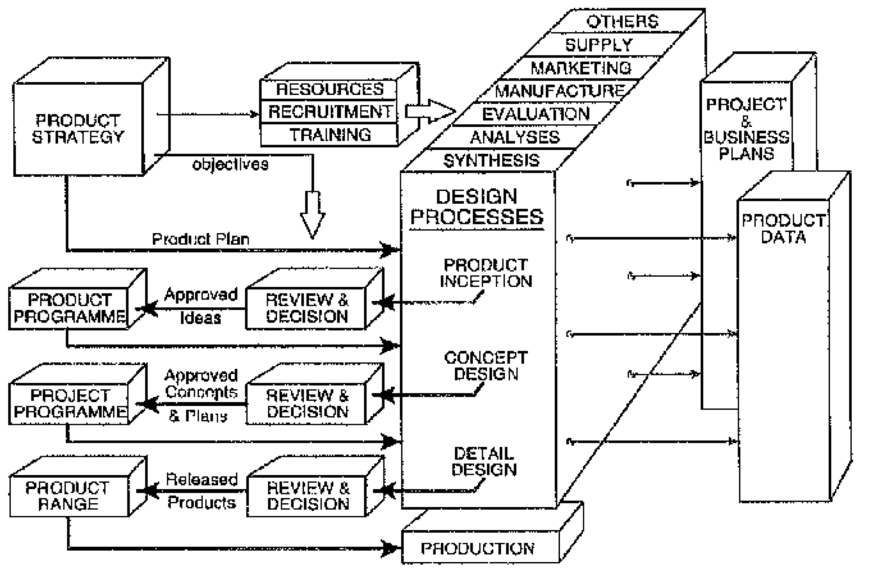


Figure E.1. A Model for the Control of Product Development

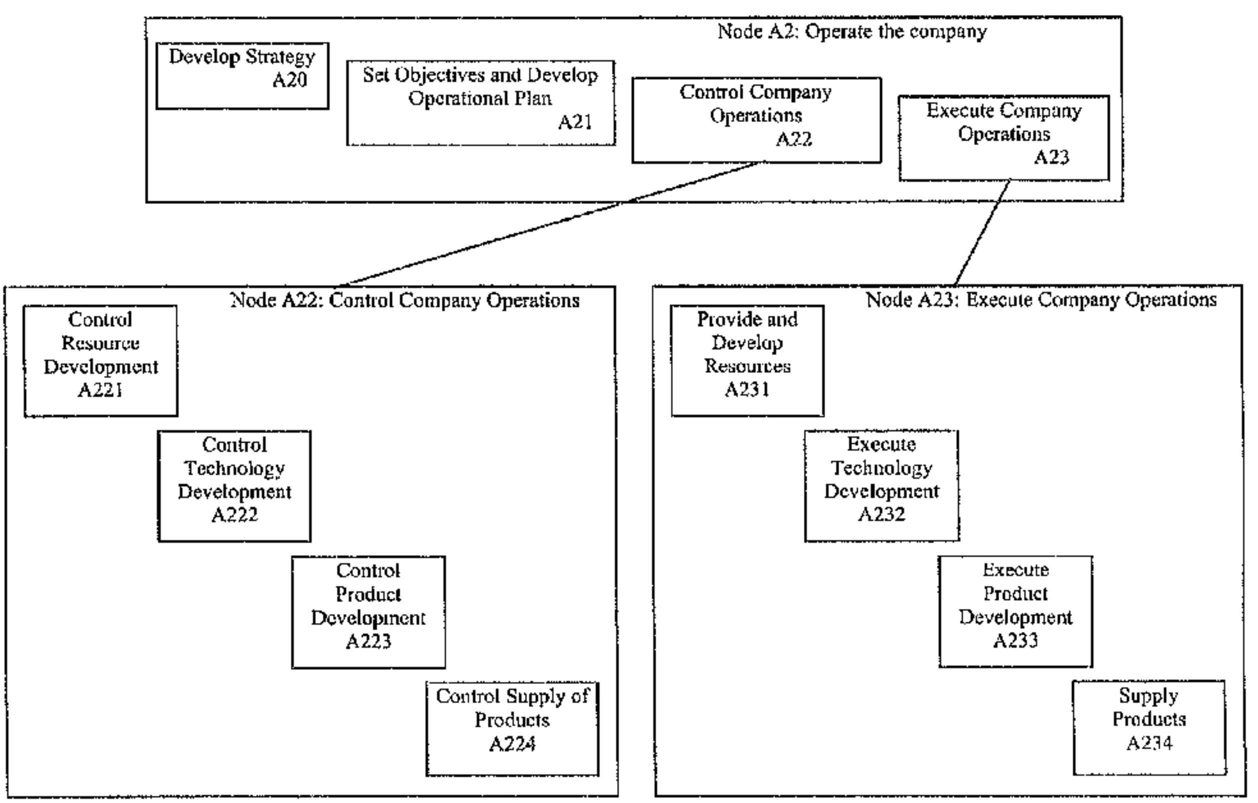


Figure E.2. Nodes A2, A22 and A23

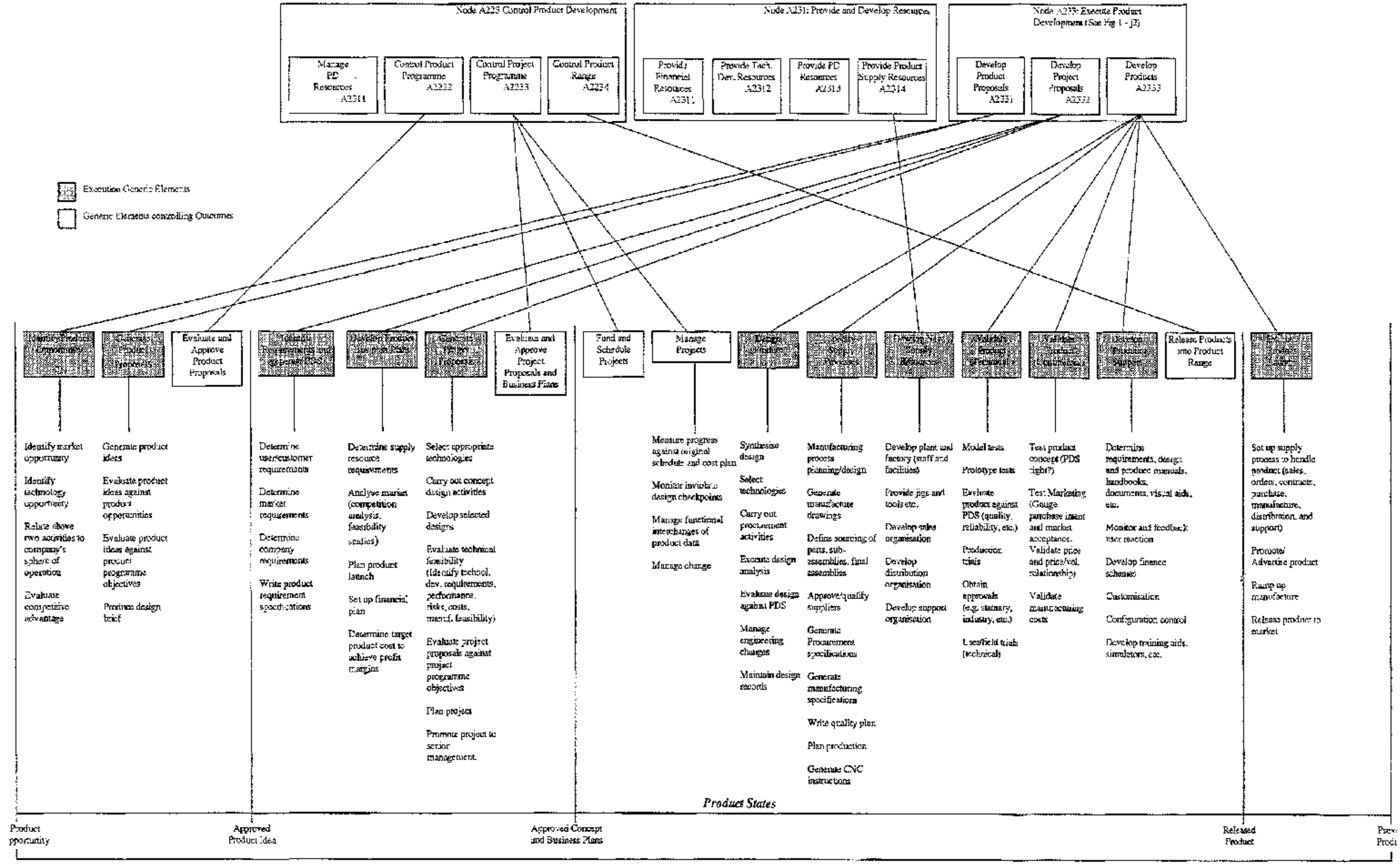


Figure 3: Generic Elements and Activities

Definitions and Abbreviations

Design Analysis:	Design analysis must quantify the functional, strength, deflection and dynamic performance aspects of the product design.
Approved Concept	A product concept has been designed and agreed to meet and Business: the requirements, and business plans have been approved.
Approved Product Idea:	Product ideas have been evaluated and adopted for use as the basis of a product programme
CFD:	Computational Fluid Dynamics
CNC:	Computer Numeric Control
Evaluation:	Evaluation is a continuous process during the embodiment design. The results of the synthesis and analysis are reviewed against the requirement of the Product Design Specification and against good engineering practice to ensure that the design is developing on a sound basis.
FEA:	Finite Element Analysis
FMEA:	Failure Mode Effects Analysis
Generic Elements:	The activities that constitute the product development process can be classified according to their contribution to a number of abstractions of the process, which are referred to as the generic elements of the process e.g. design product, develop product business plans, generate project proposals.
Procurement:	Resolving the technical and quality requirements for material, components and bought out parts, through consultation with suppliers and the purchasing and quality groups of the company.
Product Development Process (PDP):	All those activities necessary to prepare for the realisation of a physical product (new or improved) which can be produced, sold and supported as a commercially viable venture.
PDS:	Product Design Specification
Product Opportunity:	The opportunity to develop a product that the company will be able to market profitably. Such an opportunity requires that: 1. a market need exists. 2. the technological capability

to meet the need exists. 3. the opportunity fits the company's capability and objectives.

Proven Product: The product has achieved a satisfactory service record.

Released Product: The embodiment of the product has been fully defined in terms of its geometry, materials, parts and components. It has been evaluated and shown to satisfy the requirements. The manufacturing process has been fully defined and tested and the product is released into the product range ready for manufacture and for supply to the market.

Synthesis of design: Evolving the description of the product in terms of its geometry, materials and parts.

Questionnaire:

Referring to Figure E.3 please indicate against the following list those activities you think should be executed in a product development process. Indicate on the scale provided the appropriate strength of focus for your company. (0 = no focus, 1 = low focus, 5 = high focus)

Finally, please add to the list any generic elements and activities you think should be included. Activities should be added at the appropriate level in the hierarchy of Figure E.3 For example, FEA, FMEA and CFD are part of 'analysis' and should therefore be listed below 'analysis' and not added as a new generic element.

Other comments are welcome

1. Identify Product Opportunity

Identify market opportunity	0 1 2 3 4 5
Identify technology opportunity	0 1 2 3 4 5
Relate above two activities to company's sphere of operation	0 1 2 3 4 5
Evaluate competitive advantage	0 1 2 3 4 5
Others?	

2. Generate product proposals

Generate product ideas	0 1 2 3 4 5
Evaluate product ideas against product opportunities	0 1 2 3 4 5
Evaluate product ideas against product programme objectives	0 1 2 3 4 5
Produce design brief	0 1 2 3 4 5
Others?	

3. Evaluate and approve product proposals

4. Identify user requirements and generate a Product Design Specification (PDS)

Determine user/customer requirements	0 1 2 3 4 5
Determine market requirements	0 1 2 3 4 5
Determine company requirements	0 1 2 3 4 5
Write product requirement specifications	0 1 2 3 4 5
Others?	

5. Develop product business plans

Determine supply resource requirements	0 1 2 3 4 5
Analyse market (competition analysis, feasibility studies)	0 1 2 3 4 5
Plan product launch	0 1 2 3 4 5
Set up financial plan	0 1 2 3 4 5
Determine product cost to achieve profit margins	0 1 2 3 4 5
Others?	

6. Generate project proposals

Identify technology requirements	0 1 2 3 4 5
Carry out concept design activities	0 1 2 3 4 5
Develop selected designs	0 1 2 3 4 5
Evaluate technical feasibility (Identify technology development requirements, performance, risks, costs, manufacturing feasibility)	0 1 2 3 4 5
Evaluate project proposals against project programme objectives	0 1 2 3 4 5
Plan Project	0 1 2 3 4 5
Promote project to Senior Management	0 1 2 3 4 5
Others?	

7. Evaluate and approve project proposals and business plans

8. Fund and schedule projects

9. Monitor project against objectives

10. Design product

Synthesise design	0 1 2 3 4 5
Select technologies	0 1 2 3 4 5
Carry out procurement activities	0 1 2 3 4 5
Execute design analysis	0 1 2 3 4 5
Evaluate design against Product Design Specification	0 1 2 3 4 5
Manage engineering changes	0 1 2 3 4 5
Maintain design records	0 1 2 3 4 5
Others?	

11. Specify supply processes

Manufacturing process planning and design	0 1 2 3 4 5
Generate manufacturing drawings	0 1 2 3 4 5
Define sourcing of parts, sub-assemblies, final assemblies	0 1 2 3 4 5
Approve/qualify suppliers	0 1 2 3 4 5
Generate procurement specifications	0 1 2 3 4 5
Generate manufacturing specifications	0 1 2 3 4 5
Write quality plan	0 1 2 3 4 5
Plan production	0 1 2 3 4 5
Generate CNC instructions	0 1 2 3 4 5
Others?	

12. Develop new supply resources

Develop plant and factory (staff and facilities)	0 1 2 3 4 5
Provide jigs and tools etc.	0 1 2 3 4 5
Develop sales organisation	0 1 2 3 4 5
Develop distribution organisation	0 1 2 3 4 5
Develop support organisation	0 1 2 3 4 5
Others?	

13. Validate design (technical)

Model tests	0 1 2 3 4 5
Prototype tests	0 1 2 3 4 5
Evaluate product against PDS (quality, reliability, etc.)	0 1 2 3 4 5
Production trials	0 1 2 3 4 5
Obtain approvals (e.g. statuary, industry, etc.)	0 1 2 3 4 5
User/field trials (technical)	0 1 2 3 4 5
Others?	

14. Validate design (commercial)

Test product concept (PDS right?)	0 1 2 3 4 5
Test marketing (Gauge purchase intent and market acceptance. Also validate price and price/volume relationships)	0 1 2 3 4 5
Validate manufacturing costs	0 1 2 3 4 5
Others?	

15. Develop product support

Determine requirements, design and produce documents, visual aids, etc.	0 1 2 3 4 5
Monitor and feedback user reaction	0 1 2 3 4 5
Develop finance schemes	0 1 2 3 4 5
Customisation	0 1 2 3 4 5
Configuration control	0 1 2 3 4 5
Training aids, simulators, etc.	0 1 2 3 4 5
Others?	

16. Release products into product range

17. Launch product

Advertise the product	0 1 2 3 4 5
Promote the product	0 1 2 3 4 5
Ensure support/service availability	0 1 2 3 4 5
Ensure product availability (supplier's online, procurement available, manufacturing ramp-up complete, build up stocks, etc.)	0 1 2 3 4 5
Others?	

18. Other Generic Elements and Constituent Activities?

19. Does this list enable you to represent all your product development activities? Yes/No

If "No" please indicate the deficiencies.

Appendix F

Activity Effectiveness Assessment Questions

Activity characteristics are given in *italics*. Numbers in brackets refer to the Index in Table 7.1.

Solution Quality Effectiveness

Inputs

Product Data
Is the data of high quality? (1)
Is the data made readily available? (1, 2)
Is it used effectively? (1)

Controls

Objectives
Are the objectives well defined? (4)
Are objectives understood by all involved? (4)
Is understanding of objectives tested?

Information
Is the necessary information (e.g. technology, standards, market, materials) made available? (1, 2)
Is the information of high quality? (1)
Is the information utilised effectively? (1)

Execution
Is the performance of the activity and its results formally monitored and reviewed in relation to the objectives? (3)
Does feedback occur, and is the process adjusted as necessary? (3)

Means

Human, financial and time resources
Are the necessary resources provided at the right time? (5)
Are the resources used effectively to execute the activity? (5)

Staff
Do the staff executing this activity have the right expertise, knowledge, experience and motivation? (6)

Facilities and tools
Are the necessary facilities, equipment and software tools available? (5)
Are they used effectively? (5)

Organisation and structure
Does the organisation and structure (e.g. development team composition, senior management support) promote effective execution of the activity? (7)

Resource Consumption Effectiveness

Do you tend to do more than is necessary to meet the product design requirements? (Exceeding the specifications may not be effective use of resources.) (5)
Do you focus on the effective utilisation of available resources? (As opposed to focusing on a fixed delivery date) (5)
Are resource requirements for the activity identified, reviewed and agreed? (5)
Are available resources identified, agreed and allocated? (4, 5)
Do mechanisms exist to match the allocation of resources to the objectives of the activity? Are they used? (5)
Is a resource plan set up that enables a constant resource utilisation level (minimum peaks and troughs)? (5)
Is resource consumption benchmarked? (3, 5)
Is the duration of time available for this activity being used in order to minimise the cost of the activity most effectively (e.g. by resource levelling)? (5, 8)
Do mechanisms exist for identifying and evaluating alternative resources to achieve activity objectives (e.g. sub-contracting, buy-ins, consultants)? Are these mechanisms utilised? (5)
Do mechanisms exist to monitor resource consumption (% progress versus % resource consumed)? Are these mechanisms utilised? (3, 5)
Do mechanisms exist for cost/benefit analysis of increased resource consumption (e.g. increasing resource to reduce time to market)? Are these mechanisms utilised? (3, 5, 8)

Time Effectiveness

<u>Duration</u>

Is a completion date set for this activity? (3, 5, 8)
Are mechanisms used to determine whether the activity objective is achievable within the time allotted? Are they used? (5)
Do you focus on achieving the activity within in the allotted time (as opposed to focussing on resource consumption)? (5, 8)
Do mechanisms exist that allow you to determine whether sufficient resources are available to allow the activity objectives to be realised in the allotted time? Are they used? (5)
Is the time required to perform this activity benchmarked against industry standards, competitors etc.? (3, 5)
Do you try to achieve more than is necessary to meet the product design requirements? Exceeding the specifications may not be effective use of time.
Do mechanisms exist for identifying and evaluating alternative methods/resources to reduce time scale e.g. buy-ins, consultants, multifunctional teams, co-location, computer based tools, concurrency? Are these mechanisms utilised? (5, 8)
Is elapsed time continuously monitored relative to progress? (3)
Is corrective action taken to ensure completion dates are met, whilst keeping added resource consumption to a minimum and still achieving activity objectives? (3)
Is the impact on profit of late/early completion known? I.e. does a model of the impact that time to market has on profit exist? (3, 8)
Do mechanisms exist for cost/benefit analysis of added resource consumption against potential time benefits? Are these utilised? (8)

Timeliness (8)

Is this activity dependent/interdependent on others in terms of input data, information, resources, tools, facilities, etc.? If not, does/will this activity start at the earliest possible date?
If this activity is dependent or interdependent on upstream activities, have upstream activities been identified?
Has the cause of this dependence/interdependence been determined (e.g. information, resources, tools, facilities)?
Is it possible to remove the cause of dependence/interdependence (e.g. more money, more staff, new tools, restructuring, teams) to allow parallel execution?
Is it known (or monitored) at what point in time the upstream activities will permit the start of this activity?
Does/will this activity start immediately the upstream activities permit?
Is the way in which the outputs of the activity will be used considered as a control on this activity?
Can activities that are logically sequential be made to interact and therefore be performed concurrently?
Can assumptions be made about the inputs to the activity that would enable an earlier start?

Appendix G

Activity Effectiveness Assessment Questionnaires

Evaluation of procedures to assess activity effectiveness

Aim

The aim of the experiment is: 1. to attempt to find out how people form opinions about the effectiveness of activities, and 2. test methods for eliciting this information.

Method

Obtain judgements from a company expert using three different questionnaire designs. Each design encapsulates a different method.

Responses are recorded and modifications made to the most suitable method.

Note: These questionnaires are concerned only with 'Solution quality' of an activity . This is assessed in terms of quality of *execution* of the activity.

Background

Activity characteristics can be identified using the IDEF0 scheme by grouping them under; inputs, controls and means.

- Inputs are product related 'data' (i.e. information, objects, etc.) on which the activity acts. Inputs are converted or transformed by the activity. Thus the input must be WHAT is being transformed. IDEF0 was developed for manufacturing activities. The thing that was being changed i.e. on which the activity was acting, was raw material. For design the 'thing' that is being acted on by the activity is the product state i.e. the form the product as defined by the product data finds itself at any point in time. The function of an activity is to progress the state of the product.

- Controls describe the conditions or circumstances that govern the activity. According to the IDEF0 documentation (Softech 1981), controls shows WHY the activity is being executed. However for the purposes of this test it could also be interpreted as; in what way the activity is being executed, when, or to what standards, etc. For example, the PDS is an important control document.

  The question of whether a drawing, for example, is an input or a control may be asked. If the product under development is a car, say, a drawing may serve as an input or control. Should the drawing represent the state of the car at that point in time and it is this drawing that will be changed by the activity, then it is the input to the activity. However should the drawing merely be providing information (as an interface control document, for example) then it is not an input but a control.

- Means are persons, tools, data, devices etc. that are necessary to carry out the activity. They provide the means and determine HOW (using what methods, resources, etc.) the activity will be executed.

The activities used for this test are those under the generic element 'Design product' . They are listed below:

Please change these activities in order to be more relevant to your process.

- Synthesise design - Evolving the description of the product in terms of its geometry, materials and parts.
- Select technologies
- Carry out procurement activities - Resolve technical and quality requirements for material, components and bought out parts, through consultation with suppliers and the purchasing and quality groups of the company.
- Execute design analysis (Software tests (FEA, CFD, etc.)
- Evaluate design against product design specification (PDS) - A continuous process during the embodiment design. The results of the synthesis and analysis are reviewed against the requirement of the Product Design Specification and against good engineering practice to ensure that the design is developing on a sound basis.
- Manage engineering changes (to the product)
- Maintain design records

Questionnaire 1:

What degree of focus does your PDP give to the following activities. Use the following scale ***(wording to be clarified with the respondent)***:

na. Not applicable to our product or PDP
0. Do not execute this activity at all
1. Some efforts are made towards executing the activity
2. We have the process in place to execute the activity, but it is not always used
3. The appropriate methods are used to execute the activity
4. Performance is monitored and continuous improvement is underway

• Synthesise design - Evolving the description of the product in terms of its geometry, materials and parts.	na 0 1 2 3 4
• Select technologies	na 0 1 2 3 4
• Carry out procurement activities - Resolve technical and quality requirements for material, components and bought out parts, through consultation with suppliers and the purchasing and quality groups of the company.	na 0 1 2 3 4
• Execute design analysis (Software tests (FEA, CFD, etc.)	na 0 1 2 3 4
• Evaluate design against product design specification (PDS) - A continuous process during the embodiment design. The results of the synthesis and analysis are reviewed against the requirement of the Product Design Specification and against good engineering practice to ensure that the design is developing on a sound basis.	na 0 1 2 3 4
• Manage engineering changes	na 0 1 2 3 4
• Maintain design records	na 0 1 2 3 4

Questionnaire 2:

Consider the following questions and use your responses to make to help make a judgement about the effectiveness of each characteristic of each activity in turn.

Note: 1. The purpose of the questionnaire is to set the scene and address the issues with questions. Once the issues are in your mind attempt to avoid if possible rereading the questions for every activity .

2. The scale immediately to the right of *headings in italics* are for you to make a 'gut feel' judgement prior to answering the questions. Obviously as you progress through the questionnaire your 'gut feel' will reflect the influence of the questions on your judgement. Thus your 'gut feel' judgements and the assessed judgements at the end of each set of questions should differ less and less (if they ever differed in the beginning).

Activity:______________________________

Inputs

• ***Product data*** (Gut feel judgement: Low L/M Medium M/H High 0 1 2 3 4 5 6 7 8 9 10)

Is the required product data input available?
Is the data easily accessible?
Are procedures for gaining access to this data monitored and reviewed?
Are changes made to these procedures as necessary?
Is the data of a high quality in terms of representing the state of the product? Has it been agreed? Has it been tested?
Is the data utilised to effectively realise the objectives of the activity?
Is the data reviewed?

Effectiveness of inputs: Low L/M Medium M/H High 0 1 2 3 4 5 6 7 8 9 10

Controls

• ***Objectives*** (Low L/M Med M/H High 0 1 2 3 4 5 6 7 8 9 10)

Are activity objectives defined?
Are activity objectives clearly communicated to all involved?
Is understanding of activity objectives checked?
Are activity objectives reviewed?
Are changes to objectives communicated to all involved in the execution of the activity and other related parties?

Effective use of objectives: Low L/M Medium M/H High 0 1 2 3 4 5 6 7 8 9 10

• ***Information*** (Low L/M Med M/H High 0 1 2 3 4 5 6 7 8 9 10)

Is information for realising activity objectives available?
Is information necessary for effectively realising the activity objectives (e.g. design methods, new technology, markets, suppliers, etc.) easily accessible?
Are procedures for gaining access to this information monitored and reviewed?
Are changes made to these procedures as necessary?
Is the quality of the information such that it enables the effective realisation of the activity objectives?
Is this information utilised to effectively realise the objectives of the activity?
Is the information reviewed?
Are learned lessons recorded and disseminated?

Effective use of information: Low L/M Medium M/H High 0 1 2 3 4 5 6 7 8 9 10

• ***Execution*** (Low L/M Med M/H High 0 1 2 3 4 5 6 7 8 9 10)

Is performance formally monitored in relation to time/cost/quality objectives?
Are targets set?
Does bench marking occur?
Are criteria set?
Are activity results formally evaluated and reviewed?
Are reviews taking place?
Does feedback occur?
Is the process adjusted as necessary?

Effectiveness of execution: Low L/M Medium M/H High 0 1 2 3 4 5 6 7 8 9 10

<u>Means</u>

• ***Human, financial and time resources*** (Low L/M Med M/H High 0 1 2 3 4 5 6 7 8 9 10)

Have resource requirements been estimated?
Are they met?
Are they reviewed?
Are resources/schedules modified?

Adequacy of resources: Low L/M Medium M/H High 0 1 2 3 4 5 6 7 8 9 10

• ***Staff*** (Low L/M Med M/H High 0 1 2 3 4 5 6 7 8 9 10)

Are the requirements for expertise, knowledge and experience of staff (in terms of quality of execution) monitored and reviewed?
Do staff have the expertise, knowledge and experience to effectively execute the activity?
Are training requirements identified?
Is the motivation of staff given specific attention?

Effectiveness of staff: Low L/M Medium M/H High 0 1 2 3 4 5 6 7 8 9 10

• ***Facilities and tools*** (Low L/M Med M/H High 0 1 2 3 4 5 6 7 8 9 10)

Are facilities and tools for realising activity objectives available?
Are facilities and tools necessary for the effectively realising the activity objectives easily accessible?
Are procedures for gaining access to these facilities and tools monitored and reviewed?
Are changes made to these procedures as necessary?
Is the quality of the facilities and tools such that they enable the effective realisation (in terms of quality of execution) of the activity objectives?
Are the requirements of the facilities and tools monitored and reviewed?
Are the facilities and tools utilised to effectively realise (in terms of quality of execution) the objectives of the activity?
Is the utilisation of facilities and tools monitored and reviewed?
Are changes to facilities and tools made as needed to effectively realise the activity objectives?
Is the available technology reviewed regularly?

Quality of facilities and tools Low L/M Med M/H High 0 1 2 3 4 5 6 7 8 9 10

• ***Organisation and structure*** (Low L/M Med M/H High 0 1 2 3 4 5 6 7 8 9 10)

Does the organisation and structure facilitate the effective realisation of activity of objectives?

Effectiveness of organisation and structure: Low L/M Medium M/H High 0 1 2 3 4 5 6 7 8 9 10

Questionnaire 3:

Please respond to the statements below using the following:

Frequency of action:	na = not applicable	N = never	S = sometimes	M = mostly	A = always
Manner of action:	F = formal	I = informal			

Having done this use your responses to make a judgement against each characteristic in terms of effectiveness.

	Desired	Actual
<u>Inputs</u>		
• *Product data* (Low L/M Med M/H High)		
The required product data input is available	na N S M A F I	na N S M A F I
Data is easily accessible	na N S M A F I	na N S M A F I
Procedures for gaining access to the data are monitored and reviewed	na N S M A F I	na N S M A F I
Changes are made to these procedures as necessary	na N S M A F I	na N S M A F I
Data is of high quality in terms of representing the state of the product	na N S M A	na N S M A
Data is utilised to effectively realise the objectives of the activity - it has been agreed and tested.	na N S M A F I	na N S M A F I
Data is reviewed	na N S M A F I	na N S M A F I
<u>Controls</u>		
• *Objectives* (Low L/M Med M/H High)		
Activity objectives are defined	na N S M A F I	na N S M A F I
Activity objectives are clearly communicated	na N S M A F I	na N S M A F I
Understanding of activity objectives is checked	na N S M A F I	na N S M A F I
Activity objectives are reviewed	na N S M A F I	na N S M A F I
Changes to objectives are communicated to all involved in execution of the activity and other related parties	na N S M A F I	na N S M A F I

	Desired	Actual
• *Information* (Low L/M Med M/H High)		
Information for realising activity objectives is available	na N S M A F I	na N S M A F I
Information necessary for effectively realising the activity objectives (e.g. design methods, new technology, markets, suppliers, etc.) is easily accessible	na N S M A F I	na N S M A F I
Procedures for gaining access to this information are monitored and reviewed	na N S M A F I	na N S M A F I
Changes are made to these procedures as necessary	na N S M A F I	na N S M A F I
The quality of the information is such that it enables the effective realisation of the activity objectives	na N S M A	na N S M A
This information is utilised to effectively realise the objectives of the activity	na N S M A F I	na N S M A F I
The is information reviewed	na N S M A F I	na N S M A F I
Learned lessons are recorded and disseminated	na N S M A F I	na N S M A F I
• *Execution* (Low L/M Med M/H High)		
Performance is monitored in relation to time/cost/quality objectives	na N S M A F I	na N S M A F I
Targets are set	na N S M A F I	na N S M A F I
Bench marking occurs	na N S M A F I	na N S M A F I
Performance criteria are set	na N S M A F I	na N S M A F I
Activity results are evaluated and reviewed	na N S M A F I	na N S M A F I
Reviews take place	na N S M A F I	na N S M A F I
Feedback occurs	na N S M A F I	na N S M A F I
The process is adjusted as necessary	na N S M A F I	na N S M A F I

	Desired	Actual
<u>Means</u>		
• *Human, financial and time resources* (Low L/M Med M/H High)		
Resource requirements are estimated	na N S M A F I	na N S M A F I
Resource requirements are met?	na N S M A F I	na N S M A F I
Resource requirements are reviewed?	na N S M A F I	na N S M A F I
Resources/schedules are modified?	na N S M A F I	na N S M A F I
• *Staff* (Low L/M Med M/H High)		
Requirements for expertise, knowledge and experience of staff (in terms of quality of execution) are monitored and reviewed	na N S M A F I	na N S M A F I
Staff have the expertise, knowledge and experience to effectively execute the activity	na N S M A F I	na N S M A F I
Training requirements are identified	na N S M A F I	na N S M A F I
The motivation of staff is given specific attention	na N S M A F I	na N S M A F I

	Desired	Actual
• *Facilities and tools* (Low L/M Med M/H High)		
Facilities and tools for realising activity objectives are available	na N S M A F I	na N S M A F I
Facilities and tools necessary for the effectively realising the activity objectives are easily accessible	na N S M A F I	na N S M A F I
Procedures for gaining access to these facilities and tools are monitored and reviewed	na N S M A F I	na N S M A F I
Changes are made to these procedures as necessary	na N S M A F I	na N S M A F I
The quality of the facilities and tools are such that they enable the effective realisation (in terms of quality of execution) of the activity objectives	na N S M A	na N S M A
The requirements of the facilities and tools are monitored and reviewed	na N S M A F I	na N S M A F I
The facilities and tools are utilised to effectively realise (in terms of quality of execution) the objectives of the activity	na N S M A F I	na N S M A F I
The utilisation of facilities and tools is monitored and reviewed	na N S M A F I	na N S M A F I
Changes to facilities and tools are made as needed to effectively realise the activity objectives	na N S M A F I	na N S M A F I
The available technology is reviewed regularly?	na N S M A F I	na N S M A F I
• *Organisation and structure* (Low L/M Med M/H High)		
The organisation and structure facilitates the effective realisation of activity objectives	na N S M A F I	na N S M A F I

Comments

1. Have the questionnaires helped you make an informed judgement of the effectiveness of the activities?

2. If you answered NO please state why.

3. Did you find the classification of characteristics under inputs/controls/means useful?

4. Did you find that you were able to respond to the questions without needing clarification or wanting to engage in discussion as the meaning of the questions.

5. Which of the three questionnaires is better at helping you to arrive at your judgements?

6. In what way could the questions be improved? Different phrasing? Any omissions?

7. Is there any significant difference between the judgements of questionnaire 1. versus 2/3? Do you feel that this warrants using the more extensive questionnaires?

8. Do you think that these methods (with their questions - attached) could be used to assess process cost and process time dimensions of the activities? [- give a short background explanation]. If the answer is NO, how would you go about it?

Cost

For 'cost' DoPs correlated GEs and their constituent activities are evaluated with the focus on 'cost effectiveness'.

Inputs

- *Cost objectives* (Are they formally defined? Are they formally reviewed? Are they clearly communicated? Is understanding of objectives checked? Are staff aware of the implications of overspending – profit/loss?)
- *Information* (Is the right information made available for cost effective solutions? Is the information utilised in a cost effective manner? Is the information reviewed? Are changes to information recorded?)

Means

- *Staff* (Are they properly trained? Do they have the correct technical knowledge? Are they motivated to provide cost effective solutions? Do they have quick and easy access to all relevant information?)
- *Facilities and tools* (Are the right facilities and tools for cost effective solutions made available? Are they utilised optimally and used effectively? Is their use monitored and reviewed in terms of cost?)
- *Human, financial, time resources* (Is sufficient staff, time and finance allocated to realise product objective in the most cost effective manner? Are there formal review mechanisms?)
- *Organisation and structure* (Are effective systems in place to allow cost effective communication - concurrency? Are locations structured to facilitate cost effective communication? Are the right people co-located? Is cost effectiveness of communication assessed and monitored? Are changes made to improve cost effectiveness of communication?)

Controls

- *Cost performance* (What is the most cost effective method of performing this activity – self, buy-in, consultants, etc.? Are cost performance targets set? Are estimates prepared and reviewed? Is cost effectiveness formally monitored? Does cost performance benchmarking occur? Are criteria set? Are results formally evaluated and reviewed? Does feedback occur? Is the process adjusted as necessary?)

Time

For 'time' DoPs correlated GEs and their constituent activities are evaluated with the focus on 'time effectiveness'.

Inputs

- *Schedule objectives* (Are they formally defined? Are they formally reviewed? Are they clearly communicated? Is understanding of objectives checked? Are staff aware of the implications of schedule slippage - profit window, economic model?)
- *Information* (Is the right information made available to realise solutions quickly and effectively? Is the information utilised in a time effective manner? Is the information reviewed? Are changes to information recorded?)

Means

- *Staff* (Are they properly trained? Do they have the correct technical knowledge? Are they motivated? Do they have quick and easy access to all relevant information? Is staff made aware of Concurrent Engineering principles)
- *Facilities and tools* (Are the right facilities and tools made available? Are they utilised optimally and used effectively with regard to time? Is their use monitored and reviewed? Do these tool and facilities allow maximum concurrent execution of activities?)
- *Human, financial and time resources* (Is sufficient staff allocated to meet schedule? Is sufficient time allocated to staff? – number of projects for each member. Is sufficient finance made available? Are there formal review mechanisms? Can increases in resource levels be achieved quickly?)
- *Organisation and structure* (Are effective systems in place to allow fast and effective communication - concurrency? Are locations structured to facilitate fast and effective communication? Are the right people co-located? Is communication with senior management fast and effective? Is speed and effectiveness of communication assessed and monitored? Are changes made to improve speed and effectiveness of communication?)

Controls

- *Time performance* (What is the fastest method of performing this activity – self, buy-in, consultants, etc.? Are time performance targets set? Is schedule performance formally monitored? Is time effectiveness formally monitored? Does time performance benchmarking occur? Are criteria set? Are results formally evaluated and reviewed? Does feedback occur? Is the process adjusted as necessary?)

Appendix H

Derivation of Function for Degree of Impact (DI_t)

of DoP Interaction

The subject DoP to profit correlation factor, w_j, is modified according to the accumulated effect of all DoP in an interacting set. A function is sought that permits a consistent application of each DI_{ij} (the degree of impact of the ith. interacting DoP on the jth. subject DoP) such that the total cumulative effect, DI_{tj}, will not be less than 0 or greater than 1.0.

Two possibilities exist for consistent sequential application of DI_{ij} values, i.e. summation or product of all DI_{ij}. Summing DI_{ij} creates a possibility where DI_{tj} can be greater than unity, which yields a negative value for w'_j. Clearly this is illogical and summation is therefore rejected. Using some function that includes a product of all DI_{ij} values precludes the scenario (i.e. $w'_j < 0$) as the product of all $DI_{ij} \leq 1$.

The accumulated effect is obtained by applying each successive degree of impact of an interacting DoP, DI_{ij}, to the progressively reducing difference between the accumulating DI_{tj} and its maximum value of 1.0. Thus the accumulated total DI_{tj} becomes asymptotic to its maximum value of 1.0.

From Figure A8.1 it can be seen that,

for i = 1: $DI_{tj} = DI_{1j}$
for i = 2: $DI_{tj} = DI_{1j} + DI_{2j}(1 - DI_{1j})$
for i = 3: $DI_{tj} = DI_{1j} + DI_{2j}(1 - DI_{1j}) + D_{3j}(1 - (DI_{1j} + DI_{2j}(1 - DI_{1j})))$
for i = 4: $DI_{tj} = DI_{1j} + DI_{2j}(1 - DI_{1j}) + D_{3j}(1 - (DI_{1j} + DI_{2j}(1 - DI_{1j})))$
$+ DI_{4j}(1 - (DI_{1j} + DI_{2j}(1 - DI_{1j}) + D_{3j}(1 - (DI_{1j} + DI_{2j}(1 - DI_{1j}))))$

The above can be expressed generally as follows:

$$DI_{tj} = 1.0 - \prod_{i=1}^{n}\left(1.0 - DI_{ij}\right)$$

Where n is the total number of interacting DoP.

<u>Test</u>

It can be shown that for 3 interacting DoP (i.e. i = 3) using the above function and Figure A8.1 yields in both instances;

$$DI_{tj} = DI_{1j} + DI_{2j} + DI_{3j} + DI_{1j}DI_{2j}DI_{3j} - DI_{1j}DI_{2j} - DI_{1j}DI_{3j} - DI_{2j}DI_{3j}$$

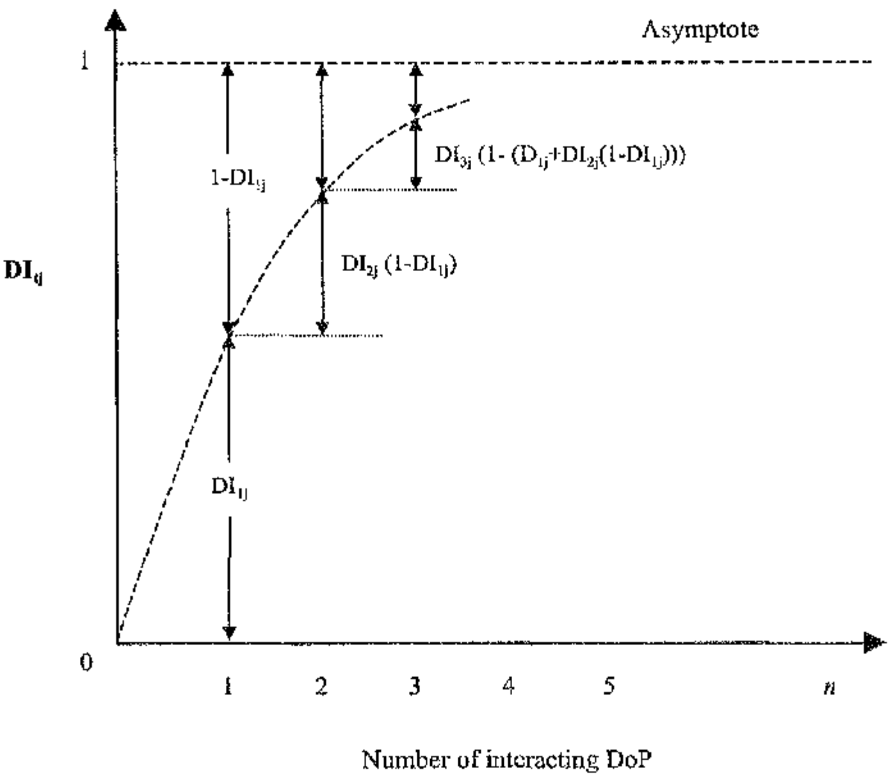


Figure A8.1. Function for DI_{ij}

To account for the more general case where an expert may wish to retain some benefit to profit from the jth. subject DoP when all interacting DoP act to negate any benefit (i.e. all $DI_{ij} = 1.0$), the retained benefit value, $SImax_j$, becomes the asymptote. It is logical that the effect of a single interacting DoP should not be diminished when SImax is taken into account. It is thus necessary to divide DI_{ij} by $SImax_j$ to counter the factoring effect of adjusting the asymptote to $SImax_j$. The function is therefore:

$$DIt_j = SImax_j\left(1.0 - \prod_{i=1}^{n}\left(1.0 - \frac{DI_{ij}}{SImax_j}\right)\right)$$

<u>Example</u>

Assume that for a single interacting DoP:

$SImax_j = 0.8$, $SI_{1j} = 0.8$ (because $SI_{ij} \leq SImax_j$), and $\eta_{1j} = 0$,

then $\quad DI_{1j} = SI_{1j} - \eta_{1j}$
$\qquad\qquad = 0.8$

therefore $\quad DI_{tj} = SImax_j\,[1 - (1 - DI_{1j}/SImax_j)]$
$\qquad\qquad = 0.8\,[1 - (1 - 0.8/0.8)]$
$\qquad\qquad = 0.8$

$DI_{tj} = DI_{1j} = 0.8$ as expected. In the case where no countering of asymptote adjustment occurs, DI_{tj} would be 0.64.

Appendix I

Note: In an attempt to limit the number of pages in the thesis, diagrams and questionnaires included elsewhere in the thesis have not been included in this appendix (although their location is indicated). Further, only one example of the record sheets for each of: solution quality effectiveness, resource consumption effectiveness and time effectiveness, has been included here. Finally, only a single example of the questionnaire used to record comments at the end of each section has been included (see page I-10).

Self-Assessment Method
for Evaluation of the Product Development Process

CONTENTS

1. TEST OBJECTIVES

The overall objective of this exercise is to test the prototype tool to evaluate a company's product development process.

Specific objectives include:

1. Assess the three effectiveness dimension (solution quality/resource consumption/time) approach.
2. Test and validate resource consumption/time effectiveness assessment methods.
3. Determine a procedure of assessing activity effectiveness. Are respondents more comfortable assessing effectiveness of one GE for all DoP or assessing effectiveness of all GEs relative to one DoP? (i.e. moving down or across the table)
4. Assess the possibility of executing a single pair-wise comparison of the GEs for each dimension as opposed to applying it for every DoP.
5. Assess the DoP interaction approach. Are respondents comfortable with this approach? What changes can be made in terms of eliciting judgements? Should fuzzy linguistic variables be included?
6. Determine the time taken to complete the assessment. Particular attention should be paid to the activity effectiveness response times. Do these diminish with familiarity?
7. Determine the role of education and experience of underlying approaches (of the respondent) in the tool's application

2. COMPANY DATA AND DOP

Test date:

Company:

Contact person:

Product:

Determinants of Profit (from questionnaire if applicable)

3. **TOOL FLOW DIAGRAM (Discuss)**

4. **GE/ACTIVITY MODEL (Discuss)**

5. **TESTS**

5.1 List of generic elements (GE) and activities of the product development process (PDP)

For each of the following activities make a 'gut feel' judgement of effectiveness for your product development process. Any scale may be used.

1. Identify Product opportunity

Identify market opportunity *(includes: Identifying market need)*
Identify technology opportunity
Relate above two activities to company's sphere of operation
Evaluate competitive advantage *(includes: Test market need and pricing; Define optimum timing for maximum profitability - lead time implications, etc.)*

2. Generate product proposals

Generate product ideas *(includes: Sourcing of new product ideas such as government laboratories, universities, competitors, consumers, employees, etc.)*
Evaluate product ideas relative to product opportunities *(includes: Screening of ideas; Identify likely delivery timing vs. optimal timing in terms of market opportunity)*
Evaluate product ideas against product programme objectives
Produce design brief

3. Evaluate and Approve Product Proposals

4. Identify requirements and generate Product Development Specification (PDS)

Determine user/customer requirements
Determine market requirements
Determine company requirements
Write product requirement specifications

5. Develop product business plans

Determine supply resource requirements
Analyse market *(includes: Competition analysis; Feasibility studies - commercial risk, opportunity cost of capital, time value of money, analyse product life and life cycle)*
Plan product launch *(includes: Compile marketing plan – Strengths/Weaknesses/Opportunities/Threats; determine time of launch; determine marketing mix – product/price/place/promotion; define marketing objectives – short/medium/long; plan promotion; plan response monitoring)*

Set up financial plan *(includes: sales forecast; cash flow of development forecast; Compile profit and loss forecast; ramp-up, etc.; specify financial needs – borrowing, equity, grants, timing, etc.; raise finance; types of income – cannibalisation, drag-along)*
Determine cost of product to achieve profit margins

6. Generate project proposals

Identify technology requirements
Carry out concept design activities
Develop selected designs
Evaluate technical feasibility *(includes: identify technology development requirements, performance, risks, costs, manufacturing feasibility)*
Evaluate project proposals against project programme objectives
Plan project
Promote project to senior management

7. Evaluate and approve project proposals and business plans

8. Fund and schedule projects

9. Manage projects

Measure progress against original schedule and cost plan *(includes: on going bottom line or pass ratios (type of cost/benefit analysis) i.e. at what point does the company permit the number of ideas to pass from 1 in 13 generated (for example) to market testing two?; project kill decisions)*
Define and monitor specific and inviolate design checkpoints.
Manage functional interchange of product data
Manage change

10. Design product

Synthesise design
Select technologies
Carry out procurement activities
Execute design analysis (Software test (FEA, CFD, etc.),
Evaluate design against product design specification (PDS)
Manage engineering changes
Maintain design records

11. Develop new supply resources

Develop plant and factory *(includes: staff and facilities)*
Provide jigs, tools, etc.
Develop sales organisation
Develop distribution organisation
Develop support organisation *(includes: Spare parts management; Field repair mechanisms; Warranty returns and control)*

12. Specify supply processes

Manufacture process planning/design
Generate manufacturing drawings
Define sourcing of parts, sub-assemblies, final assemblies
Approve/qualify suppliers
Generate procurement specifications
Generate manufacturing specifications
Write quality plan
Plan production
Generate CNC instructions

13. Validate product (technical)

Model tests
Prototype tests
Evaluate product against PDS *(includes: quality; reliability, etc.)*
Production trials
Obtain approvals (e.g. statutory, industry, etc.)
User/field trials (technical) *(includes: Develop customer test (beta) sites, etc.)*

14. Validate product (commercial)

Test product concept (PDS right?)
Test marketing *(includes: Gauge purchase intent and market acceptance; Validate product price and price/volume relationships)*
Validate manufacturing costs

15. Develop product support

Determine requirements design and produce documents, visual aids, etc.
Monitor and feedback user reaction
Develop finance schemes
Customisation
Configuration control
Develop training aids, simulators, etc.

16. Release products into product range *(an ongoing action that involves analysing cost interrelationships, market interrelationships. etc.)*

17. Execute product launch

Advertise/promote the product
Set up supply process to handle product *(includes: sales; orders; contracts; purchase; manufacture; distribution; support)*
Ramp up manufacture
Release product on market

5.2 DoP validity judgement, dimension assignation and grouping

DoP validity and dimensions

1. Valid DoP are those that do not identify target values or objectives to be met by the PDP.
2. Resource consumption dimension DoP are those that pertain to the resource consumption of activities within the PDP. All other financial issues (DoP) are treated as the 'solution quality' dimension. Each DoP must only be assigned one dimension. DoP that are initially identified as related to 2 or more must be 'split'. e.g. 'Launch date' can relate to time and solution quality dimensions. A separate DoP must be assigned to each dimension. For example, Date of launch, and, 'development duration'.
3. Respondents must be prompted for 'resource consumption' and 'time' DoP

DoP	Valid DoP (Yes/no)	Dimension (SQ/C/T)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		
12.		
13.		
14.		
15.		
16.		
17.		
18.		
19.		
20.		

For each Generic Element group the determinants that can be viewed as being handled by the same process (people, procedures, etc.). For example, for the first GE all DoP can be grouped together as a single DoP 'profitable product'.

Generic Elements	Id. prod opp.	Gen. prod props	Eval and apprve prod props	Id reqmnts and gen PDS	Dev prod bus plans	Gen proj props	Eval and apprve proj props and bus plans	Fund and sched proj	Man. proj.	Des prod	Dev new resrc	Spec suppl prces	Val prod (tech)	Val prod (comm)	Dev prod supp	Relse prod into prod range	Exec prod lnch
Determinants of Profit																	
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14																	
15																	
16																	
17																	
18																	
19																	
20																	

Comments and lessons learned

Questions:

1. Has the method enabled you to make informed judgements concerning (test subject)? If not why do you think this is?

2. In what way could the method be improved?

3. Other comments

5.3 Relative contribution of solution quality dimension DoP to profit

Instructions:

Although DoP are linked to specific dimensions they still have an impact on profit through their specific dimension. Thus DoP from one dimension are correlated to profit independent of the DoP from the other two dimensions.

Note: The following judgements are to be made with the assumption that the PDP is 100% effective to realise each DoP.

Please respond to the following question using the scale provided: "In relation to maximising profit potential of your product, which is more important DoP A or DoP B? How much more important?"

NUMERICAL SCALE	VERBAL SCALE	EXPLANATION
1.0	Equal importance of both elements.	Two elements contribute equally.
3.0	Moderate importance of one element over another.	Experience and judgement favour one element over another.
5.0	Strong importance of one element over another.	An element is strongly favoured.
7.0	Very strong importance of one element over another.	An element is very strongly dominant.
9.0	Extreme importance of one element over another.	An element is favoured by at least an order of magnitude of difference.
2.0, 4.0, 6.0, 8.0	Intermediate value between two adjacent judgements.	Used for compromise between two judgements.

PWC judgment matrix for solution quality dimension DoP to profit

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1													
2		1												
3			1											
4				1										
5					1									
6						1								
7							1							
8								1						
9									1					
10										1				
11											1			
12												1		
13													1	
14														1

1 = equally important
3 = moderately more important
5 = strongly more important
7 = very strongly more important
9 = extremely more important

5.4 Relative contribution of resource consumption dimension DoP to profit

PWC judgment matrix for resource consumption dimension DoP to profit

Resource consumption DoP	1	2	3	4
1	1			
2		1		
3			1	
4				1

1 = equally important
3 = moderately more important
5 = strongly more important
7 = very strongly more important
9 = extremely more important

5.5 Relative contribution of time dimension DoP to profit

PWC judgment matrix for time dimension DoP to profit

Time DoP	1	2	3	4
1	1			
2		1		
3			1	
4				1

1 = equally important
3 = moderately more important
5 = strongly more important
7 = very strongly more important
9 = extremely more important

5.6 Relative contribution of each dimensional group of DoP to profit

Instructions:

It may be that for your PDP the three dimensions do not have equal impact on profit. This section allows you to judge the strength of impact on profit of the three dimensional groups (i.e. solution quality, resource consumption or time).

Please respond to the following question using the scale provided:

"In relation to maximising profit potential of your product, which is more important dimension A or dimension B? How much more important?"

NUMERICAL SCALE	VERBAL SCALE	EXPLANATION
1.0	Equal importance of both elements.	Two elements contribute equally.
3.0	Moderate importance of one element over another.	Experience and judgement favour one element over another.
5.0	Strong importance of one element over another.	An element is strongly favoured.
7.0	Very strong importance of one element over another.	An element is very strongly dominant.
9.0	Extreme importance of one element over another.	An element is favoured by at least an order of magnitude of difference.
2.0, 4.0, 6.0, 8.0	Intermediate value between two adjacent judgements.	Used for compromise between two judgements.

PWC judgement matrix for dimensions/profit correlation

	Solution quality	Resource consumption	Time
Solution Quality	1		
Resource consumption		1	
Time			1

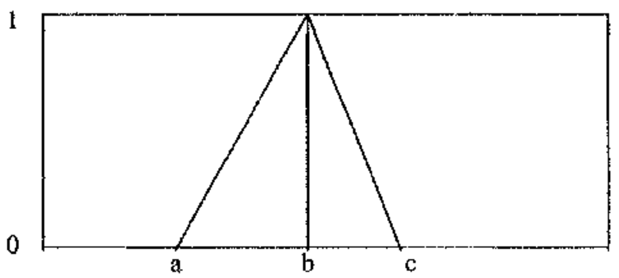
1 = equally important
3 = moderately more important
5 = strongly more important
7 = very strongly more important

5.7 Numerical values of linguistic variables

1. If you have elected to use the linguistic scale please assign a numerical value (from 0 to 10) to each member of the scale:

Not Applicable to our PDP	= NA
Should do this but don't	= 0
Low	=
Low/medium	=
Medium	=
Medium/high	=
High	=

2. If you have elected to use the linguistic scale and wish to assign fuzzy numerical values to each member please view each as a triangular fuzzy number. Three values a, b, and c (see example below) must be selected to represent each member of the linguistic scale. For example: Low = 0,0,2.5 or medium = 2, 5.5, 8, etc.



Low	0 1 2 3 4 5 6 7 8 9 10
Low/medium	0 1 2 3 4 5 6 7 8 9 10
Medium	0 1 2 3 4 5 6 7 8 9 10
Medium/high	0 1 2 3 4 5 6 7 8 9 10
High	0 1 2 3 4 5 6 7 8 9 10

5.8 Solution quality effectiveness of PDP activities in relation to activity characteristics

Consider the following questions and use your responses to make to help make a judgement about the effectiveness of each characteristic of each activity in turn.

Note: 1. The purpose of the questionnaire is to set the scene and address the issues with questions. Once the issues are in your mind attempt to avoid if possible rereading the questions for every activity.

Inputs

• ***Product data***

Is the required product data input available?
Is the data easily accessible?
Are procedures for gaining access to this data monitored and reviewed?
Are changes made to these procedures as necessary?
Is the data of a high quality in terms of representing the state of the product? Has it been agreed? Has it been tested?
Is the data utilised to effectively realise the objectives of the activity?
Is the data reviewed?

Effectiveness of inputs: Low L/M Medium M/H High
0 1 2 3 4 5 6 7 8 9 10

Controls

• ***Objectives***

Are activity objectives defined?
Are activity objectives clearly communicated to all involved?
Is understanding of activity objectives checked?
Are activity objectives reviewed?
Are changes to objectives communicated to all involved in the execution of the activity and other related parties?

Effective use of objectives: Low L/M Medium M/H High
0 1 2 3 4 5 6 7 8 9 10

• ***Information***

Is information for realising activity objectives available?
Is information necessary for effectively realising the activity objectives (e.g. design methods, new technology, markets, suppliers, etc.) easily accessible?
Are procedures for gaining access to this information monitored and reviewed?
Are changes made to these procedures as necessary?
Is the quality of the information such that it enables the effective realisation of the activity objectives?
Is this information utilised to effectively realise the objectives of the activity?
Is the information reviewed?
Are learned lessons recorded and disseminated?

Effective use of information: Low L/M Medium M/H High
0 1 2 3 4 5 6 7 8 9 10

• ***Execution***

Is performance formally monitored in relation to time/resource consumption/quality objectives?
Are targets set?
Does bench marking occur?
Are criteria set?
Are activity results formally evaluated and reviewed?
Are reviews taking place?
Does feedback occur?
Is the process adjusted as necessary?

Effectiveness of execution:	Low	L/M	Medium	M/H	High
	0 1 2	3 4	5 6 7	8 9	10

<u>Means</u>

• ***Human, financial and time resources***

Have resource requirements been estimated?
Are they met?
Are they reviewed?
Are resources/schedules modified?

Adequacy of resources:	Low	L/M	Medium	M/H	High
	0 1 2	3 4	5 6 7	8 9	10

• ***Staff***

Are the requirements for expertise, knowledge and experience of staff (in terms of quality of execution) monitored and reviewed?
Do staff have the expertise, knowledge and experience to effectively execute the activity?
Are training requirements identified?
Is the motivation of staff given specific attention?

Effectiveness of staff:	Low	L/M	Medium	M/H	High
	0 1 2	3 4	5 6 7	8 9	10

• ***Facilities and tools***

Are facilities and tools for realising activity objectives available?
Are facilities and tools necessary for the effectively realising the activity objectives easily accessible?
Are procedures for gaining access to these facilities and tools monitored and reviewed?
Are changes made to these procedures as necessary?
Is the quality of the facilities and tools such that they enable the effective realisation (in terms of quality of execution) of the activity objectives?

Are the requirements of the facilities and tools monitored and reviewed?
Are the facilities and tools utilised to effectively realise (in terms of quality of execution) the objectives of the activity?
Is the utilisation of facilities and tools monitored and reviewed?
Are changes to facilities and tools made as needed to effectively realise the activity objectives?
Is the available technology reviewed regularly?

Quality of facilities and tools Low L/M Med M/H High
0 1 2 3 4 5 6 7 8 9 10

• ***Organisation and structure***

Does the organisation and structure facilitate the effective realisation of activity objectives?

Effectiveness of organisation and structure: Low L/M Medium M/H High
0 1 2 3 4 5 6 7 8 9 10

Solution quality effectiveness score sheet

1. Identify product oppor.	DoP 1	2	3	4	5	6	7	8	9	10
Identify market opportunity	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot
Identify technology opportunity	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot
Relate above two activities to company's sphere of operation	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot
Evaluate competitive advantage	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot	p/d obj info exe res stff f+t o+s Tot

5.9 Relative contribution of activity characteristics to overall solution quality effectiveness of activities

Make judgements to determine the relative contribution of activity characteristics to overall solution quality effectiveness. The following questions should be considered:

"Which of the two characteristics A or B has the greatest impact on overall effectiveness?"
"By how much?"

The following scale should be used when making your judgements:

NUMERICAL SCALE	EXPLANATION
1.0	Two elements contribute equally.
3.0	Experience and judgement favour one element over another.
5.0	An element is strongly favoured.
7.0	An element is very strongly dominant.
9.0	An element is favoured by at least an order of magnitude of difference.
2.0, 4.0, 6.0, 8.0	Used for compromise between two judgements.

Characteristic judgement matrix

	Product data	Objectives	Information	Execution	Resources	Staff	Facilities/tools	Organ/struct
Product data	1							
Objectives		1						
Information			1					
Execution				1				
Resources					1			
Staff						1		
Facilities and tools							1	
Organisation and structure								1

1 = equally important
3 = moderately more important
5 = strongly more important
7 = very strongly more important
9 = extremely more important

5.10 Relative contribution of activities to overall solution quality effectiveness of GEs

Referring to the list of Generic Elements and activities given at the beginning of this document determine the relative contribution of each activity to the overall effectiveness of the Generic Element. Execute the pair-wise comparison method and record judgements on the matrix provided.

Note: A record sheet has been provided for 1 GE. This should be copied to provide the balance of sheets required to record judgements for the company specific PDP model.

PWC matrix for activity/GE correlations for Solution Quality dimension DoP

GE 1:

Activity number	1	2	3	4	5	6	7	8	9
1	1								
2		1							
3			1						
4				1					
5					1				
6						1			
7							1		
8								1	
9									1

1 = equally important
3 = moderately more important
5 = strongly more important
7 = very strongly more important
9 = extremely more important

5.11 Resource consumption effectiveness of PDP activities

Consider the following questions and use your responses to help make a judgement about the resource consumption effectiveness of each activity in turn.

Gut feel judgement: L L/M M M/H H 0 1 2 3 4 5 6 7 8 9 10

Do you try to achieve more than is absolutely necessary to meet the product design requirements?
Do you focus on the effective utilisation of available resources? (as opposed to focusing on a fixed delivery date)
Are resource requirements identified for the activity?
Are available resources identified, allocated (to this activity) and agreed?
Do mechanisms exist to match the allocation of resources to the objectives of the activity? Are they used?

Is a resource plan set up that details a constant resource utilisation level (minimum peaks and troughs)?
Is resource consumption benchmarked?
Is the time available for this activity being used in order to optimise the resource consumption of the activity most effectively?
Do mechanisms exist for identifying and evaluating alternative methods to achieve activity objectives with allocated resources (if already achieved then shorten the duration of the activity to improve the schedule). (Alternatives include: sub-contracting, buy-ins, consultants, etc.)? Are these mechanisms utilised?
Do mechanisms exist to monitor resource consumption of this activity (% progress versus % resource consumed)? Are these mechanisms utilised?
Do mechanisms exist to weigh effects of increased resource consumption against potential financial benefits to company? (for example, by speeding time to market) Are these mechanisms utilised?

Resource consumption effectiveness of this activity:
L L/M M M/H H
0 1 2 3 4 5 6 7 8 9 10

Resource consumption effectiveness score sheet

1. Identify product opportunity	**RC DoP 1**	2	3	4
Identify market opportunity				
Identify technology opportunity				
Relate above two activities to company's sphere of operation				
Evaluate competitive advantage				

5.12 Relative contribution of activities to overall resource consumption effectiveness of GEs

Referring to the list of Generic Elements and activities given at the beginning of this document determine the relative contribution of each activity to the overall effectiveness of the Generic Element. Execute the pair-wise comparison method and record judgements on the matrix provided.

Note: A record sheet has been provided for 1 GE. This should be copied to provide the balance of sheets required to record judgements for the company specific PDP model.

PWC matrix for activity/GE correlations for resource consumption dimension DoP GE 1:

Activity number	1	2	3	4	5	6	7	8	9
1	1								
2		1							
3			1						
4				1					
5					1				
6						1			
7							1		
8								1	
9									1

1 = equally important
3 = moderately more important
5 = strongly more important
7 = very strongly more important
9 = extremely more important

5.13 Time effectiveness of PDP activities in relation to duration and timeliness

Consider the following two sets of questions and use your responses to help make a judgement about the time effectiveness of each activity in turn.

1. Questions about time effectiveness with regard to activity schedule:

Gut feel judgement: L L/M M M/H H 0 1 2 3 4 5 6 7 8 9 10

Are mechanisms used to determine whether the activity objective is achievable within the time-scale allotted? Are they used?
Do you focus on achieving the activity within in the allotted time? (as opposed to resource consumption)
Do mechanisms exist that allow you to determine whether sufficient resources are available to allow the activity objectives to be realised in the allotted time? Are they used?
Is the time required to perform this activity benchmarked (from industry standards, competitors, customers, etc.)?
Is a time-scale target determined for this activity?
Do you try to achieve more than is absolutely necessary to meet the product design requirements?
Do mechanisms exist for identifying and evaluating alternative methods that attempt to achieve the activity objective at all within the time-scale (if time-scale already achieved then minimise resource consumption). (e.g. buy-ins, consultants, multifunctional teams,

co-location, computer based tools, concurrency – see below, etc.) Are these mechanisms utilised?
Is the elapsed time monitored continuously (relative to achieving the activity objective)?
Is corrective action taken to ensure completion dates are not exceeded whilst keeping added resource consumption to a minimum (AND still achieving activity objectives)?
Is the impact on profits of late/early completion known (i.e. does a model exist for profit impact of time to market)?
Do mechanisms exist for matching added resource consumption to potential time benefits? Are these utilised?

Time effectiveness with regard to **duration** of activity:

L L/M M M/H H 0 1 2 3 4 5 6 7 8 9 10

2. Questions about time effectiveness with regard to timeliness (the point in time that activities occur):

Gut feel judgement: L L/M M M/H H 0 1 2 3 4 5 6 7 8 9 10

Is the start of this activity dependent on any upstream activities (in terms of information, resources, tools, facilities, etc.)? If not, does/will this activity start at the earliest possible date? (The rest of the questions may be ignored)
If this activity is dependent or interdependent on upstream activities, have upstream activities been identified?
Has the cause of this dependence/interdependence been determined (e.g. information, resources, tools, facilities, etc.)?
Is it possible to remove the cause of dependence/interdependence (e.g. more money, more staff, new tools, restructuring, teams, etc.) to allow parallel execution?
Is it known (or monitored) at what point in time the upstream activity/activities will permit the start of this activity?
Does/will this activity start immediately the upstream activity/activities will permit?
Is the way in which outputs will be used considered as a control on/input to this activity?

Time effectiveness with regard to **timeliness** of activity:

L L/M M M/H H 0 1 2 3 4 5 6 7 8 9 10

Overall time effectiveness for this activity:

L L/M M M/H H 0 1 2 3 4 5 6 7 8 9 10

Time effectiveness score sheet

1. Identify product opportunity	**Time DoP 1**	2	3	4
Identify market opportunity	D t Tot	D t Tot	D t Tot	D t Tot
Identify technology opportunity	D t Tot	D t Tot	D t Tot	D t Tot
Relate above two activities to company's sphere of operation	D t Tot	D t Tot	D t Tot	D t Tot
Evaluate competitive advantage	D t Tot	D t Tot	D t Tot	D t Tot

5.14 Relative contribution of duration and timeliness to overall time effectiveness

Make judgements to determine the relative contribution of time dimensions (i.e. schedule and timeliness) to overall time effectiveness. The following questions should be considered:

"Which of the two, duration or timeliness has the greatest impact on overall time effectiveness?" "By how much?"

The following scale should be used when making your judgements:

NUMERICAL SCALE	EXPLANATION
1.0	Two elements contribute equally.
3.0	Experience and judgement favour one element over another.
5.0	An element is strongly favoured.
7.0	An element is very strongly dominant.
9.0	An element is favoured by at least an order of magnitude of difference.
2.0, 4.0, 6.0, 8.0	Used for compromise between two judgements.

Judgement: *Duration* has .... times the effect of *Timeliness* on overall time effectiveness

5.15 Relative contribution of activities to overall time effectiveness of GEs

Referring to the list of Generic Elements and activities given at the beginning of this document determine the relative contribution of each activity to the overall effectiveness of the Generic Element. Execute the pair-wise comparison method and record judgements on the matrix provided.

Note: A record sheet has been provided for 1 GE. This should be copied to provide the balance of sheets required to record judgements for the company specific PDP model.

PWC matrix for activity/GE correlations for Time dimension DoP

GE 1:

Activity number	1	2	3	4	5	6	7	8	9
1	1								
2		1							
3			1						
4				1					
5					1				
6						1			
7							1		
8								1	
9									1

1 = equally important
3 = moderately more important
5 = strongly more important
7 = very strongly more important
9 = extremely more important

5.16 Relative contribution of GEs to to PDP to realise each solution quality dimension DoP

Note: Either of the two following methods can be used. The first is not as rigorous as the second but requires less time commitment.

The Determinants of Profit for your product identified at the beginning of this evaluation can be found in the matrix.

The matrix also lists Generic Elements of the Product Development Process.

Please weight the effect that the outcome of each Generic Element has on ensuring that each determinant is realised to best effect.

A scale of your choice may be used. However the same scale should be used throughout the tool. Example: 0 (no effect) to 10 (maximum effect).

Generic Elements	Id. prod opp.	Gen. prod props	Eval and apprve prod props	Id reqmnts and gen PDS	Dev prod bus plans	Gen proj props	Eval and apprve proj props and bus plans	Fund and sched proj	Man. proj.	Des prod	Dev new resrc	Spec suppl prces	Val prod (tech)	Val prod (comm)	Dev prod supp	Relse prod into prod range	Exec prod lnch
Determinants of Profit																	
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	
14																	

PWC matrix (for determining relative importance of GEs for each SQ DoP)

GEs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1																
2		1															
3			1														
4				1													
5					1												
6						1											
7							1										
8								1									
9									1								
10										1							
11											1						
12												1					
13													1				
14														1			
15															1		
16																1	
17																	1

Which GE is more important in realising the DoP? By how much?

1 = equally important
3 = moderately more important
5 = strongly more important
7 = very strongly more important
9 = extremely more important

5.17 Relative contribution of GEs to PDP to realise each resource consumption dimension DoP

Note: Either of the two following methods can be used. The first is not as rigorous as the second but requires less time commitment.

The Determinants of Profit for your product identified at the beginning of this evaluation can be found in the matrix.

The matrix also lists Generic Elements of the Product Development Process.

Please weight the effect that the outcome of each Generic Element has on ensuring that each determinant is realised to best effect.
A scale of your choice may be used. However the same scale should be used throughout the tool.
Example: 0 (no effect) to 10 (maximum effect).

Generic Elements	Id. prod opp.	Gen. prod props	Eval and apprve prod props	Id reqmnts and gen PDS	Dev prod bus plans	Gen proj props	Eval and apprve proj props and bus plans	Fund and sched proj	Man. proj.	Des prod	Dev new resrc	Spec suppl prces	Val prod (tech)	Val prod (comm)	Dev prod supp	Relse prod into prod range	Exec prod lnch
Determinants of Profit																	
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	

PWC matrix (for determining relative importance of GEs for each RC DoP)

GEs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1																
2		1															
3			1														
4				1													
5					1												
6						1											
7							1										
8								1									
9									1								
10										1							
11											1						
12												1					
13													1				
14														1			
15															1		
16																1	
17																	1

Which GE is more important in realising the DoP? By how much?

1 = equally important
3 = moderately more important
5 = strongly more important
7 = very strongly more important
9 = extremely more important

5.18 Relative impact of GEs to PDP to realise each time dimension DoP

Note: Either of the two following methods can be used. The first is not as rigorous as the second but requires less time commitment.

The Determinants of Profit for your product identified at the beginning of this evaluation can be found in the matrix.
The matrix also lists Generic Elements of the Product Development Process.

Please weight the effect that the outcome of each Generic Element has on ensuring that each determinant is realised to best effect.
A scale of your choice may be used. However the same scale should be used throughout the tool.
Example: 0 (no effect) to 10 (maximum effect).

Generic Elements	Id. prod opp.	Gen. prod props	Eval and apprve prod props	Id reqmnts and gen PDS	Dev prod bus plans	Gen proj props	Eval and apprve proj props and bus plans	Fund and sched proj	Man. proj.	Des prod	Dev new resrc	Spec suppl prces	Val prod (tech)	Val prod (comm)	Dev prod supp	Relse prod into prod range	Exec prod lnch
Determinants of Profit																	
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
11																	
12																	
13																	

PWC matrix (for determining relative importance of GEs for each Time DoP)

GEs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	1																
2		1															
3			1														
4				1													
5					1												
6						1											
7							1										
8								1									
9									1								
10										1							
11											1						
12												1					
13													1				
14														1			
15															1		
16																1	
17																	1

Which GE is more important in realising the DoP? By how much?

1 = equally important
3 = moderately more important
5 = strongly more important
7 = very strongly more important
9 = extremely more important

5.19 Threshold DoP effectiveness

By responding to the following question, make a judgement pertaining to the level of PDP effectiveness (ηmin) required to realise the minimum acceptable level for each DoP:

"What PDP effectiveness corresponds to the minimum determinant level that must be realised to ensure that the product is able to compete in the target market and below which it cannot?"

DoP	ηmin
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

5.20 DoP interactions

Instructions:

1. Using the attached matrix identify subsets of DoP (called the interacting determinants) that impact on the benefit to be derived from each single determinant (called the subject determinant) of the total set. The following question form may be used:

   "In order to gain the benefit of getting this issue (subject DoP) right what are the other issues (interacting DoP) that must be got right as well?"

2. Using the attached matrix make a judgement as to the extent that each interacting determinant will effect the profit benefit derived from their particular subject DoP. There are two ways of viewing this:

2.1 Gates:

The ηmin values identified before may be used as go/no go gates. In other words the subject DoP only effects profit if its interacting DoP are realised with effectiveness above ηmin.

2.2 Cumulative effect:

There are various methods for eliciting this judgement. Please select one.

a. Answer the following question for each interacting DoP; "Identify a strength of influence value (SI) on a scale of 0 - 1 to indicate the magnitude of effect of this determinant in *negatively* influencing the realisable benefit of the subject DoP." (0 = no effect and 1 = maximum effect).
In other words; if the interacting DoP is not realised with 100% effectiveness, how much impact will that have on the subject DoP?

b. The same question as above but the following scale can be used:
Low influence Low to medium influence Medium influence Medium to high influence High influence.

Note: The numerical value of this judgements can be handled in a number of ways. The words can merely be assigned a score - High = 1, low = 0, medium = 5, etc., or words can have fuzzy values (triangular) assigned – with intercepts either fixed or chosen by expert (Tsaur *et al* 1997 j71), or, a pair-wise comparison (PWC) method can be used to express the linguistic variables as ratios to one another (Saaty 1990c, Saaty 1990d, Dyer *et al* 1991).

c. What will the effectiveness of the subject DoP be when the interacting DoP is ηmin? (and zero?). Are you able to relate to this question? If not can you say why?

DoP interaction matrix

NOTE: remember to use the same scale you have used throughout the evaluation.

Subject DoP	S/Q 1	2	3	4	5	6	7	8	9	10	RC 1	2	3	4	Time 1	2	3	4
Interacting DoP																		
S/Q 1	x																	
2		x																
3			x															
4				x														
5					x													
6						x												
7							x											
8								x										
9									x									
10										x								
RC 1											x							
2												x						
3													x					
4														x				
Time 1															x			
2																x		
3																	x	
4																		x

6. QUESTIONNAIRE

1. Has the tool enabled you to make informed judgements concerning your product development process? If not, why do you think this is?

2. Has the tool highlighted issues that you had not considered before? What are they?

3. Has the tool highlighted *all* areas needing attention (including the ones you were aware of)?

4. Do you consider the tool has successfully enabled you to evaluate your product development process?

5. Do you think the tool as a whole could be improved in any way? What are these?

6. Is the time taken to apply the tool; too short too long about right?

7. If the time taken needs improving how do you think this could be achieved?

Appendix J

PDP Evaluation Method Equations

	Notation
Dimensions	
1. Numbering	SQ, RC, T
2. Correlation to profit of each dimensional group of DoP	w_{SQ}, w_{RC}, w_T
Determinants of Profit (DoP)	
1. Numbering	D_i where i = 1 to *m*
2. Correlation to profit (Adjusted)	w'_i
3. Effectiveness	
• Assessed	η_i
• Threshold	η_{th}
Generic Elements (GEs)	
1. Numbering	G_j where j = 1 to *n*
2. Correlation to PDP for each DoP	w_{ij}
3. Effectiveness	η_{ij}
Activities	
1. Numbering	A_k where k = 1 to *p*
1. Correlation to GE for each DoP	w_{ijk}
2. Effectiveness	η_{ijk}
Characteristics	
1. Numbering	C_l where *l* = 1 to *q*
1. Correlation to Activity for each DoP	w_{ijkl}
2. Effectiveness	η_{ijkl}

Table J.1. Notation for Evaluation Method Variables

1. Characteristic effectiveness for each DoP:

$$\eta_{ijkl} = \text{assigned}$$

For $i = 1$ to m, $j = 1$ to n, $k = 1$ to p and $l = 1$ to q

2. Activity effectiveness for each DoP:

$$\eta_{ijk} = \sum_{l=1}^{q} (w_{ijk} \times \eta_{ijk})_l$$

For $i = 1$ to m, $j = 1$ to n, and $k = 1$ to p

3. Generic Element effectiveness for each DoP:

$$\eta_{ij} = \sum_{k=1}^{p} (w_{ij} \times \eta_{ij})_k$$

For $i = 1$ to m and $j = 1$ to n

4. PDP effectiveness to realise each DoP:

$$\eta_i = \sum_{j=1}^{n} (w_i \times \eta_i)_j$$

For $i = 1$ to m

5. Potential for maximising profit (PMP) for each dimensional group of DoP

$$PMP_{SQ} = \sum_{i=1}^{m} w'_i \times \eta_i$$

Similarly for resource consumption (PMP_{RC}) and time (PMP_T) dimensions.

6. Potential for maximising profit (PMP)

$$PMP = (w \times PMP)_{SQ} + (w \times PMP)_{RC} + (w \times PMP)_T$$

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